THE DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) AS A MARICULTURE SECTOR PLANNING TOOL IN SOUTH AFRICA

A thesis submitted in fulfilment of the
requirements for the degree of

MASTER OF SCIENCE

of

RHODES UNIVERSITY

by

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September 2003

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Dedicated to my family

ABSTRACT

The South African coastline has a high potential for mariculture development, particularly in land-based systems, due to excellent water quality, good infrastructure, and relatively cheap land in certain areas. Development of mariculture however, has been slow primarily due to the absence of a national sector development plan to coordinate contribution to development by government, industry and academia. Recent mariculture development plans however, supported by government commitment to stimulate coastal development, offers new opportunity for the sector's growth. These new sector development plans require a multi-disciplinary intensive information base with a strong regional and national spatial component.

Geographic Information System (GIS) is a spatial analytical tool, which is capable of handling such large coastal databases and analysing them. Nevertheless, many mariculture GIS planning applications, often developed in isolation and with limited practical use for decision makers, highlighted the need to develop GIS in relation to the mariculture sector development plan.

Hence, the aim of this study was to develop and evaluate a GIS for the national and regional mariculture sector planning process in South Africa, in order to identify potentially suitable areas along the South African coastline for mariculture operations. The GIS development in this study was based on the mariculture planning approach developed by PAP/RAC (1996), which recognizes the variations of scales in mariculture planning. Three case studies, representing the diversity of the South African sector plan, were selected to develop the GIS. They included: a national suitability analysis for all land-based culture systems, a specific national analysis on abalone ranching, and a detailed regional analysis of land-based culture and abalone ranching along the Namaqualand coastline. The GIS was developed separately for each case study based on a strategy consisting of six main phases, including: *identification of project requirements, developing analytical framework, selection and location of data sources, organization and manipulation of data, analysing data and verifying and evaluation of the outputs.*

Biophysical, coastal use, and infrastructure criteria were collected, sorted and analysed to identify development constraints. Based on a set of conditions, and Boolean logic and arithmetic operations, unsuitable areas were identified and eliminated. Main constraints for national land-based development included competition over space along KwaZulu-Natal Province coastline and restricted access to the coast along the south region of the Northern Cape Province, Wild Coast along the Eastern Cape Province, and Maputaland along KwaZulu-Natal Province. Ten areas along the country coastline were therefore identified as potentially suitable for land-based mariculture. Furthermore, South African abalone ranching potential was found to be limited mostly along the Western and Northern Cape Province's coastline due to the high risk of Paralytic Shellfish Poison (PSP) occurrences, alternative resource use and activities such as commercial fishery, poaching, and conservation. Hence, a total of nine areas along the Northern Cape, Western Cape, and Eastern Cape coastlines were identified as premier areas for abalone ranching.

The regional study along the Namaqualand coastline revealed potential conflict between mining activity and mariculture development due to security issues and restricted access to the coast. Land-based mariculture development was confined to the four main coastal urban areas. The highest potential for land-based mariculture was along Port Nolloth and Kleinsee coastlines, whereas marine-based (i.e. abalone ranching) potential was poor along the north part of the coast due to intense marine mining activities, restricted access to the coast, and low kelp bed density. High potential abalone ranching areas were identified south to Kleinsee, and around Port Nolloth. Potential conflict with marine mining activity was minimal since it was localised and not related to kelp bed locations.

It was concluded that GIS is a relevant and compatible tool for South African mariculture sector planning. However, future development of GIS as integrated planning tool in mariculture and coastal planning, requires updated spatial data (e.g. recreational activity), and continued interaction among project planners, mariculture specialists and GIS analysts.

Acknowledgment

This work is the result of a long collective effort of many people to whom I am grateful. I therefore, would like to extend my sincere appreciation for their support. In particular I would like to extend my gratitude to my supervisors Prof. Peter Britz and Prof. Tom Hecht, who have supported and encouraged me throughout this long journey. I thank them for the opportunity to undertake this study, the research support and guidance and the assistance with the write-up phase.

I am also grateful to my sponsors Marine and Coastal Management, and the French government, without whose financial support, this study would not have been possible. For the input on my work, I would like to thank IFREMER, who guided and inspired me at the very start of the study. I thank Dr. Rob Harris, Gillian McGregor, and Henry Holland for their support and advice. I am grateful for the cooperation I received from Alexkor Ltd. and De Beers Consolidated Mines Ltd./Namaqualand Mines, Kleinsee. Their assistance, especially with highly valuable data was vital to this study.

I am grateful for all the support I received from my friends in and outside the Ichthyology and Fishery Department, specifically, Benson for being there, Tapuwa for caring so much, and Ofer for listening and advising when I most needed. And finally I am indebted for all the support and assistance I have received for all those long years from my dear family. I am grateful, above all, to my parents who believe in me so much.

CHAPTER 1
General introduction

Introduction

The South African coastline offers opportunities for mariculture development, particularly in land-based systems (Hecht and Britz 1992, Britz and Hecht 1999). This is mainly attributed to excellent water quality, good infrastructure (e.g. roads and electricity networks) and relatively cheap land in certain areas. Mariculture has, however, been slow to develop in South Africa. Significant growth in total production only occurred during the late 1980's with the introduction of marine-based mussel farming (Figure 1.1). In the following two decades production by volume did not increase much, though output by value increased significantly as a result of the introduction of abalone farms. Noticeable was the drop in production during 2000 with the decrease in mussel production (Figure 1.2), which was the result of a change of ownership (Tom Hecht, pers. comm. Department of Ichthyology and Fisheries Science, Rhodes University, 2003).

Hence, the bulk of the South African mariculture production is currently limited to marine-based mussel and oyster culture. This is in spite of the fact that the South African coastline is exposed to high wave energy and limited space in a few protected bays, and that land-based culture (e.g. abalone) has a high potential for development (Hecht and Britz 1990, Hecht 1999). The primary reason for the limited and uncoordinated development of the mariculture sector includes the economic recession at the end of the 1980's, the political transition during the mid 1990's, and the absence of a national sector development plan to coordinate contribution to development by government, industry and academia (Hecht 1999).

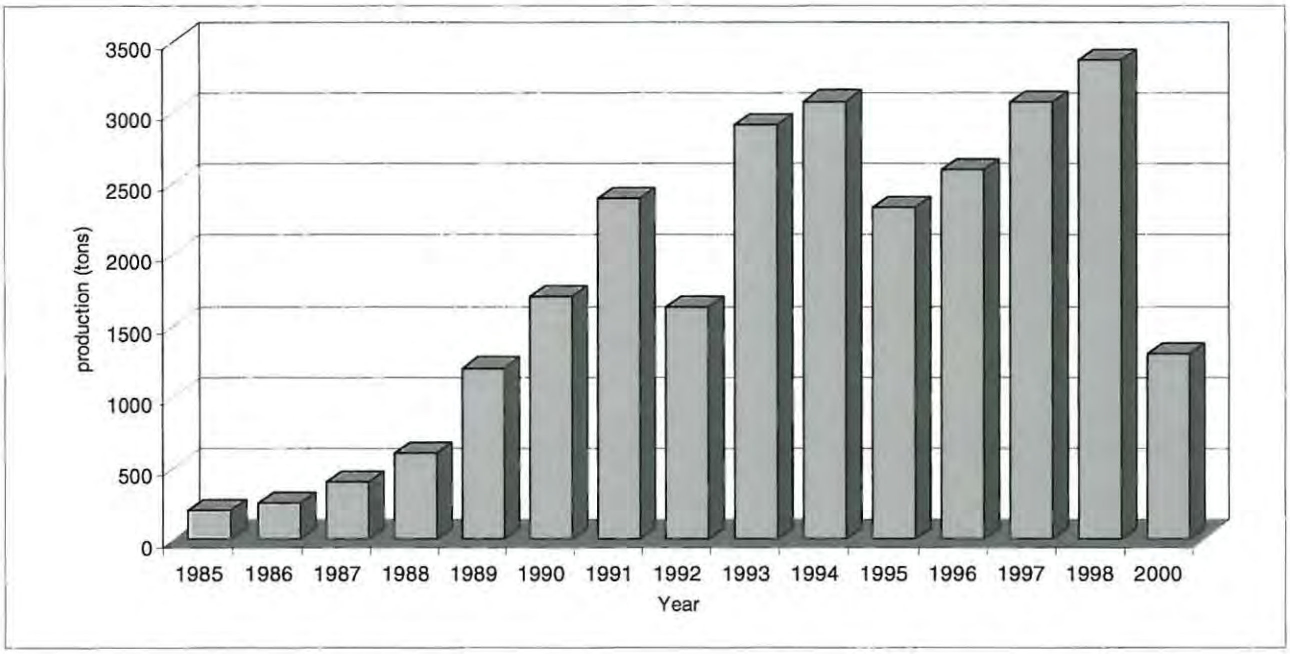
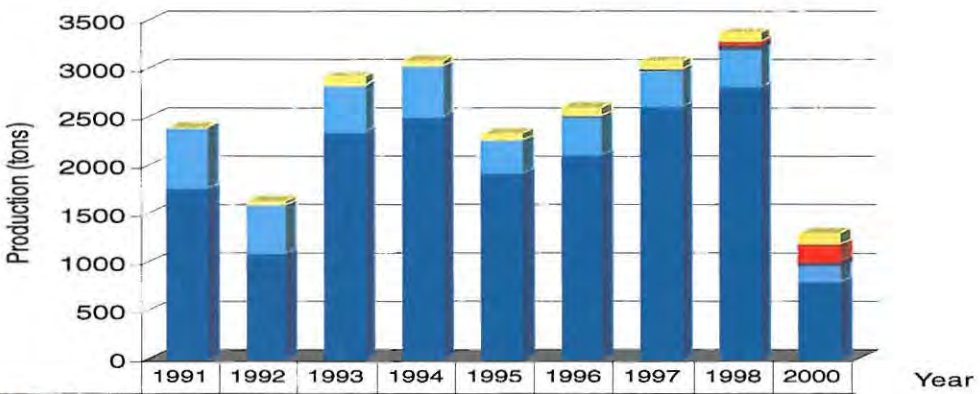


Figure 1.1: Mariculture production (tons) in South Africa from 1985 to 1998, and 2000 (adapted from Hecht *et. al* 1992, Hecht 1999, Hoffman *et. al* 2000, and Brink 2002). Data was not available for 1999.



		1991	1992	1993	1994	1995	1996	1997	1998	2000
Land-based culture	Shrimp	0	39	84	53	70	81	75	90	120
	Abalone	0	0	0	0	0	0	2	22	180
Marine-based culture	Gracillaria	0	0	0	0	2	8	10	50	40
	Oysters	633	501	480	520	339	400	380	400	170
	Mussels	1758	1086	2345	2500	1918	2100	2600	2800	790

Mussels Oysters Gracillaria Abalone Shrimp

Figure 1.2: Mariculture production (tons) by species in South Africa from 1991 to 1998, and 2000. Note the production of land-based shrimp and abalone culture has only begun established in 1992. In addition, the drop of total production during 2000 is attributed to change of mussel farm ownership (adapted from Hecht 1999, Hoffman *et. al* 2000, and Brink 2002). Data was not available for 1999.

Several studies have shown that an integrated sector plan, which involves the conservation of the environment and the promotion of socially and economically sustainable development, is required for the optimal development of mariculture (Nash 1995, Bailly and Paquotte 1996, PAP/RAC 1996). The use of sector planning is however, a relatively new approach to mariculture development, and in many countries it has failed due to insufficiently detailed planning and a lack of commitment by governments (Nash 1995).

Spatial information is an essential component in sector planning, for example, Hawaii and Ghana, cited in Nash (1995). Hence, mariculture planners require spatial tools, which can assist in planning development and monitoring the environment. Geographic Information Systems (GIS) provides a means to fulfil such needs. GIS software is an advanced analytical database tool. The development of a GIS is an issue-driven process, which provides a good framework for integrating data on a geographically referenced basis. Despite the potential capacity of GIS, at present it has very limited application as a Spatial Decision Support System (SDSS) tool for mariculture development (Nath *et al.* 2000). Considering the problems associated with planning, and the detailed information required for the development of a comprehensive sector plan, there is a need to evaluate underutilized tools such as GIS. Such evaluation, which is contextualized with existing mariculture planning objectives, could improve the application of GIS in a long-term planning setting.

National and provincial mariculture sector planning processes have been initiated in South Africa (Stenton-Dozey 1999, Britz *et al.* 2002), and provides a good opportunity to evaluate the suitability of GIS as a tool in the planning process. This evaluation however, would first require a general understanding of: 1) the interactions between mariculture activity and the environment on a spatial basis, 2) the objectives of the sector development plan and the requirements for relevant geographically referenced information, and 3) the current approaches to the application of GIS in mariculture.

The interaction between the environment and the mariculture activities

A successful mariculture sector is strongly dependent on a sustainable relationship with the coastal environment. This relationship includes maintenance of suitable biophysical conditions for farming operations, and should be based on a sound environmental planning and management approach, aimed at optimising social and economic benefits (Barg 1992, Pillay 1992, Chua 1993, Nash 1995, PAP/RAC 1996, Burbridge *et al.* 2001).

As a result of high market demand and the introduction of new culture technologies, global mariculture production has intensified and diversified over the past 50 years (Nash 1995). This has frequently led to severe environmental degradation. In most cases, this was due to a poor understanding of the environment and a lack of comprehensive and sustainable development plans (Barg 1992, Pillay 1992, Bailly and Paquotte 1996, Burbridge *et al.* 2001). The increasing pressure of coastal development, attributable to population growth and economic development, has exacerbated the conflicts between mariculture and other activities. While limited information is available on this subject, such conflicts could include direct competition for space and resources due to the expansion of established coastal users, as well as the need for conservation areas, both in the marine and the coastal terrestrial environments. Not all interactions are negative, for example, other spatially based interactions due to factors such as the proximity of infrastructure and markets have often resulted in a positive relationship between mariculture and other coastal activities (Table 1.1) (PAP/RAC 1996).

The relationship between mariculture and other coastal users can also be affected by the local social and cultural background, and what local residents consider as acceptable development (Bailly and Paquotte 1996). An example is the oyster and mussel farming industry in France, which has in recent years been developed to promote tourism. This is in contrast to mariculture in Mediterranean countries (e.g. Greece), where cage culture has had a negative impact on the attractiveness of the coastal landscape for tourism (PAP/RAC 1996). Hence, established coastal users can have a major impact on an emerging sector, such as mariculture.

The South African mariculture sector has already experienced several conflicts over the use of space with other coastal activities, specifically with recreational and industrial users along the South and East coasts (Britz 1997, DECAS/ Western Cape Province 2001). Similarly, along the West coast, the development of a Salmon farm at Saldanha Bay had to be abandoned due to resistance from local inhabitants (Louwrens 2001).

The nature of the spatial relationships (i.e. competition for space) between coastal users and mariculture is highly dynamic as it varies in time and between regions and is shaped by three main factors: the natural carrying capacity of the environment, the economy, and socio-cultural behaviour. However the limited understanding of these interactions, particularly the social and economic factors, is a major constraint in planning development.

Table 1.1: Positive (+) and negative (-) relationships between mariculture development and other users of coastal areas. The relationships are grouped into three types: space, environmental resources, and economic. Note that all relationships related to space have a negative impact on mariculture development due to competition (PAP/RAC 1996).

Relationship type		Coastal User: Industry and Harbour	Urbanization	Tourism and Recreational	Agriculture	Fisheries
	Space	• land use (-) • shipping traffic (-) • military zones (-) dredging (-) • military zone (-)	• land use (-)	• land use (-) • sailing & bathing (-) • fishing (-) • historical sites (-) • protected conservation areas (-)	• land use (-)	• spawning area (-) • finishing zone (-)
	Environment resources impact	• pollutions (-) • ballast water (-) • warmed water (+)	• sewage (-) • organic matter (-) • bacteria and viruses (-) • nutrients (-)	• sewage (-) • antifouling paints (-)	• fertilizers (-) • pesticides (-) • organic matter (-) • suspended solids (-)	• disease transmission (-) • genetic escape (-) • reseeding (+)
	Economy	• infrastructure (+)	• market (+) • infrastructure (+)	• attraction of investment (-/+) • employment (-/+) • local market (+) • infrastructure (+)	• infrastructure (+)	• attraction of investment (+) • market (+) • infrastructure (+) • fish meal for mariculture (+)

Mariculture sector planning and the need for spatially referenced data

As a consequence of these complex ecological, economic and social interrelationships, the limited resources of the environment, and the high economic potential of mariculture, national and international planning authorities have increasingly recognized the need for comprehensive sector development plans, which promote sustainable environmental development (Barg 1992).

Similarly, in South Africa, the economic potential of developing a mariculture sector has long been recognized (Genade 1984). An early assessment by Hecht & Britz (1992) of the potential of mariculture revealed limited prospects for marine-based practices due to environmental factors such as high wave energy, the limited numbers of sheltered bays and lagoons along the coast, and Harmful Algal Blooms (HAB). However, the intensive land-based culture of high value species (e.g. abalone, shrimp and ornamental fish) was found to have high potential, specifically in areas where potential competition over space between coastal users (e.g. urban, conservation, and recreational activity) is low.

Hecht (1996) has recognized the need to develop a comprehensive mariculture development plan, which includes the interactions between the coastal environment and mariculture operations, and is based on the collaboration of national and provincial governments, producer associations, and researcher authorities. This was followed by the national government's Coastal Management Policy Program (CMPP) published in the White Paper for sustainable coastal development in South Africa, which recognize mariculture as a preferred economic activity along the coast (Anon 1999). However, it was only during the first national workshop on planning for sustainable development of the mariculture sector in South Africa that a comprehensive sector plan process was initiated (Stenton-Dozey 1999). Concurrently, a regional mariculture development plan was conducted by Britz *et al.* (2002) for Namaqualand coastline, Northern Cape Province.

Sector planning constitutes a new global approach to the development of mariculture. However, because of the diverse conditions that exist for development there are many variations in the scope of sector plans. Several basic planning principles must be included, however. Ideally this should begin by addressing policy objectives at a national level, followed by identification of the limitations and strategies to overcome constraints, and concluded by the implementation of regional programs and projects (Figure 1.3) (Nash 1995).

Figure 1.3: The principle activities and suggested procedure in sector planning (adapted from Nash 1995).

While many countries recognize the importance of sectoral planning, very few have prepared comprehensive detailed policy and regional plans along planning principles. As a result, the implementation of development plans has often failed (Nash 1995). Several reasons have been suggested as major contributors to this shortcoming of planning. These include (Nash 1995):

- A lack of suitable administrative procedures and institutional organization to manage development. This is due to inadequate government resource allocation (such as lack of skills and finance). As a consequence, mariculture is often a newly developed sector with weak political power (Bailly and Paquotte 1996). In South Africa the lack of institutional organization is currently considered as a major constraint for the development of the mariculture sector at both the national (Britz and Hecht 1999) and regional (Britz *et al.* 2002b) levels.

- A lack of communication between all interested parties including national and regional government, finance institutions, producers, academic specialists, and the public (e.g. local coastal communities). The horizontal integration of mariculture into the national multi-sectoral coastal planning framework (also known as the Integrated Coastal Zone Management (ICZM) plan) is a fundamental component in sector plan development, as it ensures the sector's sustainable coordinated development. Lack of communication often results in limited integration of mariculture with other activities and hence, may result in future conflict between coastal users and interested parties.

- Insufficient detail in the plan, such as how, who, and when things will be done. Collecting and analysing the full range of natural environmental, social, and economic factors are an essential principle in the formulation of a sector plan. A lack of, or limited available information could result in generalized, ambiguous, impractical planning objectives, followed by limited planning details, and unsuccessful implementation.

For a national plan to be realistic, the varied ecological, economic and social factors, which reflect the unique identity and development requirements for each area of the country, need to be included. Thus, the development of a sector plan is based on an extensive information use process. This entails the collection, organization, and analysis of large amounts of data from various sources.

Spatial information is an essential and basic component required for mariculture sector planning. Mariculture planners are increasingly recognizing the need for spatial data, in particular for site suitability analyses (Meaden and Do Chi 1996). Site suitability analysis has been used for different objectives, such as environmental carrying capacity (Black and Truscott 1994, Levings *et al.* 1995) and socio-economic conflict resolution (PAP/RAC 1996). Spatial information can be combined from various disciplines on a geographically referenced basis. This could provide a meaningful unified format of all data, which may enhance communication among all interest parties. However, in order to achieve this, an objective and efficient tool must first be developed.

Geographic Information Systems as a planning tool

As a result of the increasing availability of data and the need for complex spatial analysis, the demand for automated spatial tools that can handle multi-disciplinary data sets and perform accurate, rapid and objective analyses has increased. Geographic Information System (GIS) software is an advanced spatial analytical tool that can fulfill this need.

GIS is capable of receiving and storing large data sets, which can then be easily manipulated, retrieved, analysed, and modelled. The outputs can be quantified and presented graphically. Data can be captured in two main model database formats known as vector and raster. The raster is an area-oriented model, where data is represented in a grid of equal sized cells or pixels. The vector model is based on the representation of geographical objects using three geometric shapes: point, line (vector) and polygons. The position of the geographic objects is described by a series of x, y and z coordinates (Dangermond 1990, Charisman 1997). In both models, the graphic features are associated with attributes (also known as non-locational data). The attributes stored in tables, are linked to the graphic features through common field identifiers (known also as primer keys), and provide additional information, such as the relationships between the graphic objects, quantified numeric data and descriptive information. Several attribute tables can be attached to the same graphic feature through the common field identifier (see example in Figure 1.4).

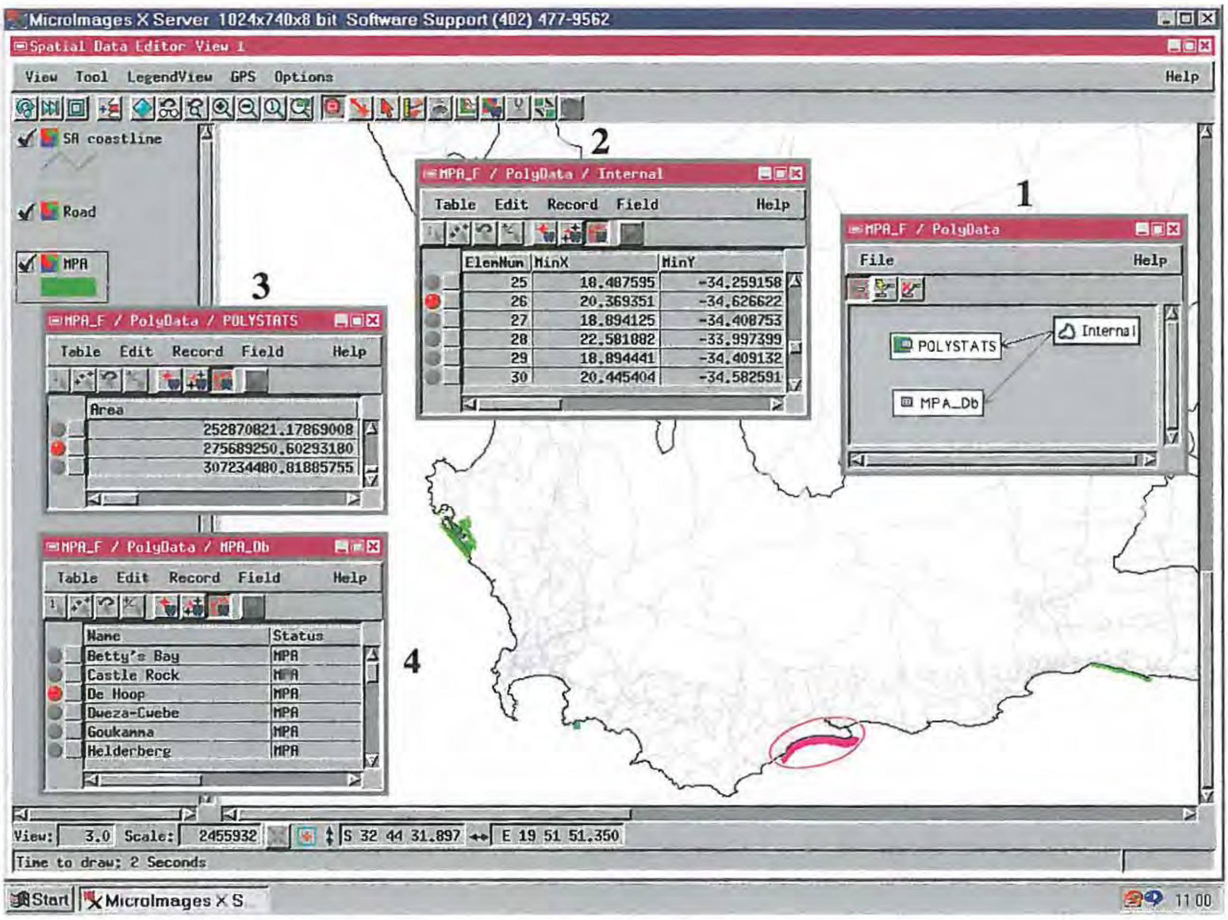


Figure 1.4: GIS (TNTMips) selected graphic feature (De Hoop Marine Protected Area circled in red) and the attached attributes with the associated information (highlighted with red marker). The relationship between the attributes tables (1) includes the common field (ElemNum) in the table "Internal" (2) to which additional attributes are attached including information on area size in table "POLYSTATS" (3), and the name and status found in table "MPA_Db" (4).

This link between spatial and non-spatial data is a fundamental feature of GIS, and the ability to manipulate and analyse both graphic and non-graphic information makes GIS a highly compatible Information System (Maguire 1991). GIS is considered as an integration of four distinct information system components: a database management system (DBMS), computer-aid design (CAD), remote sensing (RS), and computer cartography (Maguire 1991). This integration provides a wide range of application possibilities which have often been used in resource planning and management, including (Bartlett 1994):

- Database Management (DBM)
- Resources survey (e.g. site selection and resources exploration)
- Monitoring and analysis
- Modelling and simulation
- Spatial Decision Supporting Systems (SDSS)

GIS development is an on-going process with three distinct development stages, which comprise of three types of applications (Figure 1.5) (Maguire 1991, Robinson *et al.* 1995):

1. *Inventory application*: creates a consistent and complete spatial database with basic query functions
2. *Analysis application*: advanced analysis operations evaluating spatial relationships to address specific issues
3. *Management (decision support) application*: evolution from an information and transaction processing system to a decision support system

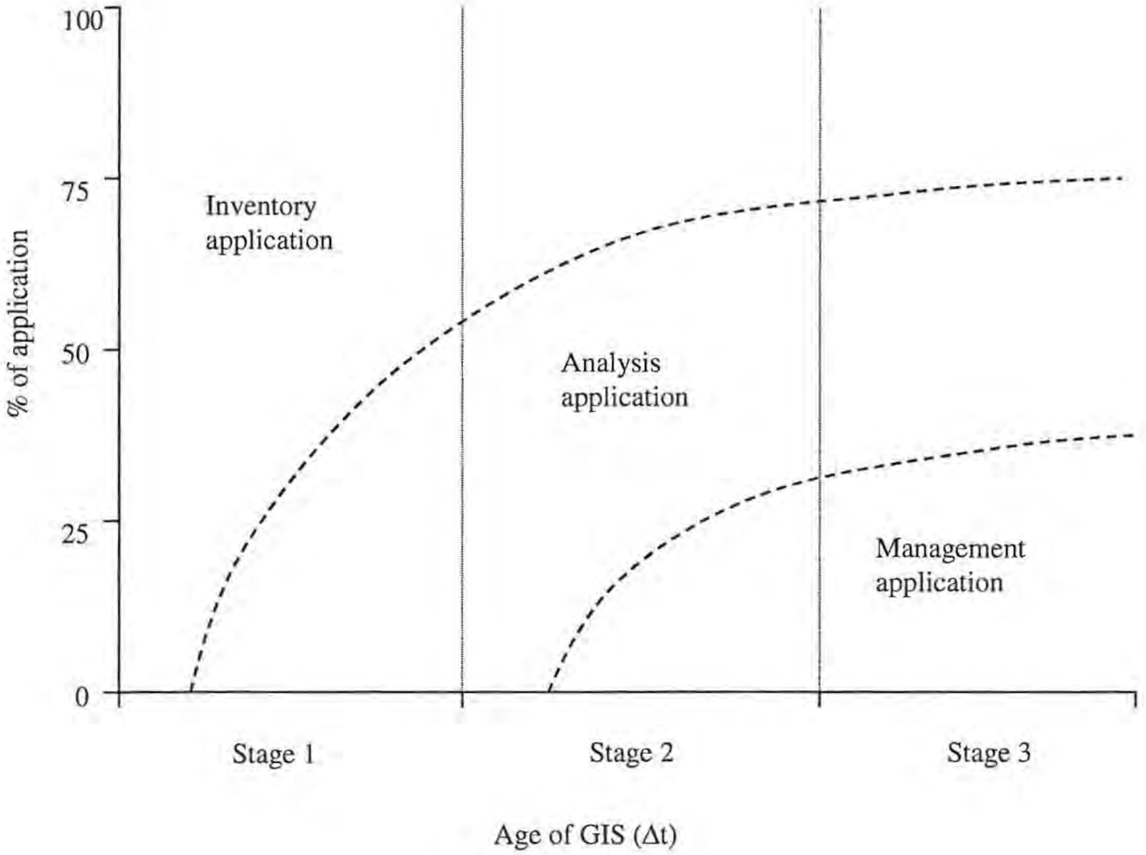


Figure 1.5: The three stages in the development of GIS applications (adapted from Maguire 1991).

GIS applications in mariculture sector planning

Over the past two decades, GIS has been applied in mariculture planning worldwide, usually as a result of the increasing need for site suitability analysis in sector development. However, these systems were often not much more than information and transaction processing systems (i.e. inventory and analysis applications, Figure 1.5), and as such, they have limited practical application for decision makers (Meaden and Do Chi 1996, Nath *et al.* 2000).

Early applications were mostly concerned with the potential of GIS as analytical tools, and its applications in mariculture site selection analysis (Kapetsky *et al.* 1987, Ali *et al.* 1991, Beveridge *et al.* 1991). As the use of GIS increased, many GIS applications provided the analysis of potentially suitable areas for entire regions (Ibrekk *et al.* 1993, Aguilar-Manjarrez and Ross 1995, Shahid *et al.* 1997, Grita 1997, Aguilar-Manjarrez and Nath 1998, Nath *et al.* 2000). However, few GIS studies have focused on site suitability at the farm level. They were mostly conducted to resolve a specific conflict between the established mariculture industry and the environment. Examples are the environmental concerns due to the salmonid cage culture systems development in British Colombia and Norway (Black and Truscott 1994), the impact of overstocking oysters in France (Durand *et al.* 1994), and the intensified competition for space between pearl oyster farmers in Tuamotu Archipelago off the French Polynesia coast (Fuchs *et al.* 1995). In spite of the diversity of scales of projects, objectives and approaches, most of these mariculture GIS applications were developed in isolation from any planning and management procedural framework. The result was that the GIS applications were often short-term projects with limited practical use or long term value for planners and managers (Nath *et al.* 2000). Several reasons have been suggested for this isolation including:

- Planners often have limited spatial understanding of the environmental, economic and social environment, and how these may affect mariculture development (Beveridge *et al.* 1991). As a result GIS use is limited, which includes lack or limited integration of socio-economic information (Ross *et al.* 1993).

- Limitations of the data (availability, accessibility, and quality) and incompatibility with GIS technology. Data availability is specifically a major constraint in most GIS developments (Meaden and Do Chi 1996). Additionally, GIS is primarily designed for terrestrial application and has major limitations when used in the coastal zone, mainly due to the unique interactions between marine and terrestrial environments (Bartlett 1993, Bartlett 1994, Clark 1995). Examples are the over simplification of the carrying capacity of fjords in Norway (Ibrekk *et al.* 1993), and the problems associated with accuracy of the climatic data, lack of socio-economic data, and the bias output by GIS criteria choices in Sinaloa, Mexico (Aguilar-Manjarrez and Ross 1995).

- The limited interaction between the end user (planner) and GIS analyst. This is often due to the academic nature of the study with limited or no consultation with end users. Alternatively, the development of GIS by consulting agencies or planning authorities often produces information regardless of the immediate need of the end users (Nath *et al.* 2000). Limited appreciation and understanding of GIS technology by end users, weak institutional planning capacity, and inadequate organizational commitment, further enhances the GIS isolation (Black and Truscott 1994, Meaden and Do Chi 1996, Cho 2001).

The limited interaction between the GIS analyst (who is often the mariculture specialist) and decision maker has long been evident. However, until very recently this major constraint has not been addressed. Nath *et al.* (2000) first highlighted the need to develop GIS through an ongoing interactive process between the end user (i.e. decision makers), mariculture specialist, and GIS analyst. Nath *et al.* (2000) reviewed four case studies with regards to the degree to which decision makers have used GIS outcomes for mariculture planning. The results show that two case studies were conducted without the presence of, or the consideration of a development plan, and were not used by any planning authority. As a result, most of the review evaluation was focused on the GIS methodology, rather than the sector development plan objectives and how GIS was designed to address these objectives.

Considering that the success of GIS as a planning tool depends entirely on it being used by planners and decision-makers, the evaluation of the GIS development with respect to the sector development plan is vital. Such evaluation could help improve the way GIS applications are conducted in the future.

Rationale, aim and objectives

The need to develop and evaluate GIS as a tool in the context of the overall mariculture-planning framework is apparent. This study attempts to develop and evaluate GIS as a planning tool for the South African mariculture sector.

The development of a GIS for the South African mariculture sector forms part of a scientific co-operation agreement between France and South Africa. This particular study was initiated during 1998 as part of a joint venture between IFREMER[1] and the Department of Ichthyology and Fisheries Science (DIFS), Rhodes University.

South African mariculture sector planning is in various stages of development. Presently, at a national level, there are general guidelines to develop mariculture, which are derived from the integrated coastal zone management plan known as the Coastal Management Policy Program (CMPP). They include the recognition that mariculture is a preferred economic activity along the coast, which should be sustainably developed in potentially suitable areas, and that the responsibility to facilitate such development plans rests with national and provincial governments (Anon 1999, Britz and Hecht 1999). Hence, at the first national workshop on planning for sustainable development of the mariculture sector in South Africa, five broad objectives were suggested, which could stimulate the development of the sector.

[1] IFREMER Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea)

They were (Stenton-Dozey 1999):

1. Increase the perception of mariculture in the country and its many benefits.
2. Provide an enabling climate for increased participation and equity in the industry.
3. Promote mariculture as an important element of integrated coastal management.
4. Establish mariculture as a supplementary source of fish and shellfish for domestic market.
5. Develop a mariculture industry compatible with responsible stewardship of the coastal regions and their resources.

Nevertheless, the lack of both a comprehensive national sector plan and an institutional support structure is still evident and needs to be addressed in the near future. The regional mariculture planning along the Namaqualand coastline on the other hand, is more advanced, where a sector plan has been developed for the Northern Cape Province by the Department of Economic Affairs and Tourism of that province (Anon 1998, Britz *et al.* 2002b).

Spatial information has been recognized by both the National (Anon 1999), and Northern Cape Provincial governments (Anon 1998) as an essential component in mariculture sector planning. Although several spatial coastal databases are set in web-based interactive formats with basic GIS display functions[2], there is still a lack of a comprehensive coastal GIS, which can provide information for coastal users and decision makers in South Africa. The context of the mariculture-planning environment, and the lack of comprehensive coastal national GIS in South Africa therefore, provide a useful setting for the development and the evaluation of GIS as a planning tool.

Hence, this study aims to develop and evaluate GIS in terms of its relevance to the national and regional mariculture sector plan progress in South Africa. This was achieved by developing the GIS for three case studies.

[2] (e.g. http://mapserver.botany.uwc.ac.za/imf/imf.jsp?site=Sacoast)

These case studies represent the diversity of the mariculture sector planning in South Africa in terms of (Figure 1.6):

- *Scales of planning-* The national strategic vs. the specific regional planning requirements
- *Culture systems and species-* The different culture species and techniques, and their respective environmental, social, and infrastructure requirements
- *Planning progress-* The different stages of planning progress (on national and regional levels) and the associated spatial information required by planners/decision makers.

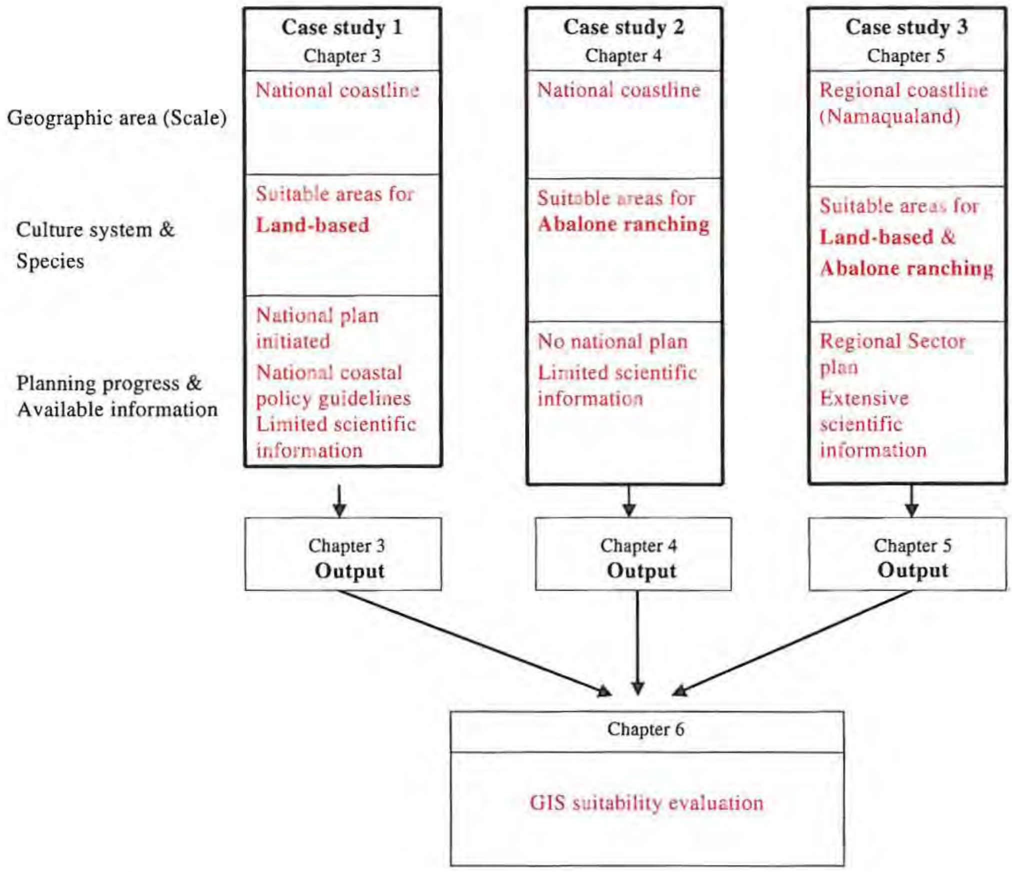


Figure 1.6: The three case studies (different in scale, culture system and species, and planning progress) used to evaluate the suitability of GIS for the South African mariculture sector. Case study 1 is a general suitability analysis for all land-based culture systems for the entire South African coastline. Case study 2 provides an additional national analysis but on a specific target species and culture method: abalone ranching. Case study 3 is more specific in scope, which includes a regional analysis of land-based culture and abalone ranching along the Namaqualand coast.

The objectives of the study were:

1. To identify suitable criteria and analytical methods, and capture relevant data into a uniform national GIS database format from the various sources, in order to identify potential suitable areas along the South African coastline for land-based mariculture operations.
2. To identify suitable criteria, capture relevant data, and identify potential suitable areas along the South African coastline for national abalone ranching activity.
3. To identify suitable criteria, and capture relevant data into a uniform national GIS database format, in order to identify the potential of land based operations and abalone ranching activity along the Namaqualand coastline.
4. To evaluate the relevance of GIS as a mariculture-planning tool, based on the data available for three case studies.

Thesis outline

This thesis is divided into six chapters and two appendixes.

Chapter 2 covers the general method and outlines the approach used in the development of the GIS as well as the evaluation of its suitability for mariculture sector planning in South Africa. Chapter 3 (case study 1) identifies the planning objectives at a national scale, and develops the GIS for identifying potentially suitable areas for land-based mariculture along the coastline. The development potential for mariculture in each of the four coastal provinces and the verification of the outputs are discussed. Chapter 4 (case study 2) presents an area suitability analysis for abalone ranching along the entire South African coastline. The output is discussed on a provincial basis with reference to current South African abalone ranching experiments. In chapter 5 (case study 3), the development of a regional GIS for the Namaqualand coastline is presented, within the context of Northern Cape provincial sector planning objectives. Suitable development areas for land-based mariculture and the potential of sections of the coast for abalone ranching are analysed. Based on the three case studies, an overall evaluation and suggestions for the development of GIS are presented in chapter 6, with regard to the existing and future South African mariculture development planning process.

CHAPTER 2
General method

Introduction

The use of GIS as a planning tool has increasingly become an integral component in coastal natural resource management (Pheng *et al.* 1992, Bartlett 1994, Clark 1995, Walker and Young 1997, Canessa 1998, Bartlett 2000, Payne 2000). Following this trend, GIS has also been applied in mariculture planning over the past two decades for various planning and management requirements, such as the assessment of the carrying capacity of fjords in Norway (Ibrekk *et al.* 1993), site selection in Sinaloa, Mexico (Aguilar-Manjarrez and Ross 1995), and modelling the environment to manage the overstocking of oysters in France (Durand *et al.* 1994). Most of these applications were however, very limited in their use as a Spatial Decision Support Systems (SDSS). It has been suggested that the reason for this is the limited interaction between GIS analysts and sector planners (Beveridge *et al.* 1991, Black and Truscott 1994, Nath *et al.* 2000). This probably accounted for the predominantly academic use of GIS, which is not based on sector development plan objectives. Development of a mariculture SDSS therefore, requires an approach that incorporates and integrates GIS development with mariculture sector plans.

Hence, this study aims to develop a GIS, based on the objectives of the South African mariculture sector development plan. By doing so, this study attempts to evaluate the relevance of GIS as a planning tool for the South African mariculture sector. In this chapter, the *approach* used to develop and evaluate the GIS is explained, followed by the GIS *strategic design*. The chapter concludes with details on the *GIS hardware and software* used, and the *scope* of the study.

Approach to GIS development and evaluation

GIS is a highly adaptable planning tool that can accommodate specific planning objectives. This is greatly attributed to its development, which is based on an issue-driven approach. The issue-driven approach implies that the GIS development is guided by selected issues (i.e. objectives), as opposed to data (i.e. data-driven approach). Identifying the issues can be achieved by continuing interactions between three types of project personnel: end users (i.e. the planner), specialists (i.e. the mariculture specialists), and the GIS analysts (Figure 2.1) (Nath *et al.* 2000). The continuous interactions ensure that mariculture development plan objectives will be comprehensively addressed by the GIS outputs.

Mariculture sector development plans may occur on different scales (i.e. national, regional, and farm level). Since GIS is based on an issue-driven approach, the development of the GIS requires it to be compatible with these different planning scales. Likewise, the South African mariculture sector entails two scales of planning: national and regional. The GIS development in this study was therefore based on a spatial planning approach developed by PAP/RAC (1996), which recognizes the variations of scales in mariculture planning. This approach includes a two-phase analysis procedure, initially developed for zoning mariculture in the Mediterranean coastal areas. This procedure is compatible with the principles of the Integrated Coastal Zone Management (ICZM) planning (PAP/RAC 1996). The first phase is a general holistic analysis (i.e. national scale) that is based on the elimination of non-suitable zones for mariculture development, such as non-compatible coastal uses (e.g. conservation and military areas). This is followed by a more detailed analysis of suitable zones based on specific culture technologies and candidate species requirements. Hence, the two-phase approach used in this study attempts to address the different objectives of the planning authorities (i.e. national and provincial governments) in South Africa.

This study describes the initial phase of GIS development, and as such it provides only preliminary evaluation of the GIS as a planning tool for the mariculture sector in South Africa. However, GIS development is a continuous process, based on dynamic interactions between all involved personnel, which tend to vary with time and according to the project requirements. In order to ensure that the GIS address planning objectives continuously, the GIS development procedure needs to be based on the iteration of the development phases (Figure 2.1). This permits re-entering of new information as time progresses, and a continuous evaluation of the GIS outputs in relation to the planning objectives.

GIS Strategic design

The potential of South African mariculture development is diverse. As a result, different development plans are required to identify, stimulate, and coordinate the developments. These plans are different in scale (i.e. national and regional), culture system (e.g. intensive land-based systems and abalone ranching) and target species (e.g. abalone and prawn). Therefore, this study attempts to develop and evaluate the utility of GIS as a planning tool with respect to the diversity of the mariculture development plans and the required information. Three case studies, representing the diverse plans in South Africa, were selected. Case study 1 is a general suitability analysis for all land-based culture systems for the entire South African coastline. Case study 2 is a specific national analysis for abalone ranching. Case study 3 is a more detailed regional analysis of land-based culture and abalone ranching along the Namaqualand coast (Table 2.1).

Table 2.1: The three case studies used for the development and evaluation of the GIS along the South African coastline.

Case study	**1** (Chapter 3)	**2** (Chapter 4)	**3** (Chapter 5)	
Geographic area	National coastline	National coastline	Regional coastline (Namaqualand)	
Culture technique	Land-based culture	Ranching	Land-based	Ranching culture
Target species	General*	Abalone	General*	Abalone
Planning progress	National sector plan initiated National coastal policy guidelines (CMPP)	No national sector plan Regional diagnostic survey & management plan	Regional Sector plan	
Available information	Limited scientific information	Limited scientific information	Extensive scientific information	

* Current and potential South African mariculture target species

The GIS was developed separately for each case study based on a strategy consisting of six main phases. They include (Figure 2.1) (Nath *et al.* 2000):

1. *Identification of project requirements*: In order to develop the GIS as an integrated planning tool for the process of decision-making, GIS objectives were first clearly identified. This included identifying existing mariculture planning processes and their objectives. Once these objectives were identified, spatial development constraints were determined and spatial objectives were selected for the development of GIS. This phase was based on communication (e.g. meetings, workshops and personal communications) between the different South African mariculture stakeholders including decision-makers, mariculture specialists and GIS analysts.
2. *Developing an analytical framework:* This phase addressed the issue of how the spatial objectives were analysed. Several analytical methods exist for integrating and analysing spatial data, including: arithmetic and Boolean logic operations, classification, simple overlay, weight overlay, neighbourhood analysis, connectivity analysis, hierarchical models, and multi-objectives land allocation. The selection of the most suitable methods was based on the project objectives and limitations. This study's main objective was site selection analysis, and as such the most suitable analyses methods were Boolean logic and arithmetic operations (Appendix A) [3].
3. *Selection and location of data sources*: Mariculture planning is dependent on various types of data, including ecology, economic, social, and infrastructural environmental conditions. This data can be gathered from a variety of sources, ranging from primary data collected in the field or that generated by remote sensing, to secondary data found in published literature, mapping agencies, and online databases. The initial data selection in this study was based on the main spatial development constraints. This was followed by an attempt to source and assess the quality of the available, accessible, and compatible databases. Quality of data was also based on data of capture, scale, and projection of data. This GIS study was based on secondary data

[3] An additional operator used in the site selection analysis was the buffer zone. Although in this study buffer zone values were set subjectively, they are variable and in future could be modified to generate different scenarios.

sources, which included: published maps, reports, remote sensing, and personal communications.

4. *Organization and manipulation of data*: Data organization and manipulation is considered as an essential phase prior to the GIS analysis. This phase contained three important elements: conversion of the data into a GIS compatible format, modification of the original data to the required GIS layer, and consolidation of the data into a suitable and functional database structure. Most of the digital formats were converted directly into the GIS internal format using the GIS built-in import function, whereas hard copy maps were digitised. Original data was sorted into separate layers of information for the GIS analysis (e.g. extraction of conservation areas from land use maps). Such modifications were done using built-in GIS functions and Script Manipulated Language (SML). Lastly, data was organized into a category database structure (i.e. biophysical, coastal user, and infrastructure) to provide readily accessible information for the end user. This was done to assist planners when new scenarios are needed and updated data is available.
5. *Data analysis and verification*: This was a central phase in the development of the GIS. It included: execution of the analytical method, computation of the relevant statistics (e.g. mean, range, classes), and the verification of the GIS outputs in each of the case studies. Verification was considered as an essential part of the GIS work for both data quality control and the testing of final outputs.
6. *Evaluation of the outputs*: In this final GIS phase, the outputs of the three case studies were jointly evaluated. The aim of this evaluation was to assess the relevance of the GIS output to the South African mariculture development plans. This included the evaluation of the GIS's ability to identify suitable sites based on given spatial constraints. This evaluation also provided future suggestions based on the identified GIS limitations.

GIS development process

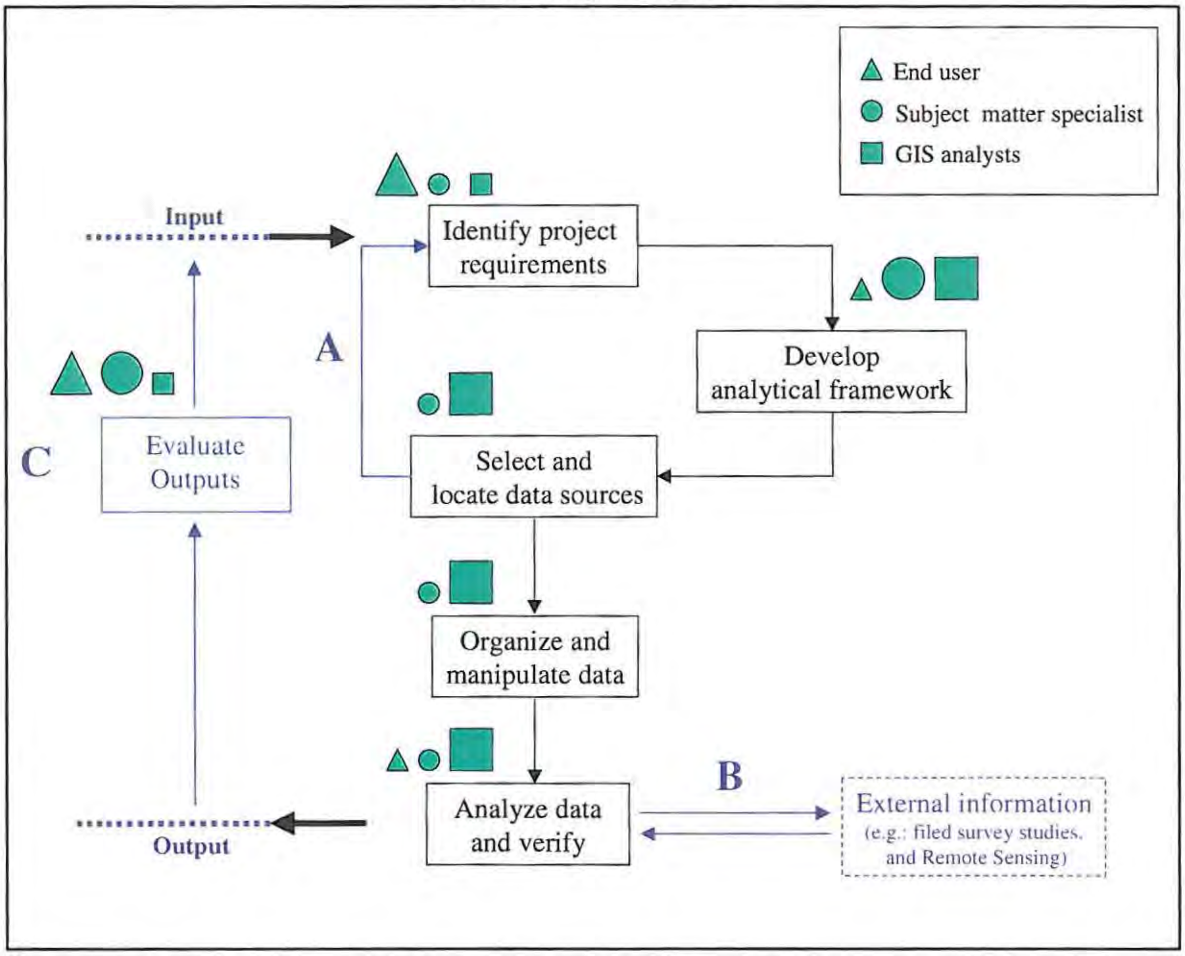


Figure 2.1: The different phases in the process of GIS development. The proportional involvement and required role of each project personnel type is represented by the symbol size. Note the iteration of the development phases (A, B, and C), and the interactions with end user (i.e. planners) intensified when project objectives/needs are identified, and again when GIS output is evaluated (adapted from Nath *et al.* 2000).

The Geographic Information System

The GIS used in this study was based on the following hardware and software:

The hardware

PC: P1, 200 mega Hz, 6 giga bits storage, 64RAM

Monitor: 65536 colour, 800X600 pixels, 17" screen

Printer: HP Deskjet 890C series

Digitizer board: GTCO type5 Tablet

The software

Operating System NT version 4 (©Microsoft)

TNTmips version 6.2 (©MicroImages)

ArcView version 3.2 (©ESRI)

TNTmips is a fully functional GIS software package with advanced vector and raster analysis tools. TNTmips is compatible with many Operator Systems (OS). The X Window System cross-platforms compatible design of MicroImages provides a GIS application that works exactly the same way in all OS, including: Windows PC's (95,98,2000 and NT), Apple Macintosh, Sun SPARCstation, HP 9000 series 700, BM RS/6000 and other workstations from DEC and Silicon Graphics (Anon 1999). ArcView is one of the most popular desktop GIS software, designed and marketed by ESRI, with full functionality of a typical GIS. ArcView runs in all Microsoft Windows Operator Systems with a point-and-click graphical user interface (GUI) and drop-down-menu system offering good design and printing output capacity. The advanced analytical ability of TNTmips and Window user-friendliness of ArcView provides a useful combination of software.

Scope

The scope of this study was the South African coastline from the mouth of the Orange River (S28° 38'10", E16° 27'35") on the west coast to Kosi Bay S26° 51'37", E32° 53'32" on the east coast. This study was limited to a buffer zone of 2km inland. The extent and diversity of the South African coast, however, required division of the coast into manageable planning and development regions. Two administrative divisions were used: provincial boundaries, and those described in the Coastal Management Policy Program (CMPP) (Anon 1999) (Figure 2.2). The provincial boundaries allowed for evaluation of the mariculture potential on a regional scale (i.e. KwaZulu-Natal, Eastern Cape, Western Cape, and the Northern Cape Provinces). The GIS output was also described based on the 13 CMPP divisions, viz., Namaqualand, West Coast, Cape Metro Area (CMA), Agulhas Coast, Garden Route, Sunshine Coast, Border Kei, Wild Coast, Hibiscus Coast, Durban Metro Area (DMA), Dolphin Coast, Zululand, and Maputaland (Figure 2.2).

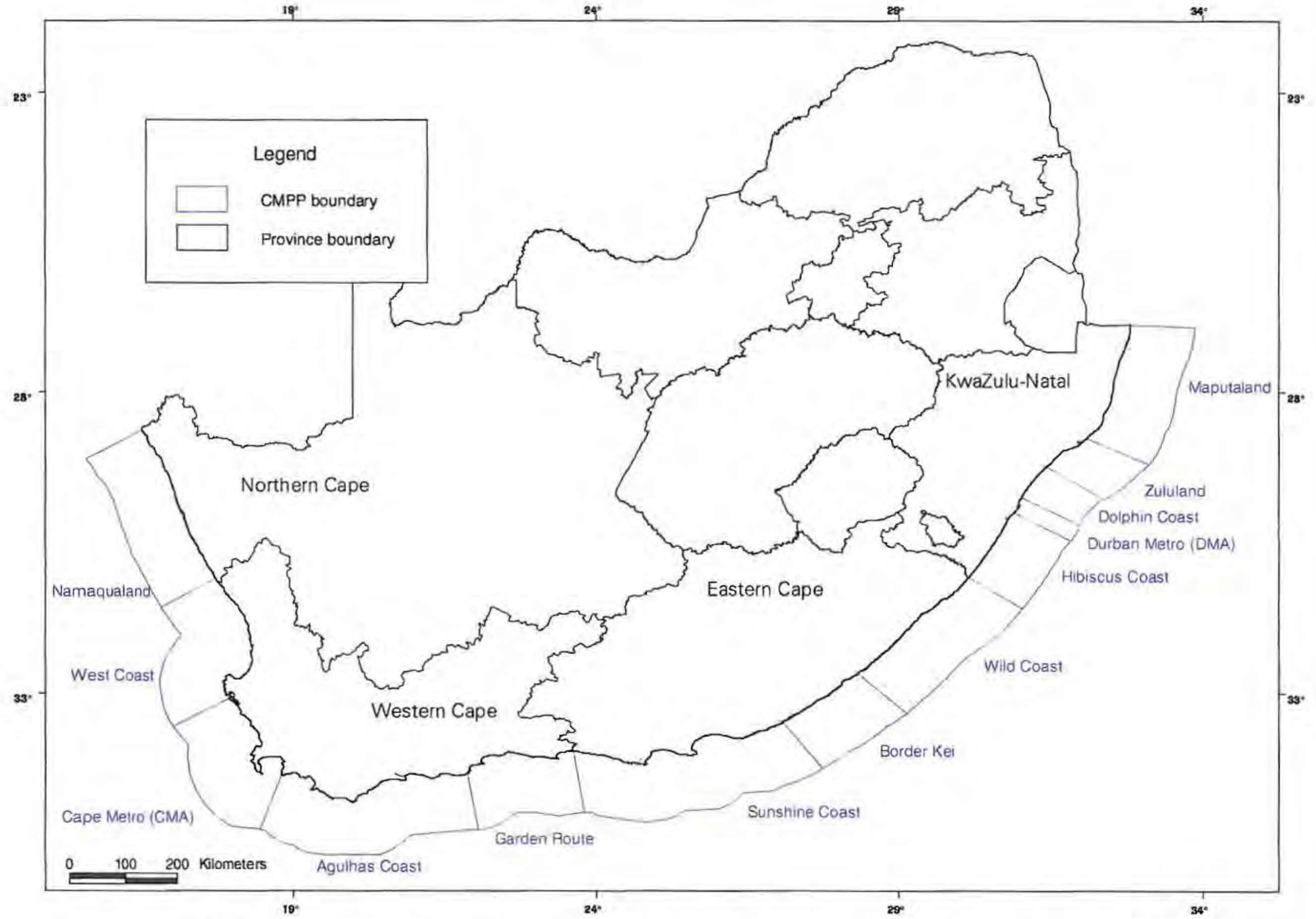


Figure 2.2: The provincial and Coastal Management Policy Program (CMPP) boundaries of the South African coast.

CHAPTER 3
A GIS based spatial evaluation of the South African coastline's suitability for land-based mariculture development

Introduction

Background and rationale

The South African mariculture sector, while in its primary stage of development, requires an institutional support structure and a comprehensive national sector plan for its development (Britz and Hecht 1999). Such a plan needs to be based on an understanding of the interactions between the sector and the surrounding biophysical, social and economic environment. These interactions have an important spatial element. Hence, spatial analysis of these factors is essential to the planning.

An early assessment by Hecht & Britz (1992) of the potential of mariculture revealed limited prospects for marine-based practices due to environmental factors such as high wave energy, the lack of sheltered bays and lagoons along the coast, and Harmful Algal Blooms (HAB). However, intensive land-based culture of high value species (e.g. abalone, shrimp and ornamental fish) was found to have high potential due to the presence of suitable coastal environmental conditions. These included unpolluted water, cheap and relatively underdeveloped land, and good infrastructure (Hecht 1999). In spite of this potential, no comprehensive spatial assessment of the environment exists for land-based mariculture development. This is particularly evident with regard to the interactions between land-based mariculture activities and dominant coastal activities (e.g. urban settlements, conservation and recreation).

The first attempt to evaluate the spatial potential of the South African coastline for mariculture development was during 1980's by Bruton (1985). Bruton (1985) concluded that the west coast region had the highest potential for mariculture development, whereas the east coast had the lowest potential. This study, based on McHarg's (1969) intrinsic suitability mapping technique and fieldwork input, contained biological, physical, social, and economic criteria, but lacked spatial detail, and to a great extent, depended on subjective inputs.

More recently, the South African Network for Coastal and Oceanic Research (SANCOR) identified the need for a national comprehensive estuarine mariculture site suitability evaluation (Anon 1998). This investigation into the suitability of estuaries for mariculture revealed a high number of potentially suitable estuaries on the east coast within the Eastern Cape Province (Cowley *et al.* 1998).

The need for mariculture site suitability analysis was further recognized in the Coastal Management Policy Program (CMPP) published in the White Paper for sustainable coastal development in South Africa (Anon 1999). At the first national workshop on planning for sustainable development of the mariculture sector in South Africa, it was proposed that the development plan and selection of strategies would be based on identifying appropriate sites for mariculture development and sharing this data among sector planners across provincial and national levels (Malan 1999). Although at present the lack of a national mariculture sector plan has resulted in a shortage of detailed objectives and strategies for development, a comprehensive spatial analysis could provide a meaningful input for the initial phase of the planning process. Hence, quantified spatial inputs could provide significant information during the diagnostic survey phase, which is performed at the start of the sector planning process in order to identify constraints and opportunities for development.

Aim, objectives, and approach

A need for a spatial evaluation of land-based mariculture in South Africa is evident, particularly in the light of the emerging national sector plan. This study therefore attempted to accommodate this need.

The aims of this study, derived from the White Paper document objectives (Anon 1999), were:

1. To identify potentially suitable areas for land-based mariculture development along the South African coastline, based on biophysical and coastal use, and infrastructure criteria.
2. To enhance communication and co-ordination among national and provincial sector planners through the integration of relevant information into one database.

Method

The identification of the potentially suitable zones for land-based mariculture development was based on site suitability analyses. However, due to the extended and diverse coastal zone of South Africa, the land-base mariculture evaluation was conducted on the basis of the four coastal provincial boundaries (i.e.: KwaZulu-Natal, Eastern Cape, Western Cape and Northern Cape). This division was in line with the proposed provincial mariculture planning and management institutional structure (Malan 1999). Each province's coastline was further divided in order to describe the output in detail. This secondary division, based on the Coastal Management Policy Program (CMPP) regions boarders (Anon 1999), contextualized the GIS outputs within the framework of the White Paper for sustainable coastal development in South Africa (Figure 2.2).

The site suitability analysis was based on a five-principle approach, described by Nath *el al.* (2000):

- Identification of project requirements (refer to aim and objectives in the introduction)
- Selection of the analytical framework
- Selection and location of data sources
- Organization and manipulation of data for input
- Analysis of data and verification of outputs

Selection of analytical framework

The objective of this study was primarily concerned with identification of potentially suitable areas for land-based mariculture operations. This was based on the elimination of the unsuitable mariculture development areas using site suitability analysis. The potentially unsuitable mariculture development areas were areas with a certain developmental constraint (e.g. competition for space). The elimination process was based on a set of conditions, which excluded the unsuitable areas with developmental constraints. Some of these unsuitable areas were selected using an arbitrary buffer zone[4]. Additional data, which was not used in the elimination process, was simply overlaid. The final output was compiled from the analysed and overlaid data, and named: the 'Biophysical-Coastal use-Infrastructure' (BCI) output.

Selecting and locating available data

Limited information was available on the required criteria for land-based mariculture development in South Africa. Consequently, the final choice of the essential criteria for national land-based mariculture development was based on the concerns mentioned in the limited literature review (Table 3.1), personal communications (Pers. Comm. Britz and Hecht, Department of Ichthyology and Fisheries Science, Rhodes University), and the available and accessible databases. Based on these required criteria the following available data for the land-based mariculture analysis was collected (Table 3.2):

[4] Note that these buffer zones are considered as variables, and in future could be modified to generate different scenarios.

Table 3.1: The major considerations for land based mariculture development (+), which were identified during the local literature review. Note that although no comprehensive spatial study is available on the impact of coastal activities on mariculture development, the urban, conservation, and recreational activities are identified by all authors as major considerations for future mariculture development.

		Considerations				
Author(s)	***Objective***	Coastal activity			Infrastructure*	Biological**
		Urban	Conservation	Recreation		
(Bruton 1985)	National mariculture Site suitability evaluation	+	+	+	+	+
(Hecht and Britz 1992)	National review of mariculture development	+		+		+
(Cowley *et al.* 1998)	National development plan for estuarine mariculture		+	+	+	+
(Britz *et al.* 2002)	Provincial abalone resource management plan	+	+	+	+	+
(Britz *et al.* 2002b)	Provincial mariculture development sector plan	+			+	+

* Access to the coast by road was identified as one of the important potential constraint of infrastructure for mariculture development.

** Habitat condition including water quality with specific reference to the impact of Harmful Algae Bloom on water quality is major biological concerns for the mariculture sector.

Table 3.2: The spatial databases selected for the land-based mariculture analysis.

Data type	Data source	Publication	Year of publication	Captured Scale
Coastal Sea Surface Temperature (SST) measurements in C° including: 1. Seasonal Average minimum SST 2. Seasonal Average Delta (Δ) SST = Av. Max. SST - Ave. Min. SST	MCM/DEAT*	(Greenwood and Taunton-Clark 1994)	1994	National
Harmful Algal Bloom (HAB) occurrences (%) along the entire South African coastline between the years 1989 to 1997	MCM/DEAT	(Pitcher 1998)	1998	National
Surf-zone discharges rates and positions (m^3/day)	Water Research Commission	(Fijen 1988)	1988	National
Estuarine mariculture potentially suitable locations	SANCOR**	(Cowley *et al.* 1998)	1998	National
Marine Protected Areas (MPA) locations and boundaries	DEAT	(Anon 2000)	2000	National
Terrestrial coastal Nature Reserves (NR) location and boundaries	DLA/Directorate of Survey and Mapping***	South African published maps	1998	1: 500,000
Urban areas	DLA/Directorate of Survey and Mapping	South African published maps	1998	1: 500,000
Recreational Activity (RA) locations (including: holiday resorts, bathing, surfing, diving and sport fishing)	MCM/DEAT	Coastal Sensitivity Atlas of South Africa (Jackson and Lipschitz 1984)	1984	1:250,000
Land-based mariculture operations locations	N/A	Britz pres. comm. DIFS, Rhodes University	2001	N/A
Road network location (including: national, highways, freeways, main and secondary roads)	DLA/Directorate of Survey and Mapping	South African published maps	1998	1: 500,000
Airport (with regular flights) location	South African Airways	(Anon 2000)	2000	N/A

* Marine and Coastal Management/ Department of Environment and Tourism (MCM/DEAT)
** South African Network for Coastal and Ocean Research/Estuarine Mariculture in South Africa Report
*** The Department of Land Affairs/Directorate of Survey and Mapping (DLA)

Data organization and manipulation

The diversity of the data and the potential for future expansion demanded an effective database management structure, and appropriate conversion and sorting procedures. Hence, the three criteria group (biophysical, coastal use and infrastructure) formed the basis of the database structure containing descriptive and quantitative information (Figure 3.1). The database was used to generate two types of output:

1. An independent output for each criteria group (i.e. a biophysical, coastal use, or infrastructure outputs)
2. An integrated output combining the biophysical, coastal use, and infrastructure outputs to generate one mariculture potential suitability ranking output (i.e. Biophysical-Coastal use-Infrastructure (BCI)).

In order to unify all the different data into one database, the conversion and sorting procedures described in Table 3.3 were employed.

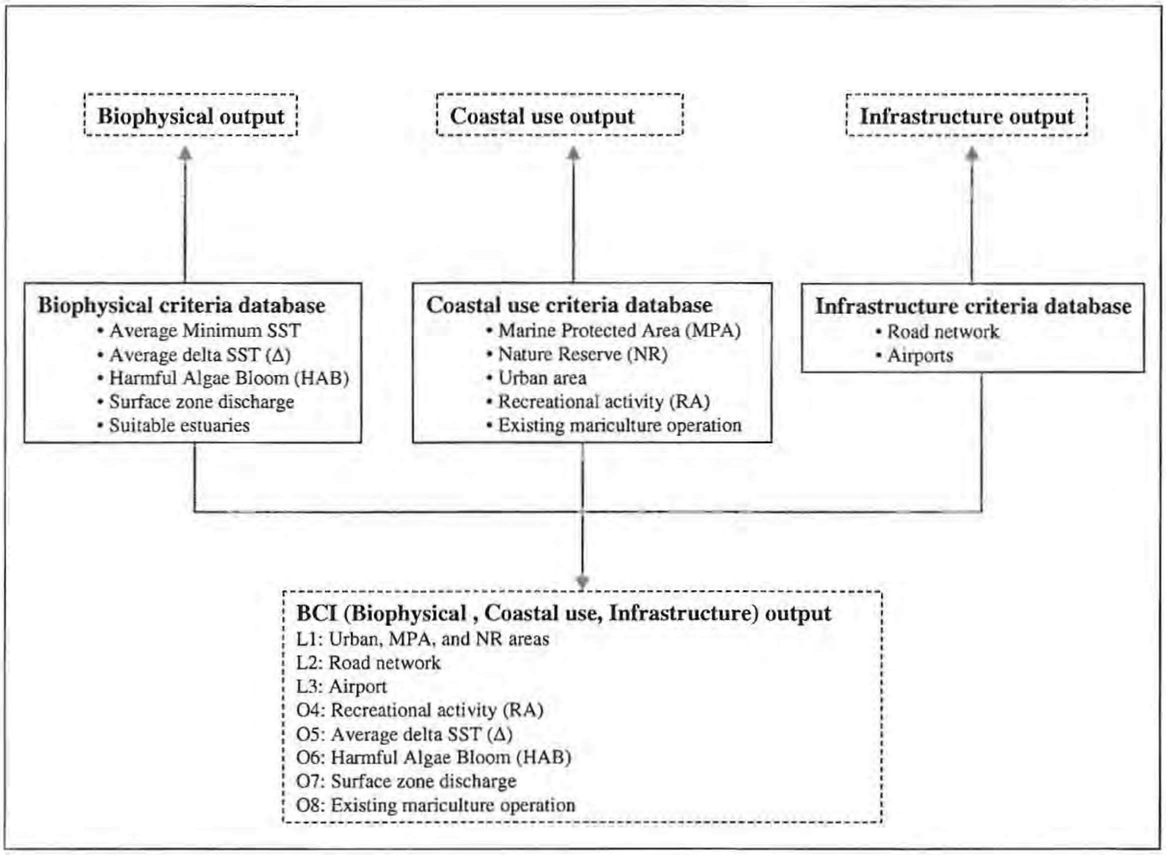


Figure 3.1: The three criteria database and the biophysical, coastal use, infrastructure and 'Biophysical- Coastal use-Infrastructure' (BCI) outputs. The BCI output was generated from the analysed data layers (L), and the non-manipulated data, termed overlays (O).

Table 3.3: The different data formats and the conversion and sorting procedures applied during the organization and manipulation phase.

	Data type	*Original format*	*Data conversion & sorting procedure*
Biophysical Criteria	**Coastal Sea Surface Temperature** (SST) measurements in C° including: 1. Monthly Ave., Min., & Max. SST 2. Monthly Ave. variation (Δ) SST = Ave. Max. SST - Ave. Min. SST	Internal report -coastal station points data	1. Seasonal min. max. averaging & variations calculation of SST 2. Digitising SST coastal station locations
	Harmful Algal Bloom (HAB) occurrences (%)	Report – map output	Digitised into GIS format
	Surf-zone effluent discharges rates and positions (m³/day)	Report	Digitised into GIS format
	Estuarine mariculture potentially suitable locations	Report Co-ordinates of estuaries	Digitised into GIS format
Socio-economic Criteria	**Marine Protected Areas (MPA)** locations and boundaries	Report Co-ordinate of MPA	Digitised into GIS format
	Terrestrial coastal Nature Reserves (NR) location and boundaries	Digital ASCII format	Converted into GIS format* Extracted from SA maps by SML
	Urban areas	Digital ASCII format	Converted into GIS format* Extracted from SA maps by SML
	Recreational Activities (RA) locations (including: holiday resorts, bathing, surfing, diving and sport fishing)	Digital GIS format	Extracted from SA maps by SML
	Land-based mariculture operations locations	Hecht and Britz, Department of Ichthyology and Fisheries, Rhodes University pres. comm.	Digitised into GIS format
Infrastructure Criteria	**Road network** location (including: national, highways, freeways, main and secondary roads)	Digital ASCII format	Converted into GIS format* Extracted from SA maps by SML
	Airport (with regular flights) locations	Timetable booklet with airfield locations map	Digitised into GIS format

* Converted by EnviroMap Ltd.

Data analysis
The analytical framework used in this analysis was based on a set of conditions, which indicated constraints for mariculture development. The following criteria and their interactions with mariculture were evaluated in order to identify these constraints and the associated conditions required to eliminate the zone within which they applied:

1. Biophysical criteria

Sea Surface Temperature variation (ΔSST)[5]*:* Preferred optimal conditions for the culture of an organism would be in areas with a low variation between minimum and maximum seasonal average SST. Hence, provincial coastal areas with a low ΔSST range were considered as potentially suitable coastlines for mariculture development. However, since the daily rate of change was not considered (an indicator for inferable mariculture site conditions), high ΔSST did not necessarily imply unsuitable coastline conditions.

Harmful Algal Bloom incidence (HAB): HAB is a major concern for the development of the mariculture sector in South Africa. The HAB occurrence data set was therefore used as a risk indicator for potential future HAB occurrence.

Coastal surface effluent discharge: This national effluent discharge point data set provides an indication of coastal water pollution from both urban sewage and industrial outlets.

2. Coastal use criteria

Potential opportunities for mariculture development are highly dependent on the intensity of competition for space between human activities, and the associated outcomes of conflicts. In this study, urban development, conservation, and recreation were identified as dominant coastal uses. Since no information is yet available on their present and future relationship with mariculture, the assumption was made that all three activities are non-compatible with mariculture development.

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[5] Average Delta SST (Δ) = Seasonal Average Maximum SST- Seasonal Average Minimum SST

The rationale for this was (Figure 3.1):

- **Urban**- Residential and industrial coastal users compete for space and affect water quality due to discharges, specifically in large metropolitan areas. This has a negative impact on the close surroundings (evaluated at a 2km distance) on mariculture development.
- **Recreational activities**- Recreational activities are usually associated with areas with an aesthetic landscape. In addition to space competition over these areas, development of land-based mariculture activities can also modify surrounding landscapes appearance (both land and sea) and by doing so have a negative impact on the recreational activity. However, in some cases mariculture can be a tourism attraction and then compatible with recreational activities and coastal tourism.
- **Conservation**- Two forms of coastal conservation areas exist along the South African coastline: Marine Protected Areas (MPA) and terrestrial Natural Reserve (NR). Both forms of conservation were considered to be non-compatible for mariculture development.

Based on the above coastal use criteria, two aspects were evaluated for the coastlines of each province (Figure 3.2):

1. Intensity of coastal use. The intensity of activities by other established coastal users was analysed to indicate how susceptible the environment would be to the newly introduced mariculture sector (marked in blue). In each province the location and extent of coastal use was described. This included calculation of the number of recreational activities per 100km coastline.
2. Spatial competition between mariculture and other coastal use was analysed in order to reveal potentially available coastline for mariculture (marked in red). Available space not utilised by other coastal uses (urban or conservation) was determined.

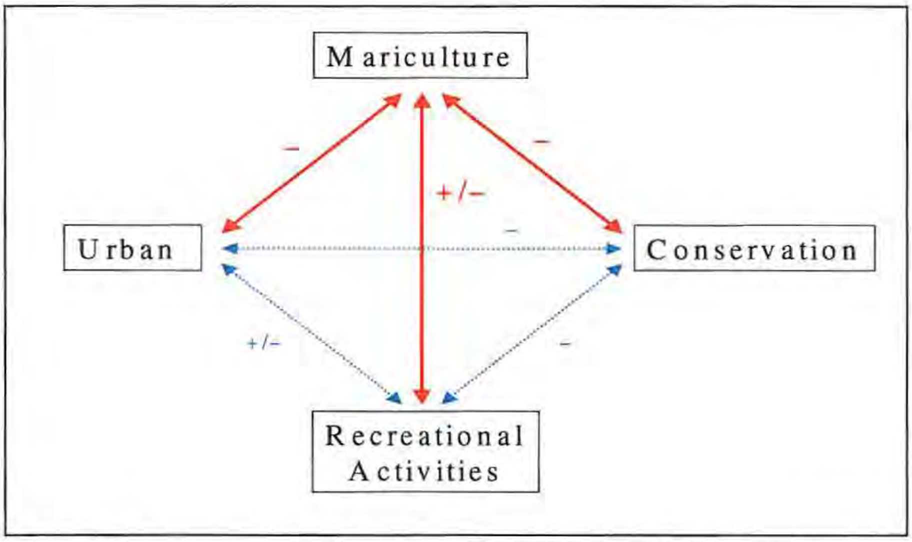

Figure 3.2: The assumed spatial interactions between dominant coastal use (included in this study) and mariculture operations (Compatible activities (+) and Non-compatible activities (-)).

3. Infrastructure criteria

Coastal infrastructure, specifically the road network, has a substantial effect on all development including mariculture. In this study, road network data was used as an indicator of accessibility to the coast. Coastal areas within 5km of distance from any road were considered accessible. Additional infrastructure included airports, which provide access to international markets. The assumption was that airports proximity is essential for some forms of mariculture operations such as live abalone or fresh fish export. Hence, a distance of less than 100km was considered as an acceptable range for farms' locations for exporting products by air flights.

Based on the above evaluation, several criteria were selected for the analysis. These criteria addressed some of the major land-based mariculture development constraints and included competition for space and access to the coast. The constraints were ranked subjectively according to their degree of impact on land-based mariculture. Further on, each constraint was associated with a potential level for mariculture development (Table 3.4).

Table 3.4: Potential suitability index for land-based mariculture. The criteria, constraints, and the associated four levels of potentially suitable areas for land-based mariculture are listed. Note that "High potential" level (**P4**) implies no development constraints.

Criteria	Constraint	Potential level	**Index**
Urban/MPA/NR	Urban/MPA/NR areas are non-compatible and have poor potential	Poor potential	**P1**
Road network	Coastal area without road access have limited potential for development	Limited potential	**P2**
Airport	Export market cannot be accessed in areas, which are not near operational airports. Hence they have moderate potential	Moderate potential	**P3**
		High potential	**P4**

Once the constraints were identified, conditions were set to eliminate them. This was done with the use of Boolean logic and arithmetic operations (Appendix A). Each potential level was identified using a sequence of combined operations. Once the areas were identified and assigned a potential level, these areas were excluded in the next potential level analysis. The constraints and operations used in the analysis are described in Table 3.5.

The final output, namely Biophysical-Coastal use-Infrastructure (BCI) output, was a potential mariculture suitability classification index map, where the highest potential areas were those that fulfilled all conditions (P4), and the lowest potential areas were those that failed to fulfil the first conditions (P1). This included the additional overlaid data (e.g. effluent discharges and Harmful Algal Bloom).

The BCI output was then further analysed in terms of optimal temperature for the growth of the two main commercial land-based cultured species (i.e. abalone and prawn).

Table 3.5: The different operations and conditions used in the land-based mariculture GIS analysis. Each constraint was analysed based on a sequence of operations combined of Boolean logic "**AND**", algebraic relation "**Subtract**", and "**Buffer zone**" operations (Appendix A). The final output presented four levels of mariculture development potential, and was named: Biophysical-Coastal use-Infrastructure (BCI) output.

Constraint	The sequence of operations used in the analysis	Potential level	Index
Urban, MPA & NR areas	[(**Buffer 2km** *Coastal area*) **AND** (**Buffer 2km** *Urban area* **AND** *MPA* **AND** *NR area*)]	Poor	P1
No road access	[(**Buffer 2km** *Coastal area*) **Subtract** (**Buffer 2km** *Urban area* **AND** *MPA* **AND** *NR area*)] **Subtract** (**Buffer 5km** *Roads*)	Limited	P2
No airport access	[(**Buffer 2km** *Coastal area*) **Subtract** (**Buffer 2km** *Urban area* **AND** *MPA* **AND** *NR area*) **AND** (**Buffer 5km** *Roads*) **Subtract** (**Buffer 100km** *Airport*)]	Moderate	P3
No constraints	[(**Buffer 2km** *Coastal area*) **Subtract** (**Buffer 2km** *Urban area* **AND** *MPA* **AND** *NR area*) **AND** (**Buffer 5km** *Roads*) **AND** (**Buffer 100km** *Airport*)]	High	P4

Abalone and prawn optimal temperature for growth

The South African coastline displays a wide range in Sea Surface Temperature (SST) and offers several opportunities for different cold-temperate and sub-tropical species culture. However, presently only two commercial land-based mariculture species are being farmed, namely: abalone (*H. midae*) and prawn (*P. indicus*). This part of the analysis attempted to evaluate the potential development areas for abalone and prawn, based on their requirements of optimal SST for growth. They were 12-20°C for abalone (Britz *et al.* 1997) and 22-33°C for prawn (Lee and Wickins 1992). This analysis was based on records of seasonal average, minimum and maximum Sea Surface Temperature (SST) from 29 Marine and Coastal Management's (M&CM) coastal stations. The point data, received from Greenwood and Taunton-Clark (1994), was then digitised in order to determine the SST profile along the South African coastline.

Hence, based on the known optimal temperature range for abalone and prawn growth, and the available SST data from coastal stations, potential optimal (P4) and sub-optimal (P3) SST regions for culturing the two species were determined. This was done by using a buffer zone and Boolean Logic operation "AND". The results consist of a map showing the location of these regions, and the total length in kilometres of potentially suitable coastline for each of the coastal provinces.

Verification of the GIS output

Verification of the output by means of ground truthing is an essential part of any GIS work, since it ensures data quality control and is a means of feedback into the analytical process (Nath *et al.* 2000). However, due to the limitations of this study and the lack of field surveys, validation was carried out by comparing the BCI output with two sources of independent information:

1. The location of existing abalone and prawn farms, which indicates that these sites are suitable for mariculture development.
2. The independent estuarine mariculture suitability survey carried out by Cowley *et al.* (1998), which highlighted the suitability of certain estuaries for land-based[6] mariculture.

Hence, these two sources of information indicate the locations of several potential suitable sites for mariculture development. The comparison of the BCI output with the locations of these potential suitable sites was therefore used as means of verification.

[6] Cowley *et al.* (1998) has evaluated the suitability of the estuarine environment for both marine and land - based mariculture system. The latter evaluation included several systems ranging from extensive to intensive culture techniques for farming species such as oysters, prawns, mudcrab, mullet, tilapia, spotted grunter, dusky kob, and seaweed.

Results

Four of the nine South African provinces share the coastline. They are the Northern Cape, Western Cape, Eastern Cape, and KwaZulu-Natal provinces. The length of the South African coastline is about 3600km and stretches from Orange River in the west to Ponta do Ouro in the east. The Northern Cape Province coastline is 340km, which is 10% of the national coastline. The Western Cape Province, Eastern Cape Province, and KwaZulu-Natal Province coastlines are 1400km (40%), 1140km (30%), 740km (20%), respectively. In the following section individual outputs for the three selected criteria groups are presented, as well as the combined Biophysical-Coastal user-Infrastructure (BCI) output with respect to each of the coastal provinces.

The biophysical criteria group output

Relatively stable Sea Surface Temperature (SST) conditions throughout the year (average delta SST<3.5°C) were identified on the West Coast within the Northern Cape and Western Cape Provinces. Typically, cold temperate conditions with an average minimum SST lower than 13°C prevail along this section of the coast. An average minimum of above 20°C was observed along the KwaZulu-Natal coastline (Figure 3.3). General trends reveal that the West Coast within Northern Cape and Western Cape Provinces was the most susceptible area for Harmful Algal Bloom (HAB) occurrences over the past 10 years, and as such was considered a high-risk area for future blooms. This is in contrast to the East Coast, along the Eastern Cape and KwaZulu-Natal coastlines, which are not susceptible to HAB and are thus considered low-risk areas for HAB's.

The main areas of high municipal and industrial effluent discharges are present on the south coast of the Western Cape Province, specifically in the Cape Town metropolitan and Saldanha Bay industrial areas. In the Eastern Cape Province two municipal sewage discharges points were identified at Port Elizabeth (10,000 m^3/day) and East London (26,800 m^3/day). In KwaZulu-Natal effluent discharges occur in Margate, Durban, and Richards Bay (Figure 3.3).

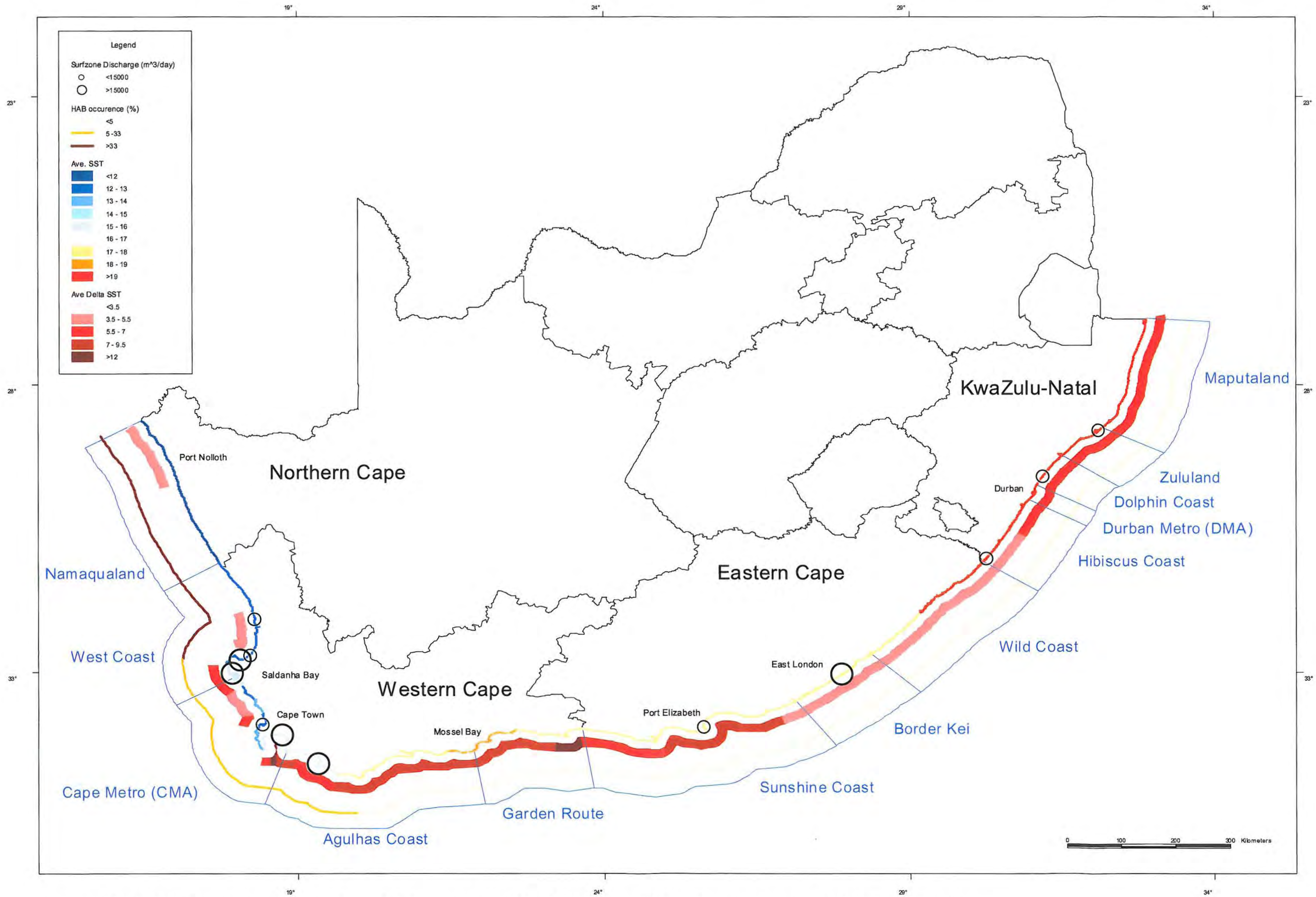

Figure 3.3: Biological criteria outputs including Sea Surface Temperature (SST), Harmful Algae Bloom (HAB), and municipal and industrial effluent discharge data.

The coastal user criteria group output

Urban, recreation, and conservation areas (i.e. Marine Protected Area (MPA) and Nature Reserve (NR) areas) were the dominant form of coastal use along the Western Cape, Eastern Cape, and KwaZulu-Natal Provinces coastlines. By contrast, the Northern Cape Province coastline is underdeveloped and not protected[7] (Figure 3.4a). MPAs are most extensive along the KwaZulu-Natal coastline, with 24% of the province coastline's occupied by MPAs. This constitutes 35% of the total MPAs in the country. In the Eastern Cape Province only 30km is apportioned as Nature Reserve (NR) areas whereas the greatest length of NR area (125 km) is located along the Western Cape coastline. The main coastal urban areas include the Cape Town (Western Cape Province) and Durban (KwaZulu-Natal Province) metropoles with an extent of 220 and 240 kilometres of coastline respectively. Hence, KwaZulu-Natal province has the greatest extent of coastal urban area (32% of the province coastline) as opposed to the Northern Cape Province with only one percent of coast being urbanised (Table 3.6). Hence, the total length of coastline utilised by urban and conservation (MPA and NR) use was highest in KwaZulu-Natal Province with over 60% of its total coastline developed, and the least in the Northern Cape Province with about 1% of the coastline developed.

The number of recreational activities (i.e.: holiday resorts, bathing, surfing, diving and sport fishing activities) per 100km coastline varies between the four provinces. The highest intensity of recreational activities was in KwaZulu-Natal Province with 18.8 activities per 100km of coastline, followed by the Western Cape Province with 15 activities, and the Eastern Cape Province with 11 activities per 100km of coastline. The lowest was in the Northern Cape Province with less than 1 recreational activity per 100km coastline (Figure 3.4b).

[7] This is excluding the proposed Namaqualand Marine Protected Area, which is about to be implemented between the Spoeg River and the Groen River.

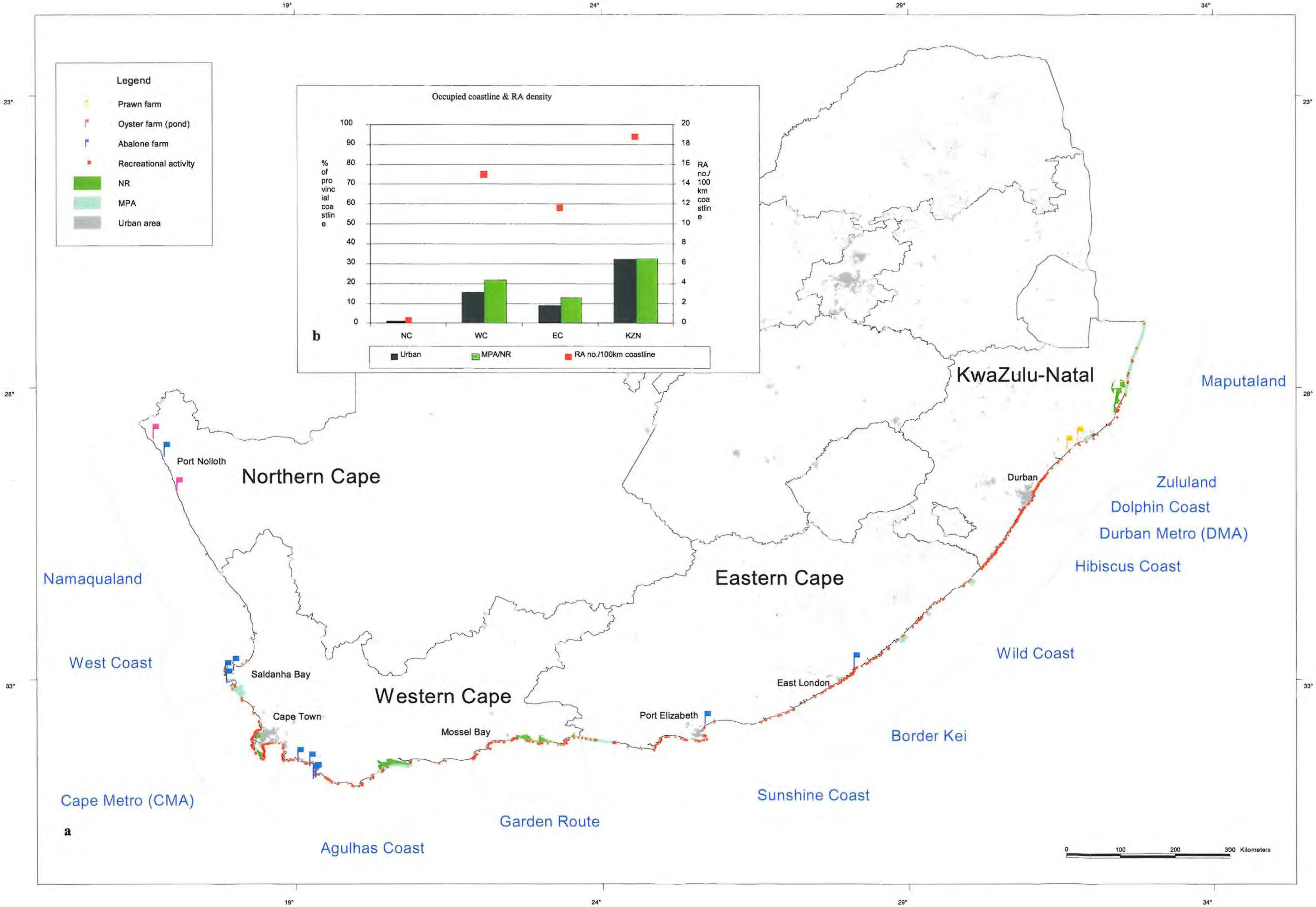

Figure 3.4: a) Dominant coastal users and land-based mariculture operations locations along the South African coast; b) proportions of coastline occupied by urban, conservation (MPA &NR), and recreational activities (RA) per 100km coastline.

Table 3.6: Spatial measurements of Marine Protected Area (MPA), coastal Nature Reserve (NR), urban areas, and Recreational Activities (RA) in each of the coastal provinces.

	Northern Cape	**Western Cape**	**Eastern Cape**	**KwaZulu-Natal**	Total in South Africa
MPA					
Coastline (km)	0*	216	126	181	523
% of province coastline	0	15	10	**24**	
Area (km^2)	0	880	743	860	2483
% of total MPA	0	35	30	35	
NR					
Coastline (km)	0	125	30	60	215
Coastline % of province	0	9	3	8	
Urban					
Coastline (km)	4	220	100	**240**	564
Coastline (% of province)	1	15	9	**32**	
Recreational Activity (RA)					
Number of RA per 100km coastline	0.3	15	11.6	18.8	
Total **MPA**, **NR** & **Urban** coastline (km)	4	561	256	481	

* Excluding proposed Namaqualand MPA

Most land-based mariculture operations along the South African coastline are abalone farms (12), which are scattered along the coastline. This includes two farms on the Northern Cape Province coastline, a cluster of eight farms along the south coast from St. Helena Bay to Danger Point in the Western Cape Province, and two farms (near Port Elizabeth and East London) in the Eastern Cape Province. Two prawn farms operate along the coast of KwaZulu-Natal and two oyster farms (earthen pond culture systems) exist in the Northern Cape Province (Figure 3.4a).

The infrastructure criteria group output

Three main regions have poor access to the coast due to the poor road network. They are the south coast of the Northern Cape Province, the Wild Coast of the Eastern Cape Province, and the Maputaland region of the KwaZulu-Natal Province (Figure 3.5a). The Northern Cape Province was identified as having the least accessible coastline with only 54% (183km) accessible by road, whereas the Western Cape coast was the most accessible with 86% (1200km) of coastline accessible by road. KwaZulu-Natal and Eastern Cape Provinces each had 58% (432km) and 74% (844km) of accessible coastline, respectively (Figure 3.5b). Three airports were identified in KwaZulu-Natal, including: Margate, Durban and Richards Bay. The Eastern Cape Province has two airports at East London and Port Elizabeth. The Western Cape Province has airports at Plettenberg Bay, George and Cape Town and the Northern Cape has airports at Alexander Bay and Kleinzee.

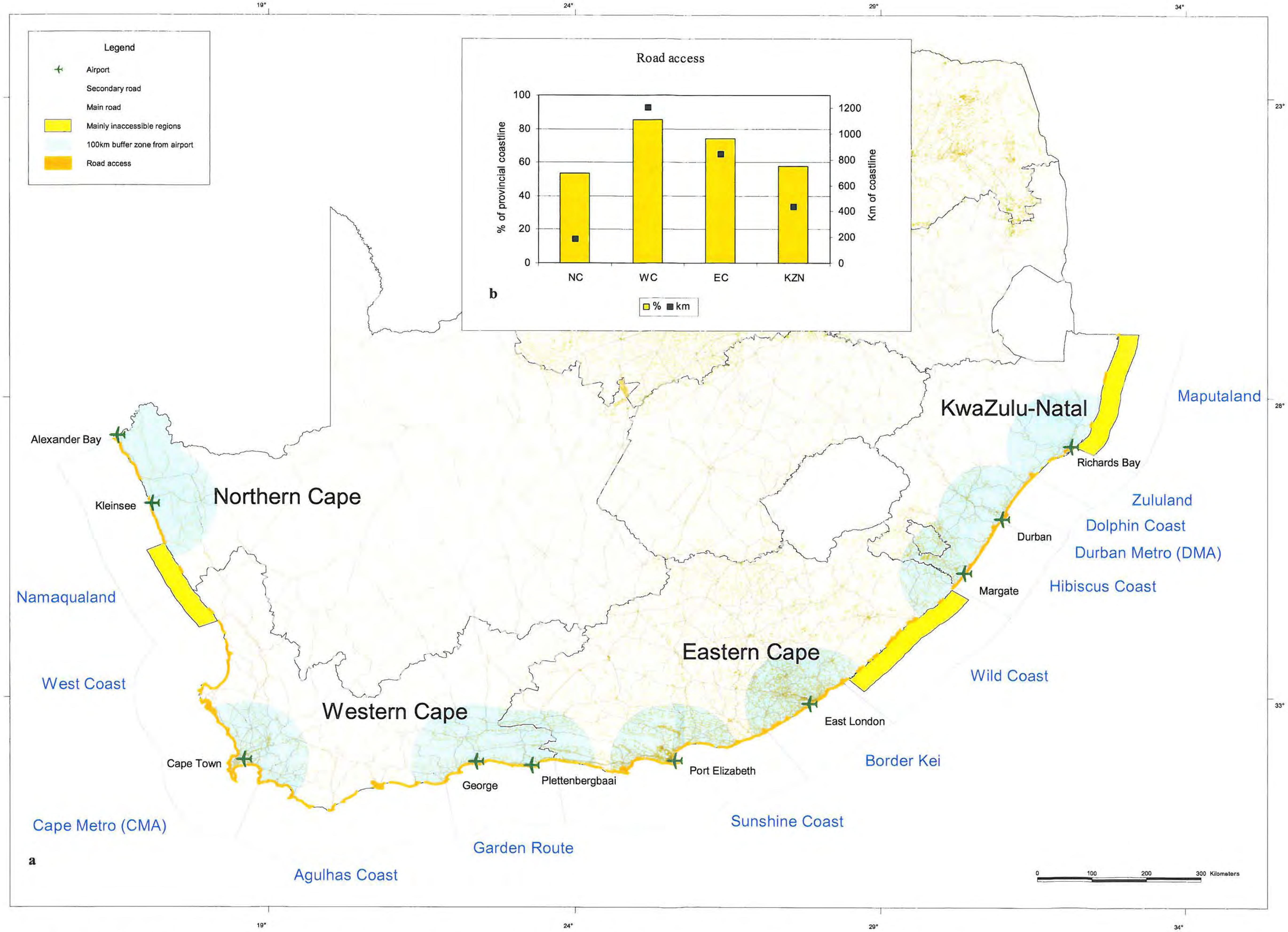

Figure 3.5: a) The location of the South African road networks, accessible coastline, and airports. b) Proportion of accessible coastline by road in kilometres and % of provincial coastline.

The land-based Biophysical-Coastal use-Infrastructure (BCI) output

The BCI analysis revealed that most of the KwaZulu-Natal provincial coastline (75% which is over 550km of the province coastline) had poor potential (P1) for mariculture development due to the extensive urban and conservation use (Figure 3.6). Only 98km (13%) of KwaZulu-Natal coastline has the highest potential coastline (P4) for mariculture development, most of which was confined to the Dolphin coast and Zululand regions. Hence, KwaZulu-Natal has the shortest length of P4 coastline on a provincial basis.

In contrast, 38% of the Eastern Cape Province (about 400km), mostly located around Port Elizabeth and East London along the Sunshine and Border Kei coasts, was ranked as high mariculture potential coastline (P4) (Figure 3.6). It was noticed was that most of the coastline accessible by road was in the vicinity of airports (Figure 3.7).

The Western Cape Province displayed the longest coastline with poor potential for mariculture development (P1) (45% of provinces coastline, which is about 600km). This was due mainly to the number and extent of conservation areas and urban development. In addition, most of the accessible coastline with moderate potential (P3) was not near (less then 100km) to an airport. Overall the areas with moderate and high potential (P3 and P4) were unevenly distributed along the province coastline (Figure 3.6).

The Northern Cape Province coastline was characterised by a combination of mostly limited potential (P2) because of its inaccessibility (50%), and high potential (P4) coastline (44%) (Figure 3.7). Most of the coastline with high potential (P4) was located along the central and northern parts (Figure 3.6). Lastly, only a total of 6% of the province coastline comprised poor potential (P1) and moderate potential (P3) areas.

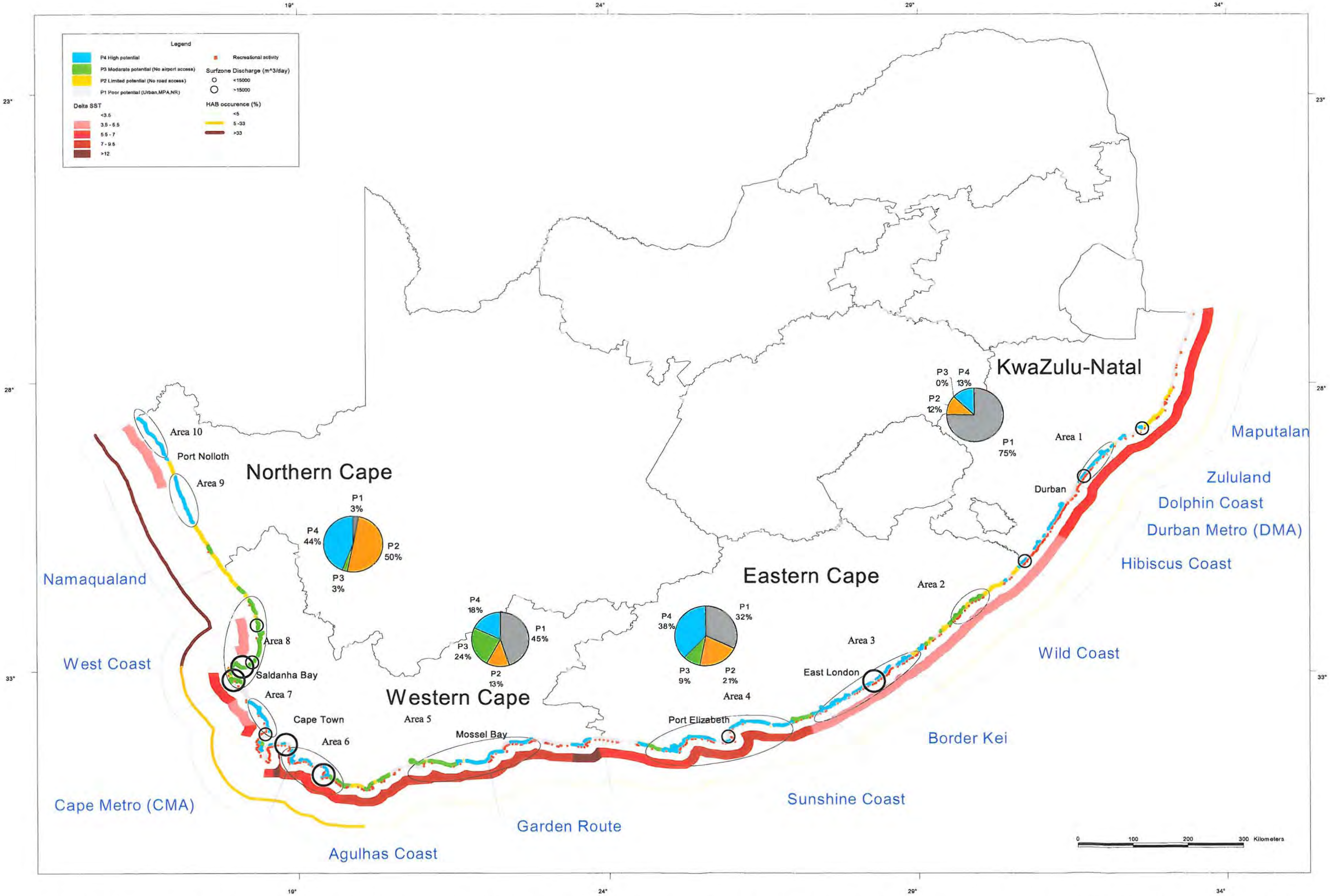

Figure 3.6: The Biological-Coastal users-Infrastructure (BCI) output, showing the four level of potential coastline for mariculture development and additional overlaid information (e.g.: HAB & SST). Moderate and high potential areas (P3 & P4) are circled (Area 1-10).

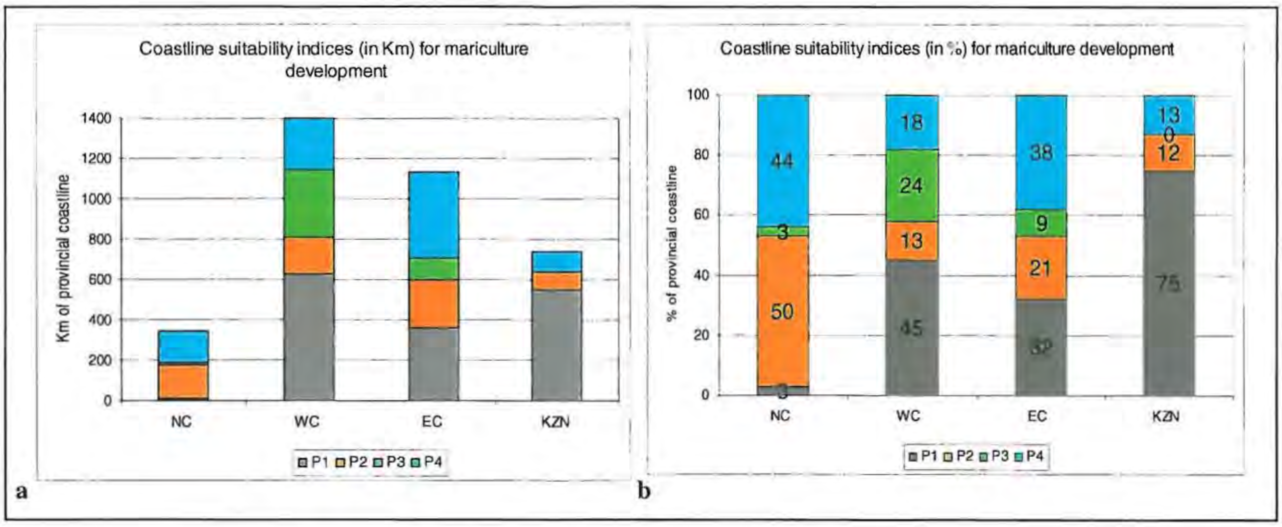

Figure 3.7: The composition of the four potential levels for land-based mariculture at each province expressed in kilometres (a) and percentage (b).

Abalone and prawn optimal temperature for growth output

The Sea Surface Temperature (SST) along the South African coastline has a generally high variation of average minima and maxima along the east coast, as compared to the west coast (Figure 3.8b). The optimal SST region for abalone included the Northern Cape, Western Cape, and most of the Eastern Cape coastline (coastal stations 1-26, Figure 3.8a). By contrast, the optimal SST region for prawn farming was confined to the KwaZulu-Natal coastline. The total length of moderate and high potential (P3 and P4) coastline within the identified optimal SST region for abalone was about 1200km. The majority of these areas are found along the Western and Eastern Cape Province coastlines (Figure 3.9b). The Eastern Cape Province and the Northern Cape Province presented the greatest proportion of suitable coastline (P4) for abalone farming. Nevertheless, in total, the Northern Cape coastline makes up only 13% of the national potential suitable coastline (P3 and P4) for land-base abalone culture. With regards to the potentially suitable coastline for prawn culture, only 74km of high potential (P4) was identified in KwaZulu-Natal Province (Figure 3.9b).

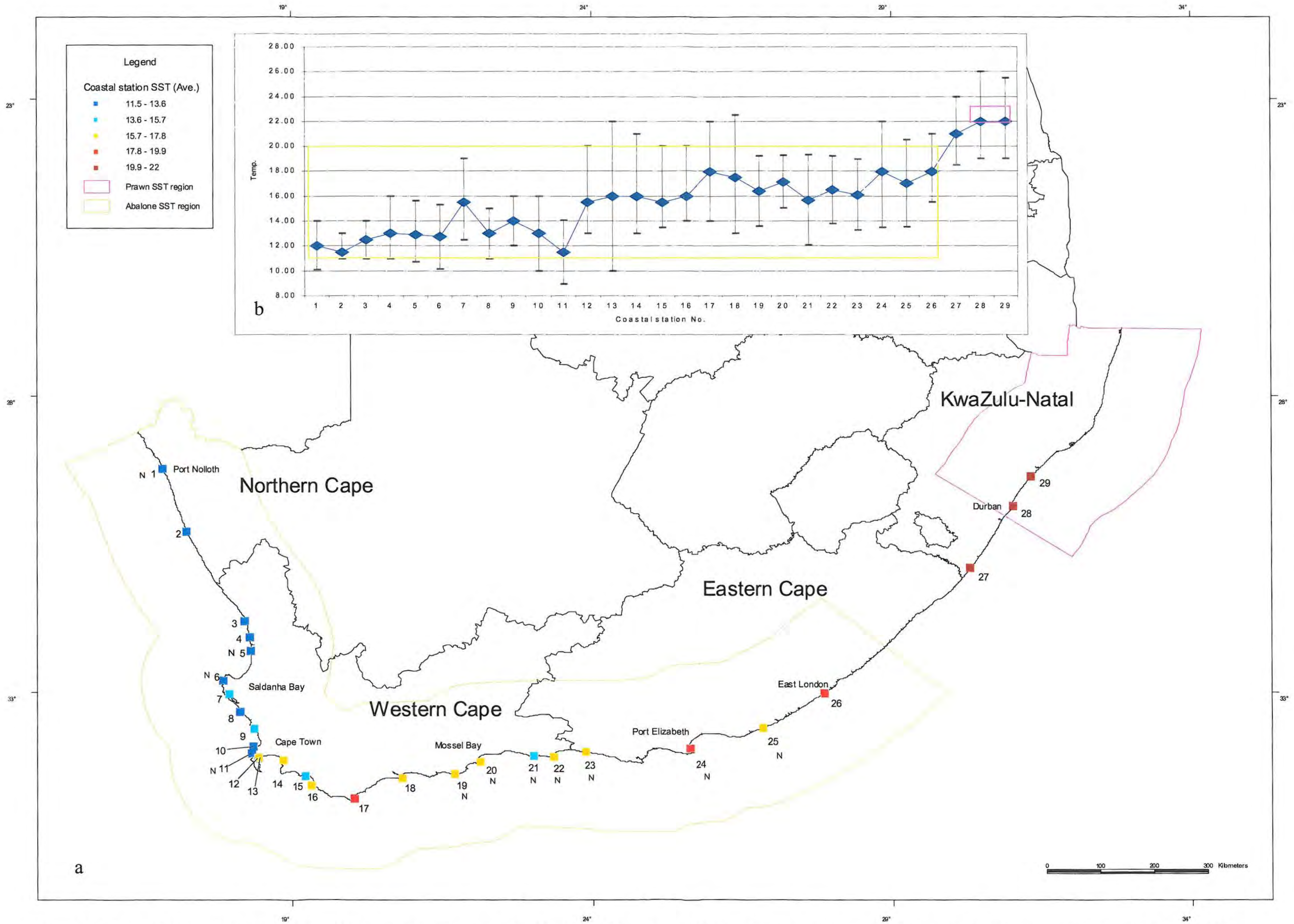

Figure 3.8: (a) The 29 SST coastal stations positions (N=new coastal station array), and (b) the South African coastal SST annual average, minimum, and maximum profile. Optimal temperature range for abalone (11-20°C) and prawn (22-23°C) are overlaid marking the potential suitable coastline for each species.

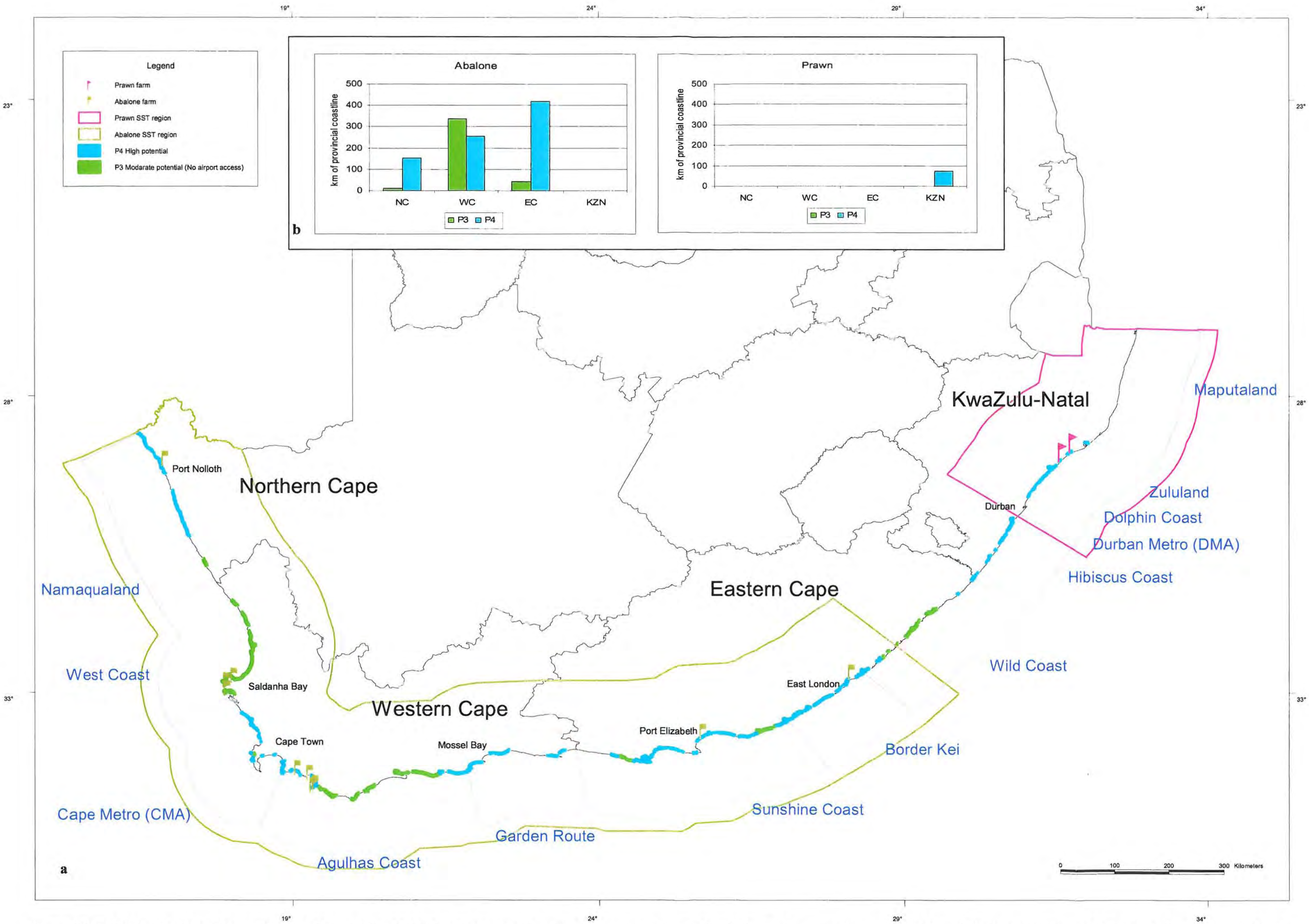

Figure 3.9: (a) Moderate and highly suitable coastal areas (P3 and P4) identified within the optimal temperature regions for abalone and prawn culture. (b) Total length (km) of moderate and high potential coastline suitable for abalone and prawn culture found in each province.

Verification of GIS output

Two sources of information, which indicate the location of several potentially suitable sites for land-based mariculture development, were compared with the BCI output as a means of verification. They included the existing land-based mariculture operations, and the positioning of potential suitable land-based mariculture estuaries surveyed by Cowley *et al.* (1998). The latter included a range of extensive and intensive land-based systems for farming species such as oysters, prawns, mudcrab, mullet, tilapia, spotted grunter, dusky kob and seaweed.

Of the twelve-abalone farms, nine were found within moderate or high (P3 or P4) potentially suitable coastline for abalone farming, and three abalone farms were located in the lowest potential (P1) coastline. The two prawn farms, however, were located within the high potential coastline (P4) (Figure 3.10).

A total of 34 estuaries have been identified as potentially suitable for mariculture development along the South African coastline (Cowley *et al.* 1998). Nineteen of these are located in the Eastern Cape. The remainder are found in the Western Cape Province (10) and KwaZulu-Natal Province (5). There are no suitable estuaries in the Northern Cape Province (Figure 3.10). Comparison of the location of these estuaries and the GIS output revealed that most of the suitable estuaries were within moderate and high (P3 and P4) potential areas. Nevertheless a large number of estuaries were also found in areas with poor potential (P1), near urban or conservation areas (Figure 3.11d). High numbers of suitable estuaries in the Eastern Cape Province were found in potentially poor (P1) areas within the vicinity of urban areas (Figure 3.11b).

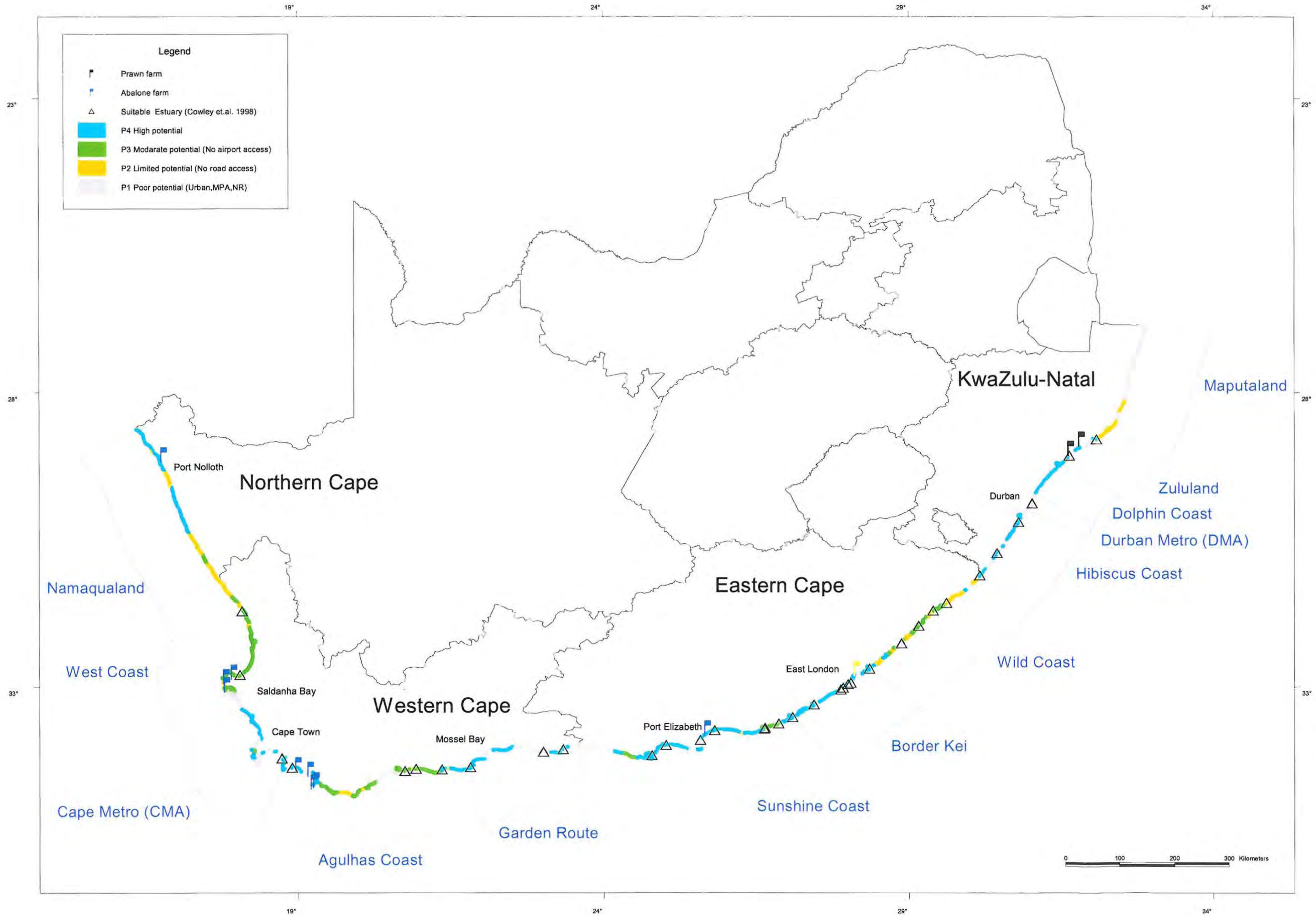

Figure 3.10: Verification of GIS output with potential suitable estuaries for land-based mariculture (Cowley *et al.* 1998), and present mariculture operation positions. Note that majority of suitable estuaries are located along the coast of the Eastern Cape Province, where as mariculture operations are concentrated along the Western Cape Province.

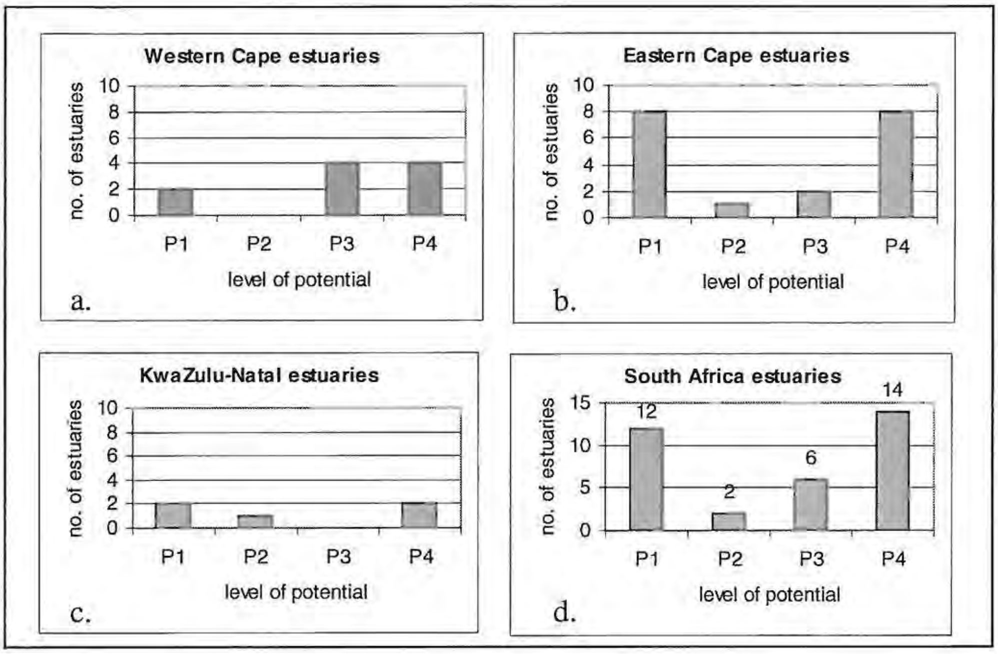

Figure 3.11: Comparison of the suitable mariculture estuaries (Cowley *et al.* 1998) with the GIS output for each province (a-c) and for the entire South Africa (d). Location of each estuary was compared with potential level (P1-P4) GIS output, and total number of estuaries for each potential level is presented. Note that the highest number of estuaries in the country is within potential levels P1 and P4 areas (d).

Discussion

Distinct natural conditions and coastal use patterns were identified in each province, reflecting the diversity of the country's coastline. The descriptive and quantitative spatial analyses of the impact of these conditions on mariculture development reveal complex interactions within the coastal environment. Hence, the following discussion is at a provincial level, followed by a comparison between provinces. Furthermore, each province has its own economic development strategy and the potential of the mariculture sector thus needs to be evaluated on a provincial as well as national basis.

<u>KwaZulu-Natal Province</u>

Favourable conditions for mariculture development in KwaZulu-Natal include the low-risk of HAB's (i.e. 0% occurrence in the past 10 years) and good infrastructure. The infrastructure includes generally good access to the coast by road, specifically along the southern region within the Durban Metropole Area (DMA) and Hibiscus Coast regions (Figure 3.5). However, although these conditions are vital for the development of the sector, the availability of the infrastructure also implies that much of the coast is under intensive urban and industrial development.

Urban development, which is a dominant feature in KwaZulu-Natal (Table 3.6), particularly in the Durban Metropolitan Area (DMA) and along the south coast (Figure 3.4), has resulted in conflicts with other coastal user such as recreational activities and conservation (Anon 1999). These conflicts are linked to the uncontrolled ribbon development in the province, which limits users' access to coastal resources. An additional reason for these conflicts is the increase in surfzone effluent discharges that degrade water quality and cause habitat destruction. Potential conflict between urban and mariculture activity is likely to occur in KwaZulu-Natal, since at present they are not compatibly designed.

Furthermore, the KwaZulu-Natal Province has the highest intensity of recreational activity in the country with more than 18 activities per 100km coastline on average, most of which are found along the Durban Metropolitan Area (DMA) coastline and southwards (Figure 3.4). These activities pose additional potential competition and conflicts over space for mariculture use.

In contrast to the southern region, the area north of Richards Bay along the Maputaland coast is dominated by conservation areas (Figure 3.4) and space for mariculture development is limited. Combined with the lack of infrastructure, this region has poor and limited potential (P1 and P2) for mariculture development (Figure 3.6).

Hence, the overall coastal space occupied by urban, conservation and recreational activities indicates high potential for competition and conflict between coastal users for space (according to the BSI analysis 75% of the KwaZulu-Natal coastline has poor potential, Figure 3.7b) that would make it difficult to introduce a new activity such as mariculture. The lack of mariculture activities along this coastline tends to bear this out.

Due to limited P3 and P4 areas (about 100km of coastline in total), potential areas for mariculture development are mostly located along the Dolphin Coast region. A specific potential area for mariculture development has been identified within this region, namely (Figure 3.6):

- Area 1 (Dolphin Coast)- E31°48’58”, S28°56’36” to E31°06’22”, S29°42’06” with about 70km coastline

A few additional potentially suitable areas were further identified in the Zululand region. The identified potentially suitable areas for mariculture development are very limited in extent in comparison to the other provinces. Developments within these areas are therefore likely to experience space conflicts, which will require a regional, high-resolution, multi-sector planning approach.

The high potential suitable areas in KwaZulu-Natal (P4) are accessible by road and are near to airports. Access to airports is an advantage since international markets are a major driving force in the development of the South African mariculture industry. Such is the case with prawn production, with most of the product being exported to the European Union market (Landman 2001). The location of the existing prawn farms, which falls within the high potential areas (P4), strengthens this argument, and the validity of the choice of this criterion.

The variation in seasonal SST in KwaZulu-Natal, particularly the low temperatures in winter within the high mariculture potential areas (<20°C, station 28 and 29, Figure 3.8b), prevents the all-year-round production of tropical species such as prawns (Evans 1993). The two existing prawn farms established within the moderate (P3) and high (P4) areas and optimal temperature region, suggest that seasonal production is a marginal commercial venture on that coastline. These farms could also provide an established node for supporting further development. A report by Landman (2001) has suggested that off-shoot initiatives are already supported by the existing prawn operations. However, in order for mariculture to compete with other well-established sectors in the province, a regional mariculture sector plan should be initiated and integrated into the new national coastal policy and Durban Metropolitan Council development plans. Due to the limited space, these development plans' aims should include the development of one or two development nodes ("Mariculture parks"), such as have been proposed by the Northern Cape Province mariculture sector plan (refer to chapter 5). These plans could lead to additional mariculture development and economic growth in the region for the local communities. Development in these nodes could also promote sustainable development, which is urgently needed, since mariculture is heavily dependent on the natural coastal environment.

Eastern Cape Province

One of the most outstanding features of the Eastern Cape Province is the long coastline (1140km), which is the second longest in the country after the Western Cape. The extended coastline and the generally lower competition for space by conservation activities and urban development compared to the KwaZulu-Natal and Western Cape provinces (Figure 3.4b), offers good opportunities for land-based mariculture development. Nevertheless, sensitive environments such as estuaries and lagoons are likely to be subject to intensive space and resources competition between coastal user groups such as conservation (specifically MPAs) (Attwood *et al.* 1997), recreational users, holiday resort development (Cowley *et al.* 1998), (Britz *et al.* 2002a) and shore-angling fishery activities (Brouwer *et al.* 1997). Hence, the use of such sensitive environments will require a comprehensive land use plan, promoting sustainable and optimal use by all sectors of the available space and resources. GIS could become a vital tool in this high-resolution planning process.

The Eastern Cape has the second longest accessible coastline (844km which is 74% of the province's coastline). Based on the BCI analysis, about 38% of this coastline was found to have high potential (P4) for mariculture development (Figure 3.7b). High and moderate (P3 and P4) potential suitable areas were found in three main locations (Figure 3.6):

- Area 2 (Wild Coast)- E29°35'34", S31°36'40" to E29°05'30", S32°04'42" with about 60km
- Areas 3 (Sunshine region)- E28°28'36", S32°37'09" to E26°56'59", S33°34'45" with about 198km
- Area 4 (Border Kei region)- E26°53'15", S33°37'25" to E24°13'37", S34°04'24" with about 232km

Areas 3 and 4, near Port Elizabeth and East London airports, could have the advantage of easy access to international markets. The two recently established abalone farms located within these regions emphasise and verify the potential for such development. Further confirmation is found in the socio-economic analysis for the National White Paper for Sustainable Coastal Development in South Africa, which has revealed the need to develop mariculture along the Border Kei coastline (Anon 1999).

The inaccessibility to the Wild Coast (limited potential, P2) was found to be a major constraint for mariculture development along the Northern part of the Eastern Cape coastline. A total of 237km (20%) of the coast is inaccessible due to a poor road network (Figure 3.5). New planning development by the provincial government, Department of Economic Affairs, has delineated the Wild Coast as a Spatial Development Area, with tourism as a lead economic sector at a few selected nodes (Anon 2001). Such development could improve infrastructure conditions for sustainable mariculture development, which could be integrated with tourism and recreational activities along the coast.

The low risk of HAB occurrence and the existence of both cold and warm temperature zones, which makes it possible to culture a broader range of species, reveals the high potential for mariculture development along the Eastern Cape coastline.

The mean sea temperature along the Eastern Cape coast is 18° C, which makes it the most suitable region for abalone culture (Britz *et al.* 1997), as far north as the Mbashe River (Figure 3.8). Moreover, seasonal coastal temperature fluctuations of a maximum of 25° C in summer and rapid daily variations in the area near Port Elizabeth, with up to 8° C change in a few hours (Schuman 1998), may stunt the growth of the abalone (Britz *et al.* 1997). Monitoring these conditions during summer through real-time Remote Sensor SST images based on GIS analysis could provide important information for farm managers at these sites.

In summary, the Eastern Cape Province coastline has a relatively high potential for mariculture development due to its generally suitable infrastructure around Port Elizabeth and East London, relatively uninhabited areas, low-risk of HAB, and wide range of temperature coastline suitable for the culture of several target species. However, a major potential drawback includes the underdeveloped infrastructure in the Wild Coast region and the limited capacity of the provincial government for coastal management (Anon 1999).

Western Cape Province

Of all provinces the Western Cape has the greatest length of developed coastline in the country. This is due to its high economic growth rate that is strongly rooted in coastal activities such as ports, fishing and tourism (Anon 1999). These conditions have been fundamental to the development of the mariculture industry, resulting in the Western Cape Province being the centre of the South African land based mariculture industry.

The results also show that the Western Cape Province has the longest potentially suitable (P3, P4) coastline (592km) for mariculture development in term of the BSI output. This potential is mostly located within four regions (West Coast, Cape Metropolitan Area, and Agulhas Coast), due to the developed road network and proximity to airports. These areas and their available length of coastline includes (Figure 3.6):

- Areas 5 (Agulhas coast and Garden Route)- E22°33'21", S34°00'00" to E20°43'43", S34°23'10" with about 182km
- Areas 6 (Agulhas coast)- E19°42'48", S34°46'03" to E18°51'03", S34°10'10" with about 90km
- Areas 7 (Cape Metro Area)- E18°29'19", S33°51'37" to E18°09'50", S33°21'45" with about 56km
- Areas 8 (West Coast)- E18°02'27", S33°02'36" to E18°10'33", S31°40'58" with about 184km

The suitable temperature range for culturing abalone (Figure 3.9), and the well-established abalone farm industry found in this area (Figure 3.10), further verifies the potential for mariculture development.

However, despite the potential outlined above there are several socio-economic and environmental limitations that should first be addressed for further development to take place. As a consequence of coastal economic growth along the coast, the Western Cape experiences cumulative development pressures which put a strain on coastal resources, secondary only to that experienced in KwaZulu-Natal (Figure 3.4b). These pressures include the limited availability of space due to urban development specifically within the Cape Metropolitan Area (CMA), conservation areas (around Saldanha Bay, CMA and the Garden Route coast), and the high number of recreational activities, in particular in the estuarine areas (Cowley *et al.* 1998). Coastal effluent discharges at three main centres namely Saldanha Bay, Hermanus and Gansbaai indicate pollution potential and potential conflict with mariculture (Figure 3.6). Considering the complexity of the province's coastal environment, a conflict resolution approach amongst users, which is based on updated databases and new planning, is essential. This is particularly important when new activities such as mariculture are considered near or within other activities (note that the location of several abalone farms is within urban areas, Figure 3.10). A case in point was a legal conflict at Pringle Bay between existing urban development and a proposed abalone farm. Much of the debate was based on an outdated land plan, which did not define new activities such as mariculture (DECAS/ Western Cape Province 2001).

The coastal environment along the Western Cape Province poses additional limitations, including a high-risk of HAB occurrence and wide fluctuations of SST in certain areas. Monthly average ΔSST measurements on the south coast, specifically along the Agulhas coast, showed wide seasonal amplitude of up to 5° C (Taunton-Clark and Shannon 1988). Similarly, measurements by Greenwood &Taunton-Clark (1994), on which this study is based, show a wide seasonal fluctuation of SST along the South-western Cape coastline (Figure 3.6). Additional primary observations have shown a high frequency of diurnal temperature fluctuations (Schuman 1998). This is a matter of concern for abalone farms and could become a constraint to the development of the entire mariculture operations along this part of the coast.

Likewise, HAB events, such as the one in the HF Verwoerd Marine Reserve in Walker Bay during 1989, which caused mortality in the natural abalone population, are a major concern for the abalone industry (Pitcher 1998). A potential solution for the above constraints would involve a monitoring program using daily SST remote sensing satellite images and the coastal stations measurements integrated into GIS database framework, where as HAB occurrence would require continuous coastal water sampling integrated with mariculture farm management. Such a monitoring system could therefore alert farmers in case of HAB bloom, which could then turn on their recalculated follow system to minimize the impact.

An example for such HAB monitoring system is the Phytoplanktonic Monitoring Network ("REPHY") initiated in France (Goulletquer and Heral 1997). In the case of South Africa, a monitoring system has recently been put in place in the west and east coasts monitoring 10 abalone farms for PSP and DSP (John Foord, pers. comm.

Marine Coastal and Management, DEAT, 2003). GIS could therefore play a major role in the development of this system for mariculture management.

In total, the potential of the Western Cape Province can be best illustrated through its current position as the leading province in the South Africa mariculture sector, in terms of the number of activities and production level (Hecht and Britz 1992, Hecht 1999). Considering that it has the longest coastline potential suitable (592km) for mariculture in terms of the BCI output, good road infrastructure and three airports, the Western Cape Province offers many future opportunities. Two specific areas with high potential for mariculture development include Area 5 and Area 8, due to lowest competition with other coastal users (Figure 3.6).

Nevertheless, major constraints still need to be addressed, including competition and compatibility among users, the dynamic nature of the coastal environment (ΔSST and HAB), as well as the limited industry monitoring capacity. Perhaps one of the most limiting factors is the lack of institutional support for the development of the mariculture sector. As with KwaZulu-Natal and the Eastern Cape, no regional sector development plans exist to promote development and improve communication and co-ordination between farmers, universities and research institutions. Collecting, sharing, and analysing spatial databases among institutions and associations using GIS could greatly assist in the overall understanding of this complex coastal environment and its interactions with the mariculture sector. Such a developed GIS could eventually be an integrated tool in the planning process of coastal development as a whole.

<u>Northern Cape Province</u>

The Northern Cape Province has unique environmental conditions in comparison to the other coastal provinces. Although it has the shortest provincial coastline in the country (340km and 10% of national coastline), a high proportion of the coastline (47%) was found to have moderate (P3) and high (P4) potential for mariculture development in terms of BCI output (Figure 3.7b).

The following facts contribute to the potential of this province as one of the most attractive coastlines in the country for emerging mariculture sector development:

1. Available space with few users due to a lack of economic development and the dominance of diamond mining activities, which effectively own the coastal area, and therefore historically excluded other users (refer to Chapter 5 for further details).
2. Low urban development (<1% of province coastline), which is concentrated at four coastal centres (Alexander Bay, Port Nolloth, Kleinsee and Hondeklipbaai).
3. Limited recreational activities (mainly concentrated along the Orange River mouth and Hondeklipbaai).
4. Absence of conservation areas along the coastline (excluding the proposed MPA south of Hondeklipbaai).
5. Excellent mining infrastructure in the areas owned by Alexkor and De Beers. This includes good road network condition and two airports near Alexander Bay and Kleinsee towns. The proximity to these airports and the access to the international market provide additional incentives for mariculture development in this region.
6. Cold-temperate species of high value, such as abalone suitable for culture in the entire region (Figure 3.8), which could be exported through these airports.
7. A relatively stable seasonal ΔSST and pollution-free seawater along the coast.

Lastly, the established mariculture operations including an abalone farm north of Port Nolloth, oyster farms south of Alexkor Bay and at Kleinsee, all within reach of the airports, verify the strategic nature of these locations (Figure 3.10).

The shortfalls of the Northern Cape coastline for mariculture development include the high risk of HAB occurrences and limited access to the coast due to diamond mining security zones. The latter may be overcome through a regional comprehensive spatial plan, which seeks to identify and resolve potential conflicts between mine management and other potential development (this has been addressed in details in Chapter 5).

Although the economy of the Northern Cape is dominated by the diamond mining sector (Britz *et al.* 2002b), the down-scaling currently occurring within the industry has resulted in the Northern Cape government making plans that include alternative economic opportunities, one of the most attractive being mariculture. This has led to the development of a comprehensive regional mariculture sector plan and the formation of the Fishing and Mariculture Development Association (FAMDA), which aims to promote mariculture development. In order to assist the sector planning process in terms of identifying the spatial opportunities, a regional GIS was established. This was done in the form of an exploration GIS and is described in detail in Chapter 5.

From these results it is clear that the potential of the Northern Cape Province is one of the highest in the country due to both natural and socio-economic conditions. Two areas in particular were identified as having the highest potential, namely (Figure 3.6):

- Areas 9 (Namaqualand)- E17°18'00", S30°22'05" to E17°02'14", S29°37'52" with 85km
- Area 10 (Namaqualand)- E16°53'53", S29°18'46" to E16°27'30", S28°38'05" with 67km

Finally, the mariculture sector development plan for the region compiled by Britz *et al.* (2002) has also confirmed the Northern Cape high potential for land-based mariculture development in the country.

Comparison between the BCI output and the Cowley et al. (1998) estuaries mariculture survey

The evaluation of the suitability of South African estuaries for mariculture development by Cowley *et al.* (1998) was based on three-phase Mariculture Suitability Evaluation (MSE) procedure. The first phase was the site selection evaluation. Three criteria were used in this phase: general biophysical features of the estuary (estuary type), available scientific information (which was associated with road accessibility), and conservation significance. The latter two criteria were re-evaluated using the present GIS database and revealed that 20 out of 34 suitable estuaries for mariculture were within moderate or high potential (P3 and P4) areas (Figures 3.10 and 3.11). However, the additional evaluation of urban development in this study reveals the importance of this criterion in the overall evaluation of estuaries for mariculture in South Africa. A total of 12 estuaries that are suitable for mariculture development (35% of all identified suitable estuaries in South Africa) are located in areas with a poor potential (P1) for development. Of these, 9 estuaries were in the vicinity of central urban development, particularly in the Eastern Cape where 6 out of 8 estuaries where in poor areas (P1), due to their proximity to urban development (Figure 3.11b). These findings highlight potential of competition and conflict over space and resources. These problems can only be overcome through comprehensive regional planning based on high-resolution and updated ecological and socio-economic data.

Conclusion

Based on the above evaluation, it was concluded that the four coastal provinces contain different potential levels for mariculture development. This potential was combined from the different constraints for development and the total measurement of high and moderate (P4 and P3) potentially suitable coastline for mariculture development (Table 3.7).

KwaZulu-Natal Province coastline was noticed to be restricted by most evaluated constraints namely: highly fluctuated SSTΔ, high effluent discharges, intense recreational activities, limited space, and inaccessible coastline. Additionally, the total P3 and P4 coastline was found to be lowest (98km) among all provinces. Hence, KwaZulu-Natal Province potential level for mariculture development is the lowest in the country. This was in contrast to the other three provinces. The Eastern Cape and Western Cape Provinces were found to have the longest high and moderate (P4 and P3) potentially suitable coastline for mariculture development in the country. However, the Eastern Cape Province was less limited by the developmental constraints than the Western Cape Province. This included lower risk of HAB occurrences, effluent discharges rate, and competition over space. The Northern Cape Province provides high potential for mariculture development. This potential is characterised by the typical West Coast environmental conditions such as pristine unpolluted coastline, stable SST Δ, and low spatial competition. The Province's potential was restricted mainly by access to the coast and high risk of HAB occurrences.

Hence, the potential of mariculture development was clearly different between the west and east coasts of the country. This, and the fact that provincial mariculture development plans are not yet in place (apart from the Northern Cape Province), implies that the mariculture sector is likely to develop at different rates in each province. However, the precise potential of mariculture development is still needed to be revealed through a high-resolution GIS analysis. For that reason, a pioneer high-resolution GIS analysis was conducted for the Northern Cape Province (Chapter 5).

Table 3.7: A comparison of the four provinces potential land-based mariculture development. The comparison is combined from the evaluated constraining criteria and from the BCI output, which include the total extents of the moderate and high (P3 and P4) potentially suitable coastlines for mariculture development. Each constraining criteria is evaluated in terms of its presence (+) or absent (-) along the province coastline. (SST= Sea Surface Temperature, HAB= Harmful Algae Bloom, BCI= Biophysical-Coastal user-Infrastructure criteria output, P3= moderate potential, P4=High potential).

	Criteria	**Northern Cape**	**Western Cape**	**Eastern Cape**	**KwaZulu-Natal**
Evaluated constraint	High SSTΔ	-	+	+	+
	Effluence discharge	-	+	-	+
	HAB occurrences	+	+	-	-
	Recreational Activities	-	+	+	+
	Potential conflict over space (Development &Conservation)	-	+	-	+
	Limited road access	+	-	+	+
BCI output	Potentially suitable areas for mariculture development (P3+P4)	(163km)	(592km)	(536km)	(98km)

CHAPTER 4

Spatial evaluation of the suitability of the South African coastline for abalone ranching

Introduction

The economic potential of abalone farming has long been recognised in South Africa (Genade 1984, Bruton 1985, Bruton and Safriel 1985, Hecht and Britz 1990, Hecht and Britz 1992, Cook 1996, Hecht 1999). However, the high initial capital required for the development of land-based culture operations and the slow growth rate of abalone makes land-based farming a high-cost venture. Ranching technology, which was pioneered during the late 1990's along the South African coastline, offers a technique to produce abalone at a lower cost (Cook and Sweijd 1999, De Waal 2002). Nevertheless, abalone ranching is still in its experimental stage, which requires long-term evaluation of ecological and economic factors (De Waal 2002). The integration of such factors on spatial basis using GIS could provide important information for national and regional planning and for the management of abalone ranching activities. Hence, this chapter attempts to provide primary spatial information on the development potential of South African abalone ranching. The rationale for this study includes a brief overview of natural abalone resources, the development of abalone farming, and the ecological and economic considerations for introducing abalone ranching in South Africa.

Biology and distribution

Abalone species (*Haliotis midae*) are found along sub-tidal areas of reef and rocky outcrops, within less than 10 metres depth (Tarr 1993). *H. midae* is a cold temperate species, which is restricted to a temperature range of 11-20°C (Britz *et al.* 1997), and is to a large extent dependent on macro-algae such as kelps as a food source (Barkai and Griffiths 1986). Abalone occur naturally along the South African coastline between St. Helena Bay (S32°42'20", E17°58'30") and Mbashe River (S32°14'16", E28°53'25") (Branch *et al.* 1994). Abalone is most abundant along the south-west coast (S32°42'20", E17°58'30"to S34°50'00", E19°59'10") where the South African abalone commercial fishery is based (Tarr 2000). The east coast (S34°50'00", E19°59'10"to S32°14'16", E28°53'25") supports additional populations of abalone, which are reported to occur on a patchy basis. Although these populations are not allocated for commercial fishing, they have in recent years been subject to heavy illegal fishery exploitation (Hauck and Sweijd 1999, Britz *et al.* 2002).

Fishery and farming abalone development

The high demand for abalone in Asia in the early 1960's led to the development of the abalone fishing industry in South Africa. The present high demand for the product is indicated by the high wholesale value of between US$20-40 per kilogram live weight (Britz and Hecht 1997). As a result of increased demand, and fishing pressure intensified by poaching, the abalone stock has been severely depleted along stretches of the South African coast (Hauck and Sweijd 1999).

The South African abalone farming industry was to an extent stimulated by increasing demand for abalone, and the overexploitation of resources, which is reflected by reductions in Total Allowable Catch (TAC) over the pass 10 years (Tarr 2000). Cooperation between the industry and research institutions in terms of research and development facilitated the successful introduction of hatchery technology in South Africa (Cook 1996). Twelve intensive land-based farms between Port Nolloth to East London are currently in operation. Production capacity is estimated at about 600 tonnes of abalone per annum (Hecht 1999).

The large capital outlay (and slow growth rates) makes land-based farming a high-risk venture that requires economic resilience and institutional support (Britz 1997). Alternative techniques such as ranching, with lower capital investment but increased risk factor, have thus been proposed as alternative means of producing abalone (Cook and Sweijd 1999, De Waal 2002, Godfrey 2003). Ranching abalone involves the release of nursery-bred animals into the wild for later recapture. Abundance of rocky reefs along the South African coastline, which provide potential suitable abalone habitat, makes this culture technique an attractive mariculture development opportunity. However, the potential of ranching is directly linked to habitat suitability and availability. Within this context, other factors, such as size at release, stocking density and predation, are critical (Cook and Sweijd 1999).

Spatial distribution of abalone habitat (i.e. rocky coast) is therefore a fundamental consideration in the development of ranching abalone.

The ecological and socio-economic implications of abalone ranching

Abalone ranching is still experimental in South Africa and its commercial viability has not yet been proven (Britz 2002). In spite of this, several experimental ranching activities for commercial reseeding operations are already taking place along both the west and east coasts (across three coastal provinces).

Abalone ranching is pioneered along the west coast of the Northern Cape Province (i.e. Namaqualand) (Cook and Sweijd 1999). The results of this experiment show a good survival rate of seeded abalone at two selected sites. Consequently, Port Nolloth Sea Farm (PNSF) was allocated a ranching concession by Marine and Coastal Management (MC&M), Department of Environment and Tourism Affairs (DEAT), for a semi-commercial ranching operation. Additional experimental operations conducted along the Namaqualand coast and at Mossel Bay area by De Waal (2002), and the east coast near Port Elizabeth and Cape St. Francis by Godfrey (2003), indicate the potential of abalone ranching along the South African coastline.

However, since the east and the west coasts contain different ecological and socio-economic conditions, the aims of these abalone-seeding operations are different. Abalones do not occur naturally along the north-west coast from the Orange River mouth to St. Helena Bay (S28°39'02", E16° 28'55" to S32°42'20", E17°58'30"). As a result, seeding is purely for commercial reasons. Along the south-east and east coasts (S32°42'20", E17°58'30" to S32°14'16", E28°53'25") where natural abalone populations do occur, reseeding abalone is aimed at restoring existing natural stock and enhancing production.

This variation in environmental conditions have additional biophysical and socio-economic implications (Cook and Sweijd 1999, Tarr 2000, Britz *et al.* 2002, De Waal 2002, Godfrey 2003, Cook and Sweijd 1999, Cook and Sweijd 1999, Cook and Sweijd 1999, Cook and Sweijd 1999, Cook and Sweijd 1999):

- The **Biophysical implications** include, firstly, potential modifications of the dynamics of the shallow coastal ecosystem specifically along the north-west coast, where abalone do not occur naturally; secondly, the impacts on local gene pool dynamics and integrity along the south-west and east coasts.
- The **Socio-economic implications** include legal issues around access rights, specifically ownership of reseeded abalone in areas with naturally occurring populations[8] (i.e. conflict with abalone fishery). Additional potential conflicts could be associated with recreational activities and conservation areas (i.e. MPA).

The different objectives of abalone ranching operations and the biophysical and socio-economic implications requires an urgent comprehensive national development plan, which is based on an integration of biophysical and socio-economic criteria, and has a major spatial component.

The primary aim of this study was therefore, **to identify potential areas for commercial concessions for abalone ranching along the South African coastline, based on integrated biophysical and socio-economic criteria.** This was attempted by means of an objective spatial analysis and a multi-criteria approach. Specifically the following objectives were addressed:

1. Determination of the available and potentially biophysical suitable areas for abalone.
2. Determination of the compatibility with other coastal users (including coastal urban area location) and availability of infrastructure.
3. Verification of the outputs of this study with present abalone ranching activities and future plans.

[8] This could be resolved by a change in a marine resource management from "open-access user right" to "territorial user right fishing" (TURF) as has been proposed in the Eastern Cape abalone fishery resource assessment by Britz *et al.* (2002)

Method

A GIS based analysis of the entire South African coastline was conducted to identify potentially suitable abalone ranching areas. This was based on the following procedure:

1. Development of a rational analytical framework
2. The identification and selection of the spatial criteria required for abalone ranching development
3. Collection, sorting and manipulation of data
4. Analysis of data and verification of results.

Development of analytical framework

This case study aim was to identify potentially suitable areas on the national scale for abalone ranching. The analytical framework in this case was therefore based on that used for land-based mariculture development (Chapter 3). This included the elimination of all unsuitable areas for abalone ranching, based on developmental constraints, and the use of Boolean logic and arithmetic operations (Appendix 2). This analysis was therefore initiated with identification and collection of spatial criteria and the associated constraints for abalone ranching development.

The identification and selection of criteria

Due to the lack of national guidelines for abalone ranching development, this case study choice of criteria was based on the Eastern Cape Province abalone management plan. The spatial component in this regional plan was central, since one of the main objectives of the plan was to identify the locations of potentially suitable abalone ranching concessions. The abalone ranching concessions were identified on the basis of a Territorial User Rights Fishery (TURF) and were termed 'Rehabilitation TURFs'[9].

[9] Rehabilitation TURFs are areas where abalone populations have been severely depleted. This could be restored by means of reseeding animal into the wild. These areas usually occur near major urban centres with easy access to the abalone resource (Britz *et al.* 2002).

The four main criteria selected to identify the 'Rehabilitation TURF' concessions were (Britz *et al.* 2002):

1. Conditions of the marine environment (e.g. the status of the abalone population stock)
2. Sufficient infrastructure
3. Coastal use
4. Size of area (economical viable unit)

This study attempted to address the first three criteria (Table 4.1). However, due to the current limited national coastal environmental data the final choice of criteria in this study was eventually based on the available data.

Table 4.1: Criteria required for abalone ranching development by Britz el al. (2002) and available GIS criteria.

Criteria chosen by Britz *et al.* (2002)	**Available GIS Criteria**
Coastal use	Marine Protected Areas (MPAs) Urban areas Abalone fishery areas
Sufficient infrastructure	Hatchery facility locations Road access
Suitable marine environment	Rocky coastline Seasonal Ave. Sea Surface Temperature (SST<20°C) Paralytic Shellfish Poison (PSP) occurrences

Data collection and sorting

The chosen GIS criteria were collected and sorted into Biophysical, Coastal use and Infrastructure criteria groups as previously described in Chapter 3. The separation of criteria into a three criteria group's database allows the generation of independent outputs for each group, as well the integration into one 'Biologic-Coastal use-Infrastructure (BCI)' output (Figure 4.2).

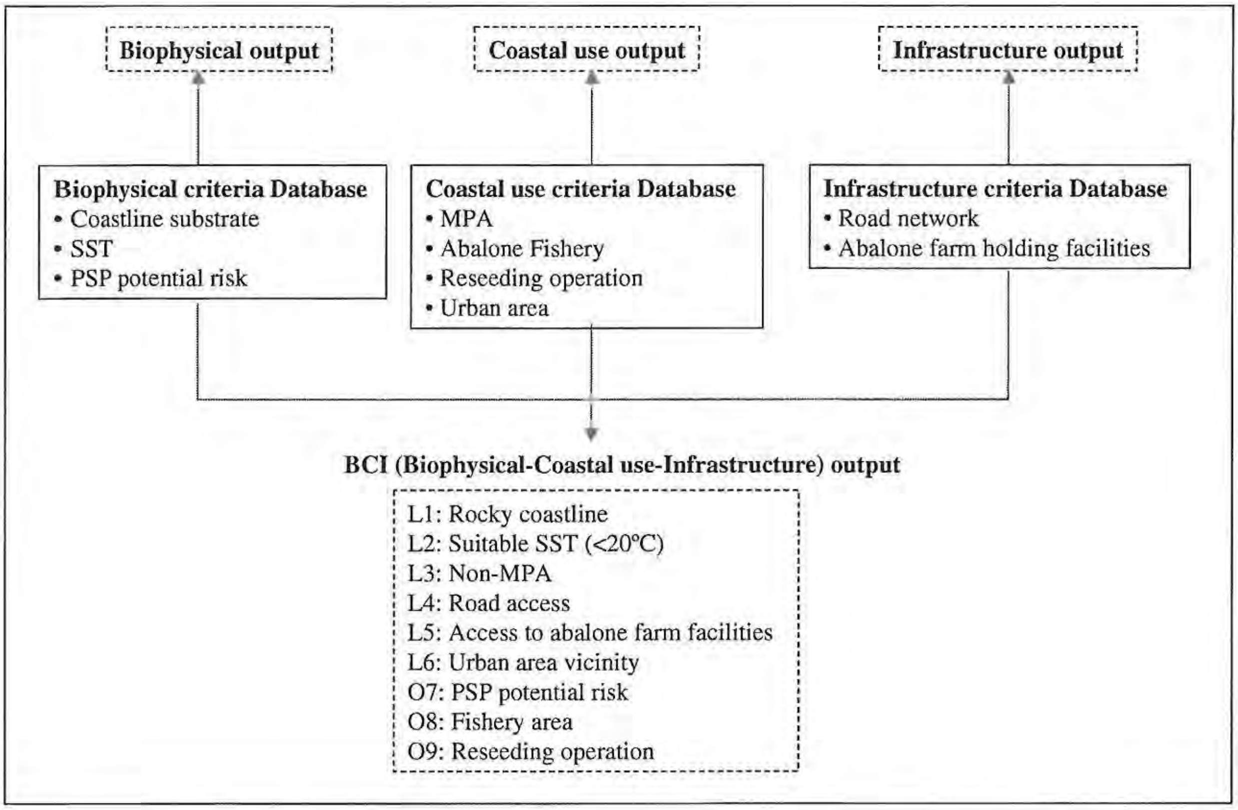

Figure 4. 2: The three database criteria groups, which were used to generate four outputs: biophysical, Coastal-use, Infrastructure, and the integrated 'Biophysical-Coastal use-Infrastructure' (BCI). The BCI output is composed from the analysed data that was named layers (L), and the non-manipulated data, which was named overlays (O).

The data was obtained in two formats (digitally and as published hard copy). The data from the published literature was digitised as a GIS vector layer, followed by the attachment of the relevant attributes. The digital data was imported as vector layers into the GIS file format using the "import" built-in GIS software function. Where necessary, specific information was extracted from the imported data by selecting the required attributes using the built-in Spatial Manipulate Language (SML) script query. The following data was collected, converted and sorted in this GIS study:

The Biophysical criteria group:

- The Coastal Sensitivity Atlas, published by the Department of Transport[10] (Jackson and Lipschitz 1984), provided valuable data on coastal substrate types including different types of rocky and sandy beaches. All rocky coastlines (including 'exposed rocky headlands' and 'wave-cut rocky platforms', as described in Jackson *et al.* (1984)) were extracted by SML script queries.
- Coastal Sea Surface Temperature (SST) data was collected from Marine and Coastal Management's (MCM/DEAT) "old" (Greenwood and Taunton-Clark 1994) and "new" coastal stations arrays. This data, which included 29 point data along the South African coastline with seasonal average SST between the years 1980-1990, was used to determine the geographical boundaries of abalone maximum optimal temperature for growth (i.e.: SST>20°C) (Britz *et al.* 1997). This data was digitised into the GIS.
- The geographical locations of Paralytic Shellfish Poison (PSP) occurrences for the past 10 years were extracted from Pitcher (1998) and digitised into the GIS.

The Coastal use criteria group:

- Marine Protected Areas (MPA) located along the entire coastline of South Africa are planned and managed by Department of Environmental Affairs and Tourism /Marine and Coastal Management/ Bio-diversity working group. The

[10] This atlas was produced with a view of assessing the entire South African coastline and its resources in terms of sensitivity to oil pollution.

location and orientation of all MPA's was described in government gazette (Anon 2000), and subsequently digitised into a GIS format.

- The location of commercial fishery zones was obtained from Tarr (2000) and digitised into the GIS.
- The location of coastal urban areas was provided by the Department of Land Affairs/Director survey and mapping digital 1:500,000 published maps. Data was converted from ASCII into the GIS file format by EnviroMap Ltd. Urban areas were extracted from the maps by SML script queries.
- The location of all experimental abalone-seeding activities were verified by Britz (pers. comm., DIFS, Rhodes University, 2002) and digitised into GIS format.

The Infrastructure criteria group:

- Road network information was obtained from the Department of Land Affairs/Director survey and mapping digital 1:500,000 published maps, and Department of Environmental Affairs and Tourism/Environmental Potential Atlas (ENPAT 1997). Information was extracted by means of the attached attribute table and SML script queries.
- As above, the location of the abalone hatcheries and farms was verified by Britz (pers. comm., DIFS, Rhodes University, 2002) and digitised into a GIS format.

Data analysis and verification

The GIS analysis was based on the interactions of the criteria for abalone ranching. This included the following assumptions (Figure 4.1):

Marine Protected Areas (MPA) are defined as "no take" zones along the South African coastline (Attwood *et al.* 1997). Presently, in such areas no activity, including commercial ranching, can occur. This status could change in future with reseeding aimed at restoring natural stocks and/or enhancing production.

Coastal urban areas included all metropolitan and small settlements along the coast. The vicinity of abalone natural resources to these urban areas can provide economic upliftment. However, the issue of security associated with abalone poaching and access rights has to be addressed if these areas are to be ranched.

Abalone fishery areas are commercial fishery zones, which are mostly overexploited. Ranching activities could provide a means of rehabilitating the natural resources required to improve catches (Tarr 2000).

Paralytic Shellfish Poisson (PSP) is a syndrome caused by biotoxins, synthesized by dinoflagellates, which accumulate in abalone tissues (Pitcher 1998). This health-risk concern is a potential threat to the industry, especially where high frequency occurrence of PSP been recorded[11].

Sea Surface Temperature (SST) (range 11-20°C) is considered to be a fundamental factor in determining the natural distribution of abalone (Britz *et al.* 1997). Hence, areas with average monthly temperature of 20°C and above were considered as not suitable for ranching.

Rocky coastlines were used to indicate potentially suitable areas for abalone, as only limited and patchy information is currently available on the locations of the suitable habitat for abalone. This is mostly confined to local field surveys of abalone population in the south coast (Tarr 1993, Tarr 2000), along the Eastern Cape (Wood and Buxton 1996), and remote sensed data on kelp beds along parts of the West Coast (Sampson *et al.* 2001). Considering this, the assumption was made that rocky coastline is at present the most suitable indicator for identifying potential suitable abalone habitat at a national level[12].

Road access to the coast is perceived to determine the potential for abalone ranching development. This excludes access from the sea by boat, which was not included in this study.

Farms facilities for abalone seed production are seen as providing the necessary infrastructure for producing and storing abalone prior to their release. Hence, proximity to these infrastructures is an important criterion.

[11] For example, during 1999 two abalone farms on the west coast could not export abalone for several months following a PSP event, which result in high levels of toxin in the abalone flesh (Britz, pers. comm., DIFS, Rhodes University, 2002).

[12] Note that rocky coastline could not be used to estimate potential abalone production.

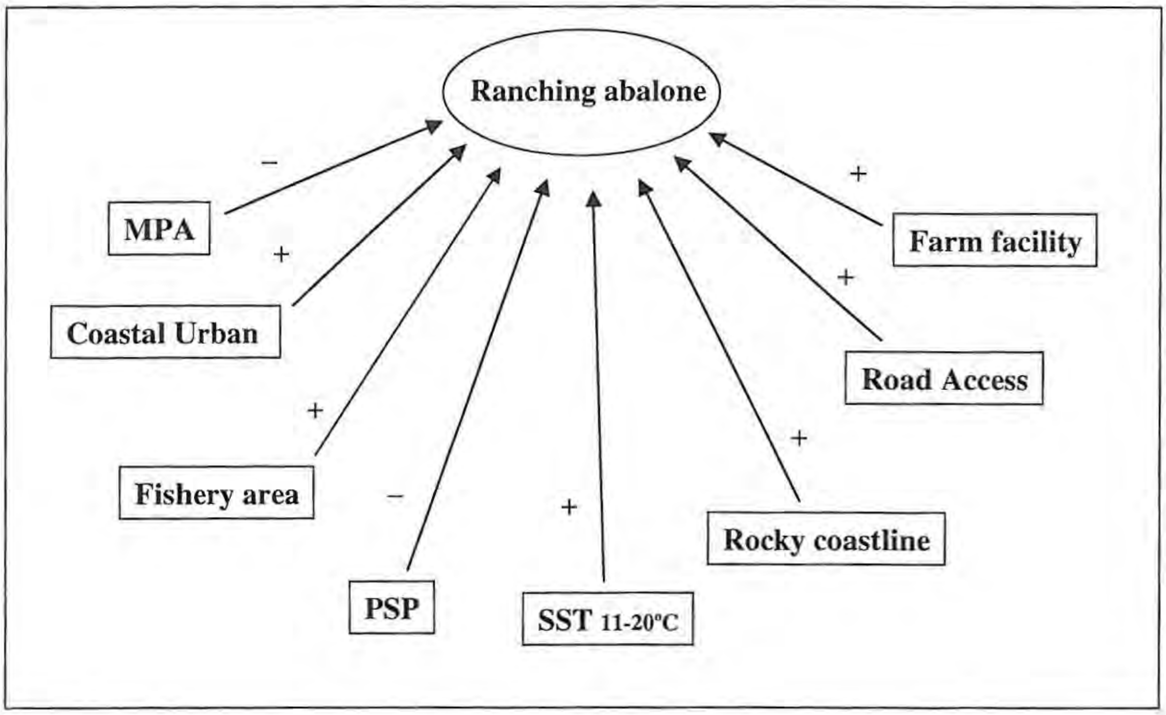

Figure 4.1: The assumed constraints (-) and the promoting (+) effects of each criterion on abalone ranching. These assumptions form the basis for developing the analytical framework.

Based on the above interactions, this GIS analysis aimed to evaluate the potential of the rocky coastline for abalone ranching in South Africa. Five criteria were found suitable for this analysis, namely: Rocky coastline, SST, MPA, road access, and proximity of abalone farms and hatcheries. The analysis was based on the following procedure (Table 4.2):

1. The five suitability criteria in the GIS analysis for abalone ranching were logically ranked from the least to the most exclusive.
2. A set of conditions and operations (i.e. Boolean logic "AND" and "OR", algebraic relation "less then" (>) and "Subtract", and buffer zone (Appendix A)) were selected for each criterion to identify the specific constraint and extract the unsuitable coastlines for abalone ranching development.
3. The extracted coastlines were assigned a potential level and excluded in the next potential level analysis.

The Biophysical-Coastal use-Infrastructure (BCI) result was presented as a potential suitability classification index map of the rocky coastline in South Africa.

Table 4.2: The five levels of potentially suitable rocky coastline for abalone ranching development and the associated criteria, development constraints, and analyses.

Criteria	**Development constraint**	**Analysis (conditions & operations)**	**Potential level**	**Index**
Sea Surface Temperature (SST)	Areas with seasonal average SST>20°C are not suitable abalone environments and have no potential	[(*Rocky coast*) **AND** (*average SST*>**20°C**)]	No potential	P1
Marine Protected Area (MPA)	Ranching activity currently cannot develop in and around MPA. Hence, these areas have poor potential for ranching.	[(*Rocky coast*) **AND** (*average SST*<**20°C**) **AND** (**Buffer 2km** *MPA*)]	Poor potential	P2
Road network	Development of ranching is limited in areas that are not accessible by roads. This implies limited potential for development	[(*Rocky coast*) **AND** (*average SST*<**20°C**) **Subtract** (**Buffer 2km** *MPA*) **Subtract** (**Buffer 5km** *Roads*)	Limited potential	P3
Abalone hatchery	During the commercial phase, suitable ranching sites that are not in close range to abalone farm facilities will be constrained with spat (is this spelling 'spat' correct?) supply. This implies moderate potential areas.	[(*Rocky coast*) **AND** (*average SST*<**20°C**) **Subtract** (**Buffer 2km** *MPA*) **AND** (**Buffer 5km** *Roads*) **Subtract** (**Buffer 100km** *Abalone farm*)	Moderate potential	P4
		[(*Rocky coast*) **AND** (*average SST*<**20°C**) **Subtract** (**Buffer 2km** *MPA*) **AND** (**Buffer 5km** *Roads*) **AND** (**Buffer 100km** *Abalone farm*)	High potential	P5

The moderate and high potential rocky areas (P4 and P5) for abalone ranching was further analysed in terms of their proximity (i.e. 5km) to urban areas. This was based on the assumption that potentially suitable rocky areas for abalone ranching in the vicinity of urban areas can provide economic upliftment to local communities (Britz *et al.* 2002). This analysis therefore, was based on the following set of conditions and operations:

[(*Rocky coast*) **AND** (*average SST*<**20°C**) **Subtract** (**Buffer 2km** *MPA*) **AND** (**Buffer 5km** Urban areas)]

Finally, in order to verify the GIS analysis, the BCI output was compared with existing and proposed ranching concessions, and present ranching sites.

Results

Biophysical criteria group

The South African rocky coastline appeared to be distributed inconsistently along approximately 1454km (Figure 4.3). The Western and Eastern Cape Provinces possess the majority of the country's rocky coastline (44% and 33%, respectively) (Figure 4.4a). In comparison, the KwaZulu-Natal and the Northern Cape, only have 9% and 14% of South Africa's rocky coastline, respectively. In proportion to the total coastline of each province, however, the Northern Cape was found to have the greatest proportion of rocky coastal environment. Approximately 60% of its coastline is rocky (Table 4.3).

Table 4.3: Distribution of rocky shore in the four coastal provinces.

Province	Total km shore (km)	Rocky shore (km)	% of the province coastline	% of South Africa rocky shore
Northern Cape	340	205	**60**	14
Western Cape	1400	635	45	**44**
Eastern Cape	1140	485	42	**33**
KwaZulu-Natal	750	130	17	9
Total	3630	1454		

Most of South Africa's rocky coastline is located within areas with an average SST<20°C. About 19% of the country's rocky coastline (comprised of the entire KwaZulu-Natal rocky shore and 29% of the Eastern Cape rocky shore coastlines) has an unsuitable temperature range for abalone, which implies no potential development for abalone ranching (P1) (Figure 4. 4b). Additionally, a high risk of PSP (over 32% frequency concurrence) was found along the West coast from Jacosbaai north to the Orange River mouth.

Coastal user criteria group

The natural distribution of abalone from Saldanha Bay to Mbashe River supports both recreational and commercial fisheries. Commercial fisheries are located within 8 designated zones along the south coast in the Western Cape (St. Helena Bay to Agulhas point) (Figure 4.3).

The potential rocky coastline (P3-P5), within a 5km radius of urban areas, found in the Western and Eastern Cape was about 48% and 29%, respectively. In the Northern Cape, however, only 15% of this potential rocky coastline is within 5km of urban areas (Figure 4.5a).

With regard to conservation, only a small portion (14%) of the total rocky coastline, which has temperatures suitable for abalone, falls within MPA's (P2). Most of these areas are found within the Western Cape (Figure 4.4a).

Lastly, the experimental abalone ranching sites along the Western Cape province (Mossel Bay), the Eastern Cape (near Port Elizabeth), and the northwest coast of the Northern Cape (south of Port Nolloth), are located within moderate (P4) or high (P5) potential areas (Figure 4.3).

Infrastructure criteria group

At a national level, road access to the coast was not found to be a major potential limiting factor. However, this differed specifically along the Northern Cape province coastline, where about 37% of the rocky coastline is not accessible by roads (Figure 4.4b). The additional analysis, which included a buffer zone of 100km around existing abalone hatcheries (the required infrastructure for producing and storing abalone seed prior to their release), revealed that a major part (i.e. 36%) of the total potential rocky coastline (P2-P5) in the country was within close distance to existing abalone hatcheries, and has a high potential (P5) for ranching.

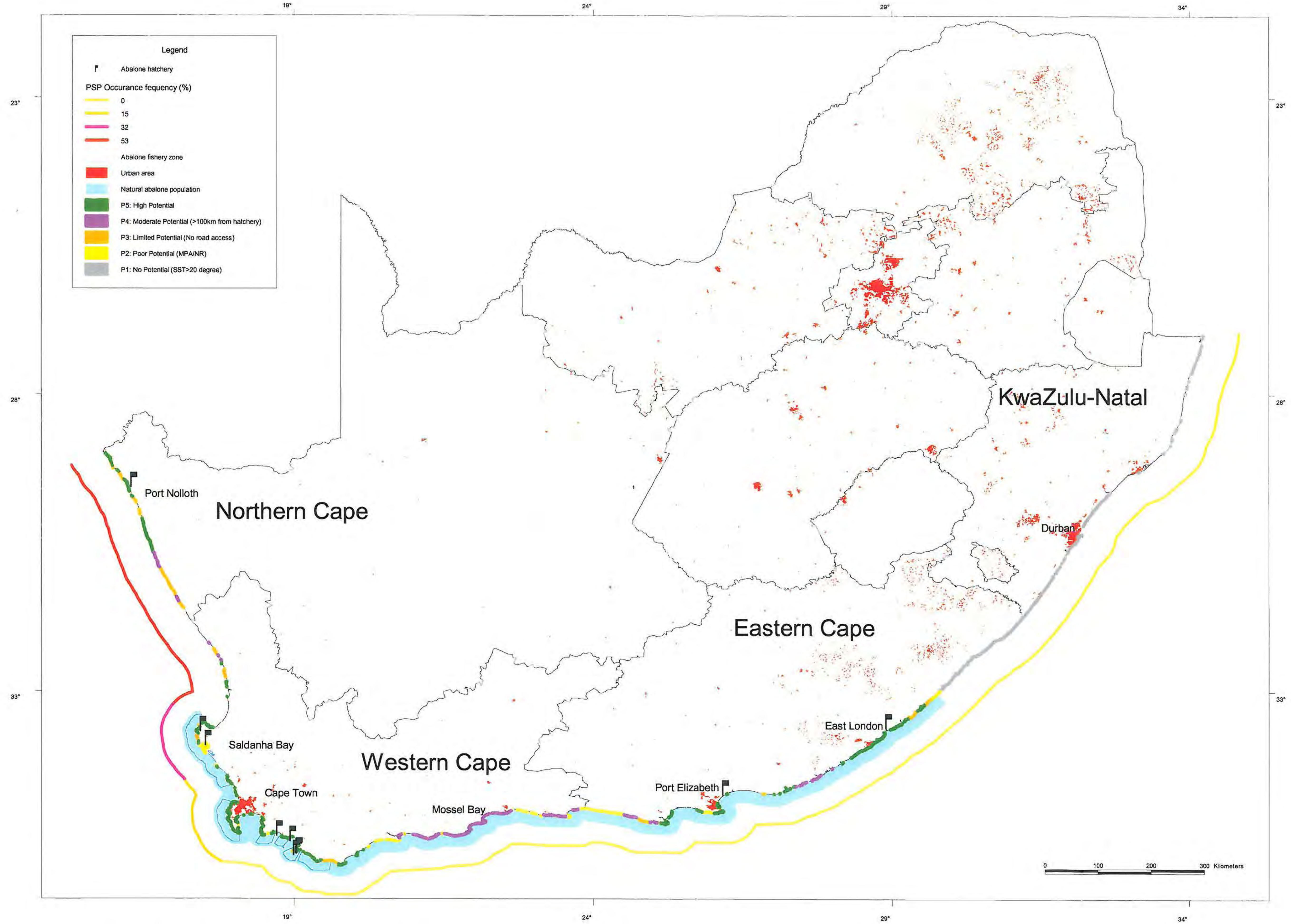

Figure 4.3: The five levels of potentially suitable rocky areas for abalone ranching (P1-P5). Additional information includes the locations of abalone farms, abalone natural distribution and fishery zones, urban areas, and intensity of Paralytic Shellfish Poisson (PSP) occurrence.

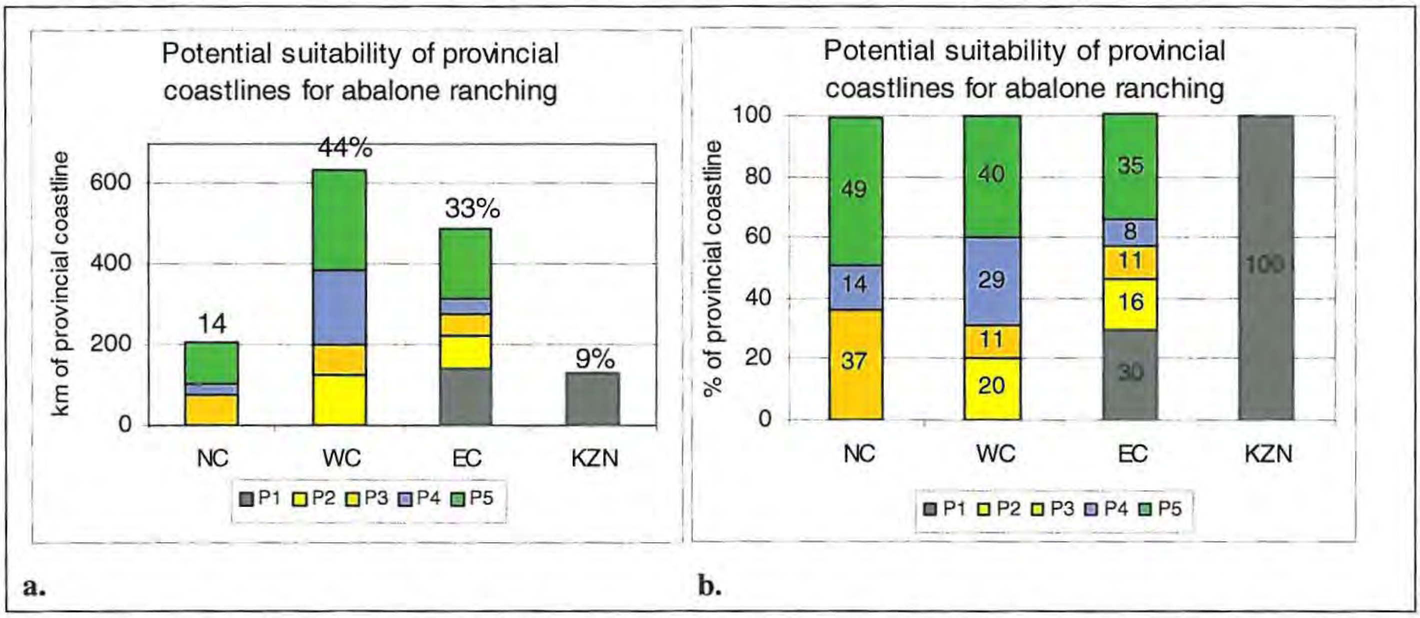

Figure 4.4: a) Proportion of the five potential levels (P1-P5) in the four coastal provinces expressed in kilometres and as a percentage from total national rocky coastline, and b) the proportion of the five potential levels in each province expressed as a percentage. P1=No potential (SST>20°C), P2=Poor potential (MPA/NR), P3=Limited potential (no road access), P4=Moderate potential (>100km from abalone farm), and P5=High potential (no constraint).

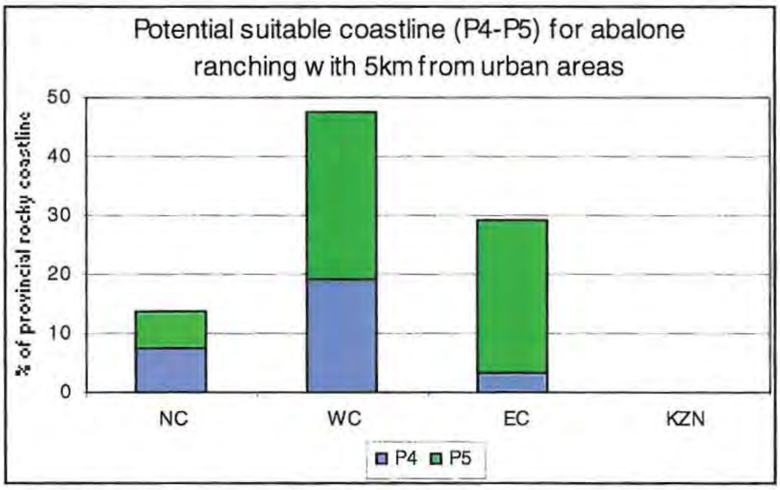

Figure 4.5: The lengths of potentially suitable rocky coastline for abalone ranching (P4-P5) within a 5km distance from coastal urban areas proportional to the total rocky coastline in each province.

Discussion

The following discussion provides a first national overview of the potential for abalone ranching development. On the basis of provincial comparisons, it offers an insight into the interaction of several determining factors including potential habitat, coastal use, and infrastructure. Thus, although the outputs rely on limited data, they provide a spatial perspective that until now has not been available for coastal planners.

KwaZulu-Natal Province

The KwaZulu-Natal coastline is an unsuitable environment for the growth of abalone (*H. midae*). This is due to the high average SST along the east coast, and hence was excluded from this analysis.

Eastern Cape Province

The Eastern Cape Province has over 340km of combined moderate (P4) and high (P5) potential coastlines for abalone ranching. This includes:

- an extended rocky coastline (24% of total rocky coastline of the country);
- a suitable temperature range;
- a low-risk of PSP occurrence;
- limited MPA (16%); and
- limited inaccessible coast by road (11%) (Figure 4.4b).

Three major areas were identified as potentially suitable for ranching (Figure 4.6):

- Area 1 (East London region)- S32°25'03", E28°42'54" to S33°13'04", E27°36'50" with about 235km
- Area 2 (Port Elizabeth region)- S33°54'08", E25°37'16" to S33°54'42", E25°18'24" with about 64km
- Area 3 (Cape St. Francis region)- S34°00'53", E24°55'52" to S34°11'43", E24°45'59" with about 70km

Two actual experimental ranching operations (near Port Elizabeth and Cape St. Francis) within high potential areas (P5) in Area 2 and 3 (Figure 4.6) lend support to the outputs of the present analysis and the initial choice of criteria for this study. Furthermore, the management plan for the Eastern Cape abalone resource (Britz *et al.* 2002) identified one "Rehabilitation TURF" (abalone ranching) concession in an area west of Cape Recife (S33°59'18", E25°17'47" to S33°59'00", E25°40'26"). This corresponds to Area 2 identified in this study providing an additional support to the outputs of the present analysis (Figure 4.6).

The high portion (29%) of the provincial rocky coastline, which is potentially suitable for abalone ranching (P4-P5), is situated in the vicinity (5km) of urban areas (Figure 4.5), suggesting that abalone ranching could provide a good economic opportunity for coastal urban communities. Similar results by Britz *et al.* (2002) have shown that most abalone resource users (legal and illegal fishermen) are resident in main coastal urban centres. Based on these findings, Britz *et al.* (2002) has suggested that such urban centres could act as pivot to which concessions of abalone ranching could be linked. Developing such legal concessions is seen as essential due the increase in abalone poaching pressure on natural stocks, and their potential for socio-economic upliftment in local communities.

Western Cape Province

The Western Cape Province is the hub of the South African abalone fishing industry. This Province also has the longest rocky coastline in the country (635km, representing 44% of the entire country's rocky coastline). The moderate and high potentially suitable rocky coastline for ranching abalone (P4-P5) stretches for over 400km along the province, and was identified with four main areas (Figure 4.6):

- Area 4 (Mossel Bay)- 34°01'11", E22°32'40" to S34°22'32", E21°04'20" with about 190km
- Area 5 (the Hermanus region)- S34°46'04", E19°42'39' to S34°09'31", E18°51'26" with about 180km

- Area 6 (the Cape Town region)- S34°06'31", E18°28'36" to S33°29'49", E18°18'36" with about 180km
- Area 7 (St. Helena Bay)- S32°52'13", E17°53'00" to S32°46'51", E18°06'32" with about 50km

The location of Area 4 as potentially suitable for ranching is further supported by the experimental abalone ranching work of De Waal (2002). However, Area 4 was only noted as having moderate potential (P4) in this study as it is outside of a range of 100km from any abalone hatchery. Hence, the development of abalone farming facilities within this area could improve the potential for ranching.

Areas 5, 6 and 7 are situated within the zones allocated for commercial abalone fishing (Figure 4.6). Catches are declining in all major commercial abalone fishery zones and reductions in TAC are likely to occur in the future due to the increasing pressure from illegal fishing and ecological changes[13] (Tarr 2000). Ranching abalone combined with co-management with local communities could provide rehabilitation solutions in areas where natural abalone stocks have been severely depleted.

Finally, a very high portion of moderate and high potential (P4-P5) suitable rocky coastline (48%), falls within the vicinity of urban areas (Figure 4.5), suggesting a high potential for social benefits from abalone ranching for local communities. However, the close proximity of local communities to abalone resources could also introduce or intensify conflicts with regard to access rights. For example, conflict was reported to occur between commercial divers and poachers living in the same community (Hauck and Sweijd 1999), highlighting the sensitivity associated with utilizing these resources. One of the biggest constraints to developing ranching in this province includes the extensive conservation areas (MPA's), specifically in the western and eastern regions of the province coastline. The high portion (20%) of rocky coastline found in MPA's, highlighted the potential conflict between conservation and abalone fishery activities

[13] An increase in lobster distribution in abalone fishing areas has resulted in reduction of sea urchins density due to lobster predation. This in turn has negatively effected abalone recruitment, as juvenals abalone shelter under sea urchins (Day and Branch 2000).

(Figure 4.5b). An additional constraint is the high-risk of PSP occurrence along the west coast (north-west from Cape Point) (Figure 4.3). Major improvements in abalone farm management have taken place, including the introduction of the PSP monitoring system along the west and east coasts of South Africa (John Foord, pers. comm., Marine Coastal and Management, DEAT, 2003). However the absence of an updated development plan and an approach to managing conflict resolution is a major constraint to the development of abalone ranching in the Western Cape Province.

Northern Cape Province

Abalone ranching in South Africa was pioneered on the Namaqualand coast of the Northern Cape Province (Britz 1997, Cook and Sweijd 1999). About 60% of the Province's coastline was found to have moderate or high (P4 or P5) potential rocky coastline for ranching, but concentrated mainly around two areas (Figure 4.6):

- Area 8 (the Kleinsee area)- S30°22'00", E17°17'49" to S29°37'50", E17°02'38" with about 90km
- Area 9 (the Port Nolloth area)- S29°13'58", E16°51'30" to S28°39'20", E16°29'30" with about 80km

A semi-commercial experimental concession has been allocated south of Kleinsee to Port Nolloth Sea Farm (PNSF). The seeding sites within this 100km concession as well as the additional sites at Port Nolloth have yielded encouraging growth and survival results (De Waal 2002), supporting the results of this study. The main limitations on the use of this coastline include high-risk of PSP occurrence, and the limited road access to the coast in the southern region of the Province. A more detailed investigation of the potential of abalone ranching along the Namaqualand coastline is presented in Chapter 5.

Conclusion

In conclusion, the provincial assessment showed that the Western Cape has the longest stretch of potentially suitable coastline (within four areas) for abalone ranching development. However, this suitability is constrained by the high risk of PSP occurrences on the west coast, alternative resource use and activities such as commercial fishery, poaching, and conservation, and the limited infrastructure at specific locations. The Eastern Cape Province, with the second longest rocky coastline, was particularly attractive for abalone ranching development due to low-risk of PSP occurrence, the low number of competitive users, and a supportive infrastructure. Lastly, the Northern Cape shows acceptable biological potential at specific sites for commercial ranching (De Waal 2002). There is an urgent need to evaluate the implications of the potential hazard of PSP along the Northern Cape coastline (Areas 8 and 9), as it is a major concern for the industry (Pitcher 1998), if any further development takes place. In contrast to the Eastern and Western Cape (Areas 4 and 6) where reseeding is aimed at fishery rehabilitation and enhancement of local populations, the Northern Cape potential (Areas 8 and 9) is strictly targeted at commercial farming activities (Figure 4.6). This has both management and legal advantages for the implementation of the "territorial user right fishing" (TURF) system, since there is no natural population present and all seeded animals can be claimed as a financial farming activity investment.

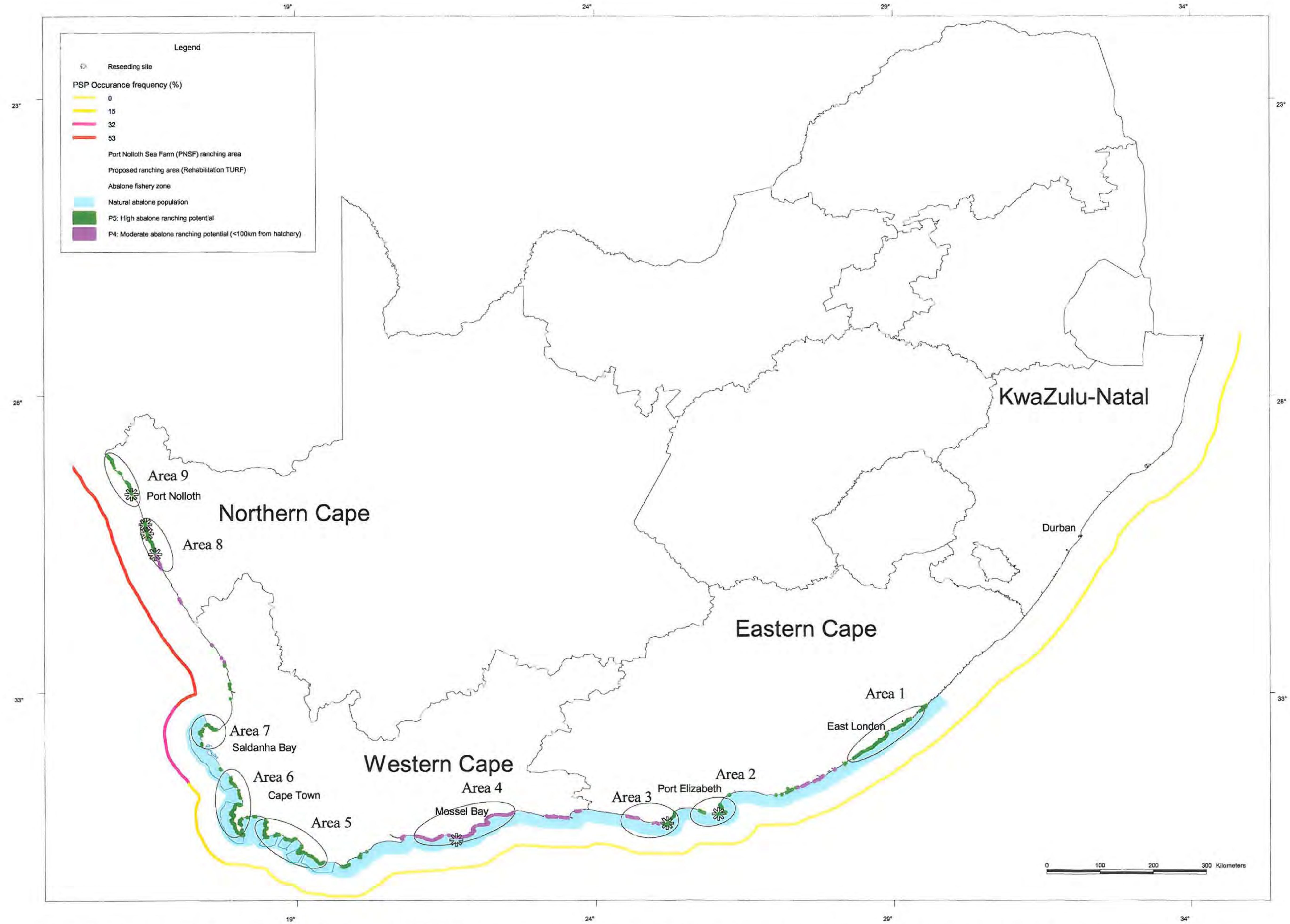

Figure 4.6: Rocky areas (1-9) with moderate and high potential (P4 & P5) for abalone ranching along the South African coastline. Additional information includes abalone ranching sites, PNSF ranching areas, and proposed ranching area (i.e. Rehabilitation TURF).

CHAPTER 5

Spatial evaluation of mariculture potential along the Namaqualand coastline

Introduction

The mariculture sector in South Africa requires a plan to promote sustainable economic development (Hecht 1996, Britz and Hecht 1999). However, due to the diversity of the South African ecological, social and economic coastline conditions, such a plan must include detailed regional development plans. These regional development plans should reflect the unique identity and development requirements for each region, and related to the overall national sector development plan objectives (Hecht 1996). Considering that South African regional economic development is the responsibility of the provincial governments, regional mariculture sector development plans should be initiated by provincial authorities.

A case in point is the Northern Cape Provincial Government, which has recognized the economic potential development of the Namaqualand coastal region (Anon 1998). In this context, mariculture sector was identified as a high potential economic activity, which required a comprehensive sector plan. This recommendation was followed by a regional sectoral stock taking and diagnostic survey (Britz *et al.* 1997), and a comprehensive fishing and mariculture sector plan (Britz *et al.* 2002b). Based on the diagnostic survey and the sector plan, two main mariculture opportunities were identified for development. They included land-based operation (i.e. intensive culture of shell-fish, finfish, and seaweed), and marine-based operation (i.e. abalone ranching). In addition, preliminary national spatial results of this study (refer to chapters 3 and 4), revealed the extensive potential for mariculture (land-based and abalone ranching) along the Namaqualand coastline. Hence, as a result of this study's output and the ongoing regional sector development plan, a high-resolution spatial analysis was conducted to assist in the identification of potentially suitable sites for land and marine-based mariculture development in Namaqualand. The following sections introduce the physical, economic and social setting of the Namaqualand coastal region, and the rationale for this analysis.

A physical and economic overview of the coastal Namaqualand region

The Northern Cape Province is the largest province in the country ($362{,}556km^2$, which is 30% of the area of South Africa). The coastal area of the Northern Cape Province falls within the Namaqualand magisterial region (Figure 5.1). The Namaqualand coast is 340km long, stretching from the Orange River mouth (S28°39'02", E16° 28'55") in the north to the bounder of the Western Cape Province in the south (S31°09'27", E17°45'49"). A gradual topographic decline occurs from east to west, which is dominated by Sandveld plain shrub-like vegetation (Plate 5.1). The region is characterised by dry climatic conditions, which include variable precipitation (20-250mm annually). Air temperature ranges between winter maxima and minima of 19C° and 2C°, and summer maxima and minima of between 33C° and 17C°, respectively. The coast is a mineral rich area, which includes deposits of diamonds, copper, zinc, lead, silver, bauxite, pegmatite, limestone and kaolin (Scott Wilson Planning and Development Resources 1998).

The Namaqualand marine environment (situated along the Benguela upwelling system) forms the cold temperate biogeographic zone and consists of a dominant rocky coastline with extended kelp bed reefs with patchy sandy beaches (Plates 5.2 and 5.3). This environment is characterised by sea surface temperatures ranging from 10-15 C° and rich nutrient levels, which support high levels of primary production and diverse and abundant marine flora and fauna. Namaqualand possesses a year-round high-energy coastline, with no protected bays. Apart from the wetland environment (proposed RAMSAR site) located within the Orange River mouth, all catchments remain dry for most of year, with occasional surface water during the wet winter months (CSIR 1994).

The population density in the Namaqualand region is low: 1.5 $person/km^2$. This population is mostly concentrated around four major coastal centres visible: Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai towns. The economy is largely dependant on the mining sector (58% of regional Gross Geographic Production (GGP)), whereas the balance comprises of fishery, tourism, and agriculture sectors (Mather 1999).

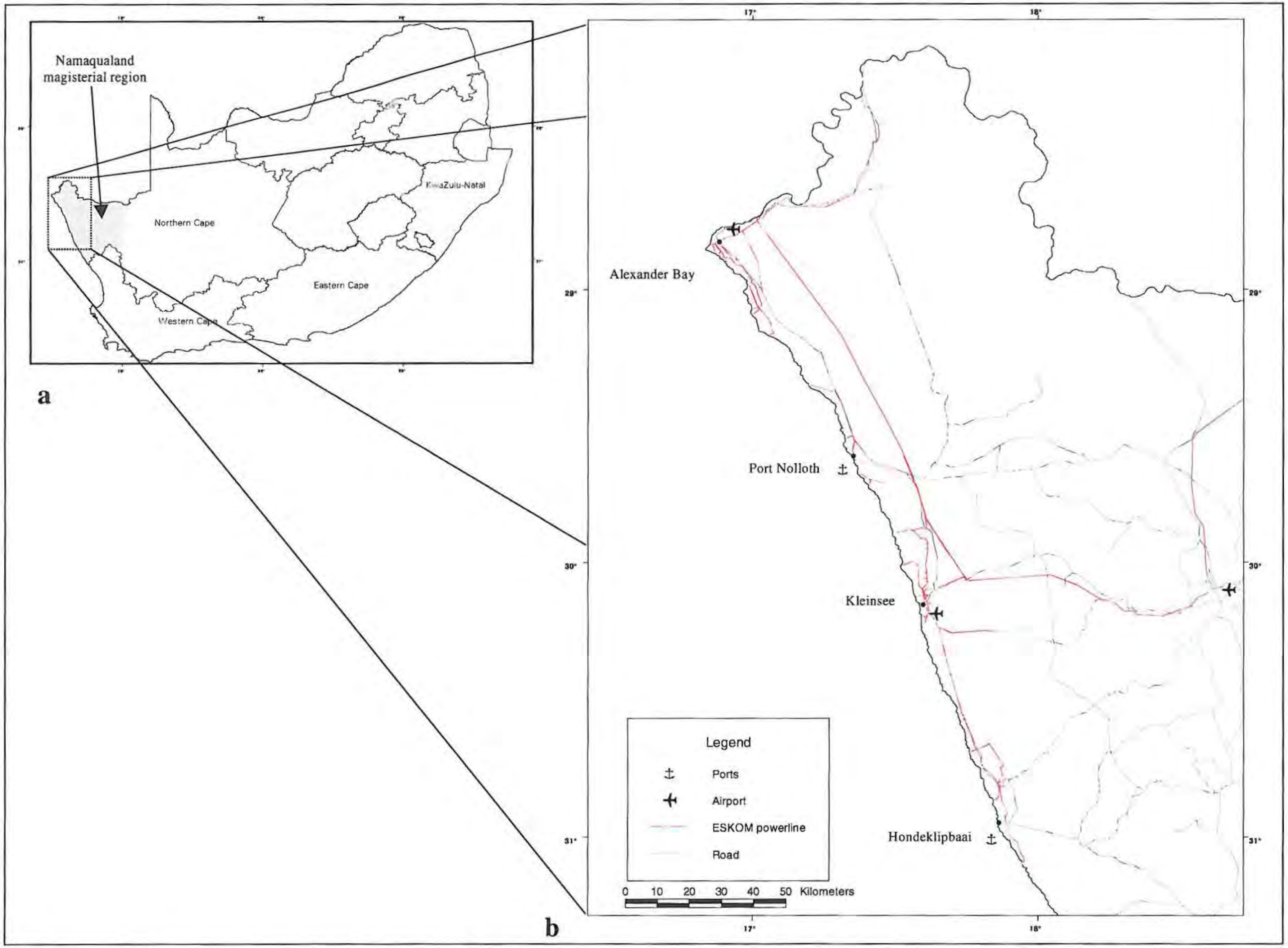

Figure 5.1: (a) Magisterial regions of South Africa showing the location of the Namaqualand magisterial region. Note the size of Namaqualand and its total coastal length in proportion to the rest of the country. (b) The four development areas (i.e. Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai), and the available infrastructure along the Namaqualand coastline.

Plate 5.1: The Namaqualand coastal landscape, characterized by its gradual topographic slope, Sandveld plain shrub-like vegetation, and dry climate.

Plate 5.2: The dominant rocky coast and high-energy wave action along the Namaqualand coastline.

Plate 5.3: Submerged kelp bed reefs found along the coastline of Namaqualand.

Plate 5.4: Land based operations include the process of stripping the overburdens, which result in modification of the coastal landscape.

The mining sector consists primarily of diamond mining, which is located predominantly along the coastal region. As a result of the diamond mining activities infrastructure is well developed along the coastal region, and includes: roads and electricity networks, seawater pump stations, harbours and airports (Table 5.1).

Table 5.1: The dominant sectors, roads network, airports, and harbours conditions at the four coastal centres of Namaqualand (Scott Wilson Planning and Development Resources 1998, Britz 2002).

Area	**Dominant Sector**	**Roads network**	**Airports**	**Harbours**
Alexander Bay	Diamond mining (production decline with an employment impact)	Very good tar roads	Very good (international flights)	Very small jetty (for diamond vessels <15m)
Port Nolloth	Fishing and services	Very good tar roads	Small private (light aircrafts)	Small natural harbour (for vessel <22m)
Kleinzee	Diamond mining (stable for next decade)	Good dirt roads	Very good tarmac runway (medium size aircrafts)	Non
Hondeklipbaai	Fishing and Tourism	Good dirt roads	Non	Very small jetty (<14m vessels)

However, both land and marine based mining operations also have negative impacts on the coastal environment (Barkai and Bergh 1992, CSIR 1994, Mackenzie 1996, Scott Wilson Planning and Development Resources 1998, Lane and Carter 1999). Land based operations include the process of overburdens stripping and excavation of terrace gravel, which results in modification of the landscape (Plate 5.4). Additional outcomes of these operations include the development of roads, encampments and tailing dumps, and littering of discarded mining gear, which might affect water quality and devalue coastal land for other users (CSIR 1994, Mackenzie 1996, Lane and Carter 1999). High security zones in these areas provide limited access to the coast, thereby preventing the development of other sectors.

The shore-based marine mining operations are located along the surf zone (a marine strip zone of 33m from Low Water Mark), and the "A" mining concession areas (a strip zone from 33m to 1000m from Low Water Mark). These operations include mining by divers from boats (Plate 5.5) and from the shore using a portable pump (Plate 5.6). The negative impacts of these marine mining activities include marine habitat modification, which results from the cutting of kelp and pumping of gravel (Barkai and Bergh 1992, Lane and Carter 1999).

Nevertheless, due to adverse prices, a lack of new ore reserves and stagnating production, the mining sector has been in decline in recent years. Unless new reserves are identified and technology change implemented, mining production in Namaqualand is likely to continue scaling down (Mackenzie 1996, Scott Wilson Planning and Development Resources 1998). This will have major implications for employment in the region. Alternative economic opportunities are therefore urgently required. Developing such economic opportunities however, involves the planning and implementation of a comprehensive regional sector development plans.

The potential development of mariculture along the Namaqualand coastline is therefore evident. It includes favourable environmental conditions such as the rich nutrient water with a high level of primary production, the well-developed diamond-mining infrastructure, and the urgent need for alternative economic opportunities. The suitable environmental conditions for culture high valued species such as abalone using land-based system and/or ranching technique further motivate mariculture development in this region.

However, in spite of these favourable conditions, mariculture is still in its embryonic stage of development. This includes the abalone farm at Port Nolloth (Plate 5.7) and the experimental seeding abalone concession south to Kleinsee (allocated by Marine Coastal and Management, DEAT) by Port Nolloth Sea Farm (PNSF), and the two oyster farms at Kleinsee and Alexander Bay (Plate 5.8) areas. Main constraints for the sector development include the year-round high-energy coastline with no protected bays, the high security zones in mining diamond operation areas, which provides limited access to the coast, and the lack of a coordinated national mariculture development plan.

Plate 5.5: Mining diamond boats used along the Namaqualand coastline. Note the extended pipe used by the divers when operating from the boat.

Plate 5.6: Shore-based mining diamond operation (white arrow) along the 'surf zone' of the Namaqualand coastline.

Plate 5.7: The abalone hatchery of Port Nolloth Sea Farm (PNSF) located north to Port Nolloth.

Plate 5.8: The oyster farm situated in Alexkor mined-out area.

Rationale

As a result of the economic imperative and the lack of national mariculture development strategies,[1] the Northern Cape Province initiated a regional fishing and mariculture sector plan (Anon 1998). Among the main regional constraints for mariculture development, identified by the sector plan, was the limited access to the coast (due to mining activities) (Britz *et al.* 2002).

The aim and objectives of the provincial sector plan were subsequently set to remove the constraints and stimulate development. This was based on sector plan principles (Figure 1.3), and included defining achievable development targets[2] (which are derived from the national policy guidelines and the regional stock taking and diagnostic survey), followed by the selection of strategies and projects, and concluding with the implementation.

The following two development targets (within the medium-term) with a definable spatial component were identified in the sector plan (Britz *et al.* 2002b):

- Target 1: "Promote two land based aquaculture development parks"
- Target 2: "Identify two other concession areas for abalone ranching enterprises"

Spatial analysis is a vital component in the choice of sector planning strategies. The need for this component was recognized in the Northern Cape Provincial Government development strategy (Anon 1998). The Northern Cape Government identified GIS as the most suitable approach due to its multi-criteria analytical capacity. This study examines the suitability of GIS as a Spatial Decision Support System (SDSS) capable of assisting planners in their choice of strategies. This was done by transforming the sector plan targets into spatially defined objectives/problems.

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[1] To date, national government's main role has been limited to resource management and policy formulation, and has lacked planning strategies to implement the new Marine Living Resource Act (Britz *et al.* 2002b).

[2] A set of priority actions within a time frame designed to promote the development of the sector.

Hence, extracted from the sector plan targets (Britz *et al.* 2002b), the aim of this study included:

1. **To determine the two most suitable development-areas for land-based mariculture**
2. **To determine two additional suitable areas for abalone ranching**

Method

Two separate site suitability analyses were conducted in this study to address the two opportunities for mariculture development: land and marine based systems. Both analyses included the coastal zone between the Orange River mouth and Hondeklipbaai (S28°39'02", E16° 28'55" to S30°18'52", E17°16'37"). The land-based analysis examined the general potential for suitable target species (shellfish, finfish or seaweed), while the marine-based analysis assessed the potential for of abalone ranching.

Choice of criteria and analytical framework for land-based GIS analysis

Due to the socio-economic needs (i.e. high unemployment), and infrastructure location, the land-based analysis was focused on the four coastal urban centres[14] (i.e. Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai) in terms of their potential for mariculture development (Figure 5.1b). Hence, the aim of this analysis was to compare the potential of each development area (i.e. Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai) for land-based mariculture, and to provide a spatial input into the decision of where the two land-based mariculture parks should be established (refer to Target 1).

Based upon the assumption that marine environmental conditions (such as SST range and oxygen levels) are generally homogenous along this coastline, mining activities were considered as the dominant variable determining development in this region (Britz *et al.* 2002b). The study was therefore based mainly on three criteria: land availability (mined-out areas), coastal accessibility (high and low security zones), and mining infrastructure (coastal pump stations, which imply the presence of developed electrical distribution and roads networks).

[14] Referred to in this study as 'development areas'.

Further motivations and assumptions for each criterion in this study included:

- **Mined out areas:** The underlying assumption was that mined out areas are of no use for future diamond mining and hence are suitable for any other use or development such as mariculture.
- **High security zones:** The high security zones around the mining activities prevent any development even in mined out areas, unless the status changes to a low security area. Quantifying the extent of high security zones for each development area provides an idea of the overall suitability of that area for development, and indicates the potential for conflict with mining companies over security issues.
- **Low security and municipal zones:** Since most of the region is dominated by diamond mining activity, zones with low security status are generally smaller. Municipal zones, which are either private property or government owned, are included in this output since they provide, like the low security zones, access to the coast for development. This criterion provides an indication of the accessibility of each development area, and therefore an indication of its overall potential for mariculture development.
- **Pump station infrastructure:** Seawater pump stations, which are used for the processing of diamonds, were considered as potential development sites since they provide a reduction in the initial cost of infrastructure needed for mariculture operations. In addition, pump stations provide a good indication as to whether infrastructure is developed in that region such as electricity and road networks.

Based on the above chosen criteria and assumptions, each of the four development areas was assessed in terms of the total mined out area, high security area, and low security area. In addition, the quantified output included an estimated ratio between high and low security areas in each development area.

Choice of criteria and analytical framework for Marine-based GIS analysis

The marine environment of Namaqualand includes a high-energy coastline with no sheltered bays, and limiting conditions for marine-based farming development (such as cages and rafts). Nevertheless, the highly productive environment including vast kelp beds areas and pollution free water conditions, offers a good opportunity for ranching abalone (Britz and Hecht 1997, Cook and Sweijd 1999, De Waal 2002, Britz *et al.* 2002b).

The potential of ranching is largely dependent on habitat site suitability (Cook and Sweijd 1999, De Waal 2002). The Namaqualand region on the West Coast, although outside the natural distribution of abalone, consists of a similar kelp bed (*Ecklonia maxima*) habitat to that of the south coast where the commercial fishery for abalone is situated (Tarr, 2000). These habitats provide the major source of nutrition for abalone; and potential abalone production has been estimated based on distribution and abundance of kelp beds (Tarr 1993, Sampson *et al.* 2001). Based on the surface area of kelp beds obtained from the aerial-photo measurements and abalone density from a diving survey, an estimated ratio of production of 1,042kg abalone per 1ha surface kelp bed was calculated in the major fishing grounds in the Western Cape Province (Tarr 1993). A similar ratio was used by Sampson *et al.* (2001) to project potential production for ranched abalone at several sites along the Namaqualand coastline.

Despite this, the overall potential for abalone ranching in the region is dependent on ecological and economic impacts by both marine and land diamond mining activities. This includes the restricted access to the coast due to land-based mining, and the localised but severe ecological impacts due to kelp bed cutting and habitat modification resulting from marine based diamond mining activity (CSIR 1994, Lane and Carter 1999). The marine-based analysis, therefore, aimed to evaluate the current and future spatial potential for developing abalone ranching areas (refer to Target 2 above) on the basis of available kelp bed area (i.e.: indicator of potential abalone production areas) and the location of high security zones and the marine mining activities (i.e.: indicator of present and potential conflict with abalone ranching). The evaluation was done in three phases: (1) regional distribution of kelp beds and marine mining activities per mining concession zone, (2) the present and potential location of abalone ranching areas, and (3) potential conflicts with marine mining at the proposed abalone ranching areas (Figure 5.2).

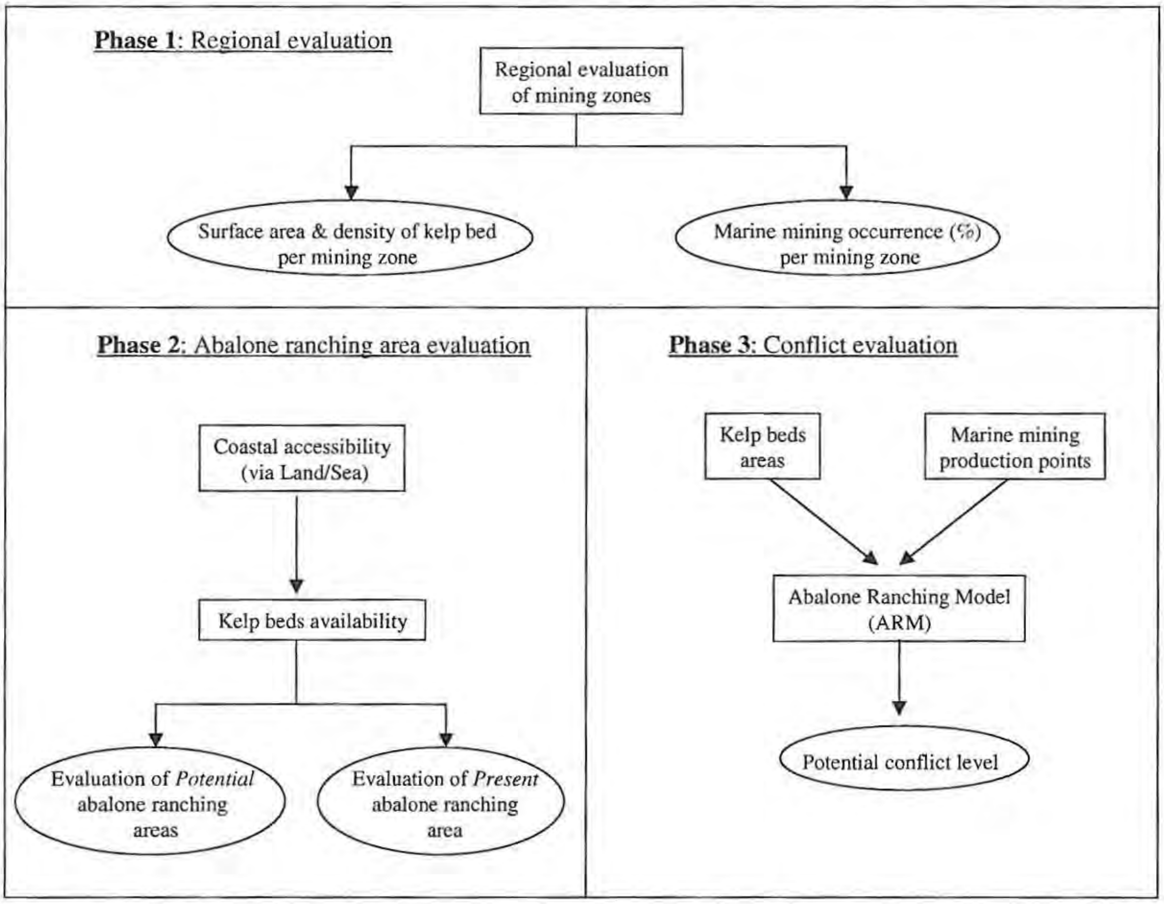

Figure 5.2: The three phases in the marine-based analysis: Phase 1 is a regional evaluation of marine mining activities and kelp beds location based on marine mining concession zone boundaries, Phase 2 determined the location of potential abalone ranching areas based on the accessibility of coast via land and sea, and kelp bed availability, and Phase 3 evaluated the potential spatial conflict between marine mining and potential abalone ranching areas.

Data collection and sorting for the Land and Marine-based GIS analyses

In order to perform these analyses, data was first collected for the entire Namaqualand coastal region. Two types of data, namely mining data and kelp bed Remote Sensed (RS) data, were used in these analyses. They comprised:

1. Mining data: Comprehensive data was received from the mining companies Alexkor Ltd and De Beers Consolidated Mines Ltd/Namaqualand Mines, Kleinzee. The data was received in both digital (DXF and DWG files) and hard copy formats. Data was then converted and imported into GIS format. Information included:
   - Mining concession zones
   - Onshore diamond mined out areas
   - High and low mining security zones
   - Seawater pump station infrastructure
   - Reported marine production points by Alexkor diving operations in the "A" mining concessions areas (a surf strip zone from 33m to 1000m from Low Water Mark). Data was available along the mining concessions areas 1 to 4.

2. Remote Sensed kelp bed data for the West Coast: The Remote Sensing (RS) images of kelp beds were generated by the DEAT/MCM/Seaweed Unit aerial surveys conducted during 1996-1997. This data was created with the aim to reassessing the location and quantity of the seaweed resource (in particular the kelp bed resources) along the South African coastline. Data was provided digitally in GIS format.

Additional data was collected and was overlaid in the final outputs. This included:

- Roads network
- Coastal town
- Mariculture activities (i.e. abalone and oyster farms, and seeding abalone sites)
- Ports
- Airports

An additional criterion, identified as an issue of concern, was the Orange River high-risk flood zone (Branch *et al.* 1990, CSIR 1994, Mackenzie 1996, Mather 1999, Lane and Carter 1999, Britz *et al.* 2002b). The periodic flooding of the Orange River has an impact on the coastal life in the subtidal zone of 10-30km from the river mouth (Branch *et al.* 1990). In this study, 20km of coastline from the Orange River mouth was considered as a potentially severely disturbed environment for any mariculture activities, and hence was identified as a low mariculture development potential zone.

Land-based mariculture analysis

The land-based analysis included two spatial analytical operator tools:

- Buffer zones- zones within 0.5, 1 and 2km radius from all pump stations in each of the development area, were identified.
- Boolean logic operation "AND" (intersect)- Each of the identified buffer zones from pump stations were intersected with mined-out areas, and high and low security zones, in order to quantify the total suitable and unsuitable area, per development area, respectively.

Based on this the following calculations were preformed:

- The total mined-out area (in ha) within a 0.5, 1 and 2km radius from pump stations at the four development areas: Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai.
- The ratio (as a percentage) of High and Low Security zones within 2km from pump stations (to provide an indication of the potential conflict level between mining and other developments around the security issue).

Marine-based mariculture analysis

The three marine-based analysis phases included the following details:

Phase 1 (Regional evaluation): This phase provided a general regional analysis.

The output contained:

- Proportion (percentages) of the marine production points found in mining concessions 1-4
- Total kelp bed surface area (ha)
- Kelp bed density per kilometre of coastline (ha/km), using:

$$\frac{\text{Total surface area of kelp beds (ha) per mining zone}}{\text{Total coastline (km) per mining zone}} = \text{Kelp bed density (ha/km)}$$

The outputs of kelp bed densities were categorised into four density levels: 0, below 2, 2 to 10, and above10 ha kelp bed / km coastline.

Phase 2 (Abalone ranching area evaluation): This was a two-step analysis, which evaluated the coastline's potential for ranching based on accessibility to the coast and availability of kelp beds. The initial step determined the accessibility of the coast from both land and sea. This was based on the high security mining zone locations and a 20km boat range from the nearest port/jetty. The results are presented in three potential levels of coastline:

- ***No potential***- coastline without access either from land or sea.
- ***Moderate potential***- coastline with limited access only from the sea (within 20km radius from nearest port/jetty).
- ***High potential***- coastline with good access from land (not within high mining security zones).

The second step of the analysis included assessing the total kelp bed surface area along:

- The accessible coastlines (i.e. high and moderate potential coastlines) identified in the first step.
- The existing experimental abalone ranching area[15] (i.e. mining concessions 5 and 6).

Total abalone production was then estimated, based on kelp bed surface area.

[15] At present only one experimental abalone ranching area has been allocated along the Northern Cape Province for Port Nolloth Sea Farm (PNSF).

Phase3 (Conflict evaluation): In order to identify the extent of the potential conflict between marine mining and potential abalone ranching activities, an Abalone Ranching Model (ARM) was developed. The ARM is based on the assumptions that the location of kelp beds (within 1km from coastline) is an indication of potentially suitable abalone habitat, and that the areas with a radius of 20m from all marine mining production points are not favoured for ranching activities[16]. ARM included the following steps:

1. Conversion of all kelp beds from vector into raster coverage.
2. Development of a raster-distance model (named: Mining Intensity Model (MIM)) from all the marine production point data.
3. Integration of the kelp beds data and the marine mining production model (MIM).

The first two steps were preformed using fixed GIS functions, whereas ARM was generated using Spatial Manipulation Language (SML) script (Appendix 3), which is an integrated script language in TNTmips© GIS software. Furthermore, the ARM is a raster-based output, which evaluates a coastal marine strip of 1km (i.e. surf zone and "A" concession mining area). ARM simplifies the interaction between potential ranching areas (kelp beds) and marine mining intensity by identifying four different areas, and three potential levels for ranching abalone. This included areas of:

1. No potential- no kelp beds & no mining activities
2. No potential- no kelp beds & mining activities
3. Low potential- kelp beds & mining activities (i.e. **potential conflict**)
4. High potential- kelp beds & no mining activities

Therefore, outputs from MIM and ARM included measurements in percentage of: total high intensity mining area in the abalone ranching area, total conflict area (kelp & mining) in the abalone ranching area, total non-conflict area (kelp & no mining) in the abalone ranching area, ratio of marine mining found in kelp beds ((mining + kelp) / mining)[17], and ratio of kelp beds effected by mining ((mining + kelp) / kelp)[18].

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[16] The distance from the marine production point was based on the assumption that the immediate mining impact of pumped sediment on the substrate does not exceed 20m radius. However, this could be modified in future.

[17] An indication of whether kelp beds are preferred location for marine mining.

[18] An indication of the level of impact marine mining has on kelp beds

Results

1. Mariculture Land-based analysis

Four coastal centres are located along the Namaqualand coastal region: Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai (Figure 5.3). Alexander Bay and Kleinsee are privately owned by the mining companies Alexkor and De Beers, respectively. These towns are entirely supported by the mining activities. By contrast, both Port Nolloth and Hondeklipbaai, although located within the mining region, offer livelihoods based partially on fishing and living marine resources (Mather 1999). The following results provide details on the mining environment in each of the four areas.

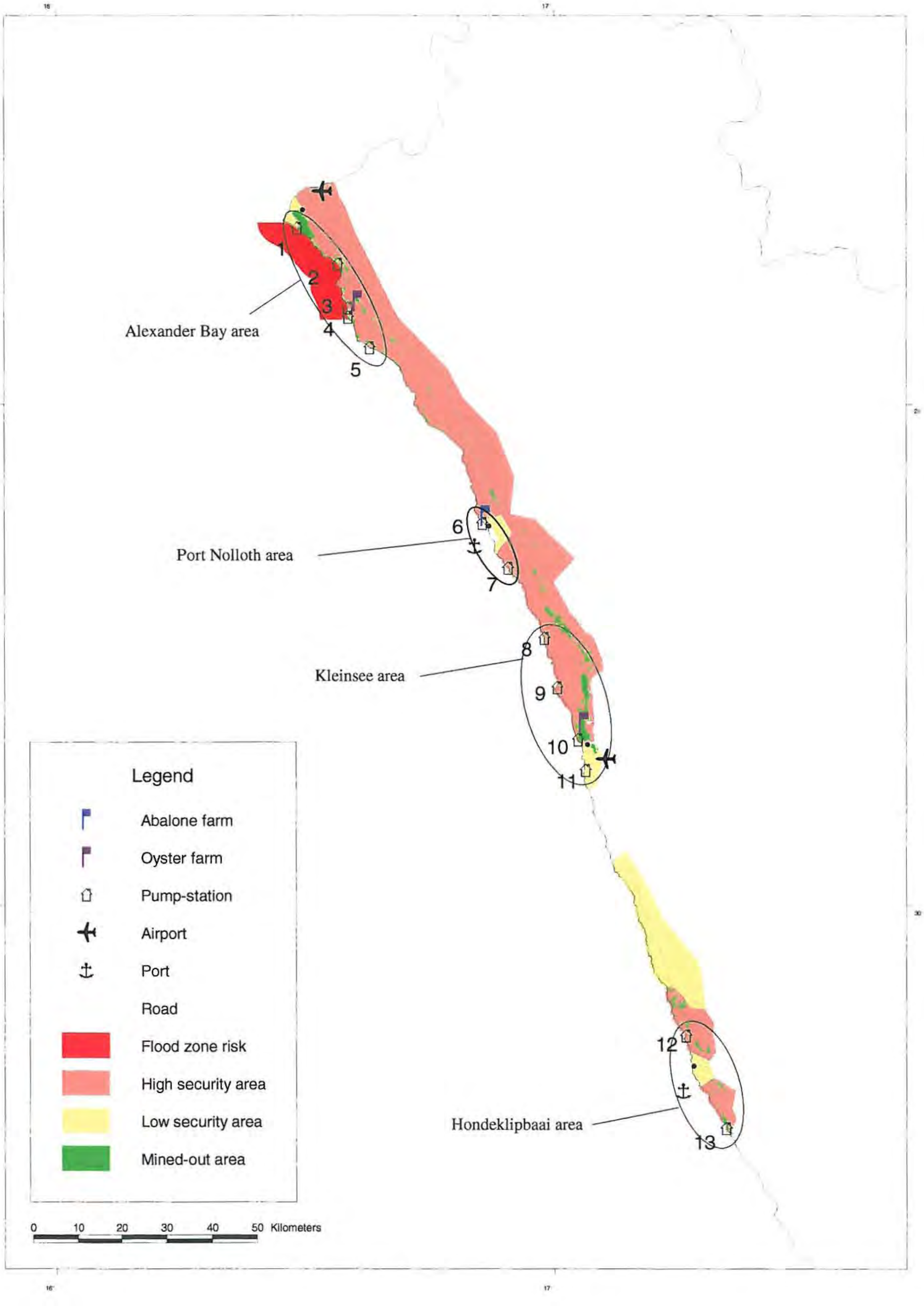

Figure 5.3: Security levels, mined out area, and pump stations (1-13), at the four development areas: Alexander Bay, Port Nolloth, Kleinsee, and Hondeklipbaai (circled).

Mined out areas

Alexander Bay was found to have the larger area of mined out land (667ha). This area is twice as large as the Kleinsee area. By comparison, the Hondeklipbaai area possessed only 94ha of mined out land. There was no mined out land available at Port Nolloth (Figure 5.4a).

High security areas

Alexander Bay was found to have the greatest extent of high security areas: approximately 2800 ha. In comparison, 1910ha of high security area was present at Kleinsee, 1292ha in Hondeklipbaai, and 563ha in Port Nolloth areas (Figure 5.4b).

Low security and municipal areas

Among the four development areas, Kleinsee was found to have the largest low security area (681ha), followed by Port Nolloth (556ha). Hondeklipbaai area had no low security areas and Alexander Bay only 222ha (Figure 5.4c).

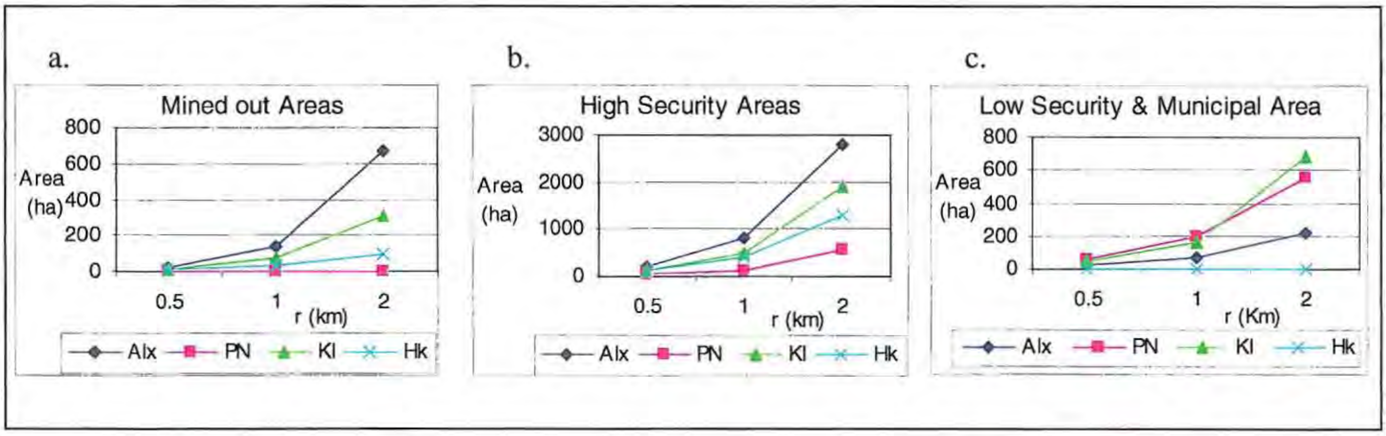

Figure 5.4: Mined out (a), high security (b), low security and municipal (c) areas measurements for the four development areas

Proportion of High and Low Security areas

It is evident that although infrastructure is more developed at Alexander Bay, with five pump stations than at Hondeklipbaai (2 pump stations), both areas are dominated by high security zones (Figure 5.5). This could imply that conflict between mining and other development over the security issue is more likely to occur. Infrastructure at Kleinsee is more developed than in the Port Nolloth area (i.e. 4 Vs. 2 pump stations, respectively). Both areas, however, contain large portions of low security areas, which could imply lower potential for conflict between mining and other development (Figure 5.5).

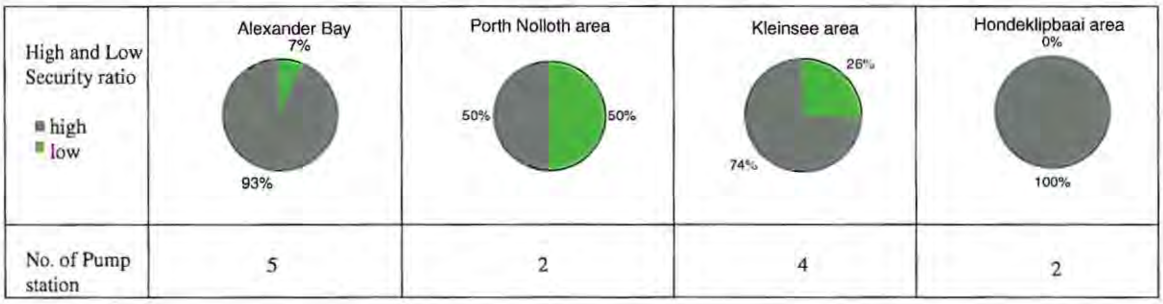

Figure 5.5: Number of pump stations, and ratio between high and low security areas within a 2km radius from the pump stations of each development area.

Present mariculture activities in the region are found at three locations: a grow-out oyster farm 25km south of Alexander Bay, an abalone hatchery farm 1.5km north of Port Nolloth, and a grow-out oyster farm, 2km north to Kleinsee. Lastly, the coastline 25km south of the Orange River mouth is considered to have low potential development for mariculture due to the high-risk flood zone of freshwater from the Orange River.

2. Marine-based analysis

The three phase marine-based analysis provided the following outputs:

Phase1 (Regional evaluation)

The Northern Namaqualand coastline displayed a predominantly low kelp bed density with a calculated surface area of about 65 and 55ha along the coastal concession areas 1 and 2 respectively. A rapid increase in kelp density and total surface area is noticeable to the south from mining concession areas 3 to 6. Kelp density peaks in concession area 4, which has a total of 1094ha of kelp bed surface area (Figure 5.6).

Most of the marine mining activities take place within mining concession areas 1 and 3. Similar information was not available for the southern part of the coast (i.e. mining concession areas 5, 6 and 7).

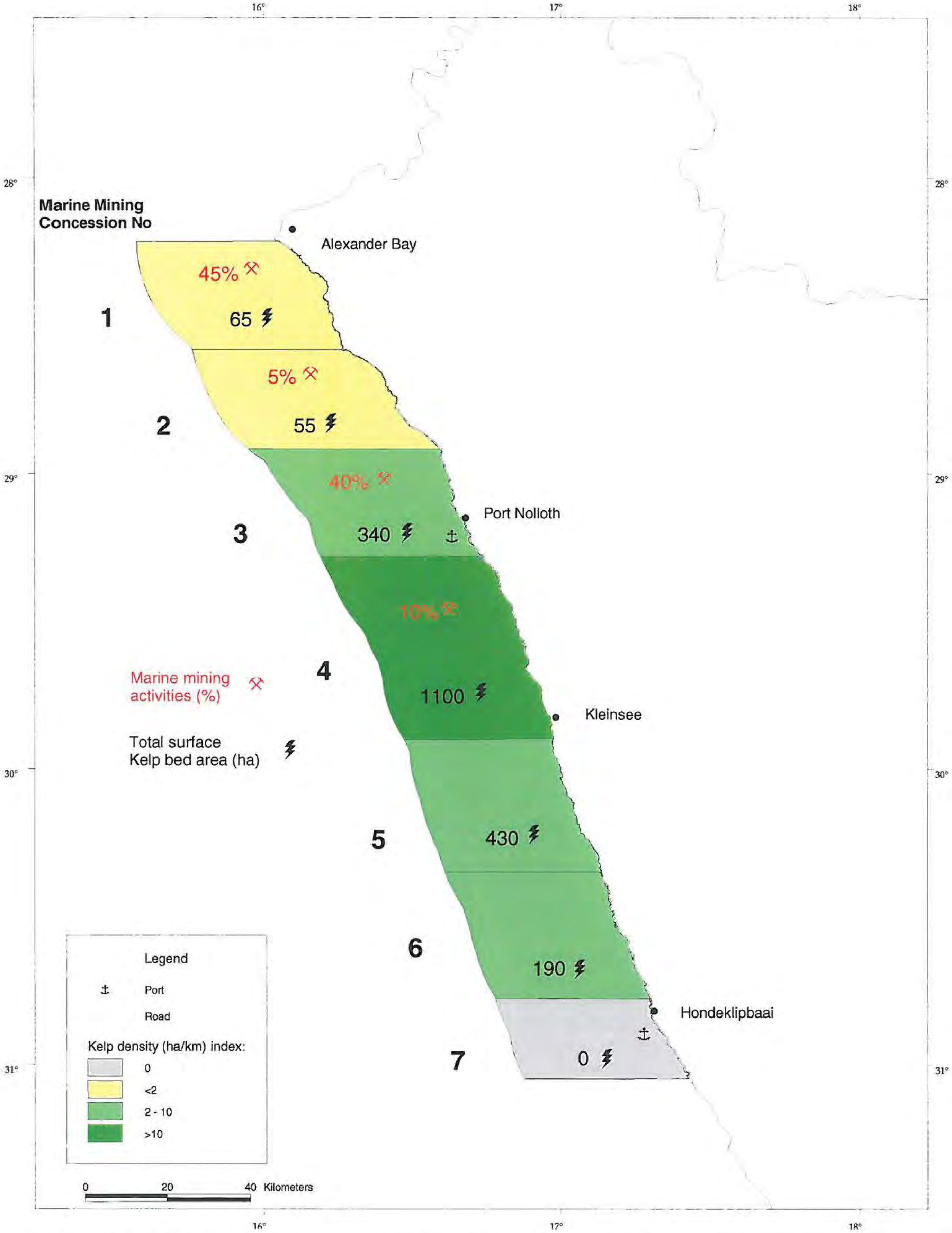

Figure 5.6: Kelp bed area and marine mining intensity in mining concession zones (1-7) on the Namaqualand coast. Note that the north part of the region has the lowest kelp density (ha/km of coastline) and lowest total surface kelp bed areas. The highest intensity of marine mining was present in mining concession 4.

Phase 2 (Abalone ranching area evaluation)

The two-step analyses provided the following information.

During the first step, three potential levels of coastlines were identified (Figure 5.7):

- No potential- two areas inaccessible from land or sea were identified along the coast within concessions 1 and 2, and partially within concession 4.
- Moderate potential- where the coast is inaccessible from the land, two jetties at Port Nolloth and Hondeklipbaai provide a 20km radius of access from the sea by boat. Sea access was identified within concession 3, and partially within 4, 6, and 7.
- High potential- Three areas at Port Nolloth (concession 3), South of Kleinsee (concession 5 and 6) and Hondeklipbaai (concession 7), were identified as providing ready access to the coast over land.

During the second step of the analysis, kelp bed extent was determined in the high and moderate potential areas for ranching. The mining concession area 7 (adjacent to Hondeklipbaai) was identified as not being a suitable abalone ranching area due to the absence of kelp beds, and thus excluded in this analysis. Port Nolloth Sea Farm (PNSF) abalone ranching area was found to cover about 100km of coastline. The total kelp surface area of about 620ha was found to vary in density along the PNSF abalone ranching allocated coastline. The lowest density was recorded at the south section of the coast (Figure 5.8).

The remaining accessible coastline areas were evaluated as additional potential ranching areas. Three accessible areas of the coast, with extensive kelp beds, were identified as potential ranching areas. These areas included Kleinsee South (KS), Port Nolloth North (PNN), and Port Nolloth South (PNS) (Figure 5.9). Total kelp bed surface areas at PNN, PNS, and KS were found to be 171, 597, and 120 ha, respectively. One experimental abalone ranching site of Port Nolloth Sea Farm (PNSF) was found within Kleinsee South area (Figure 5.9b).

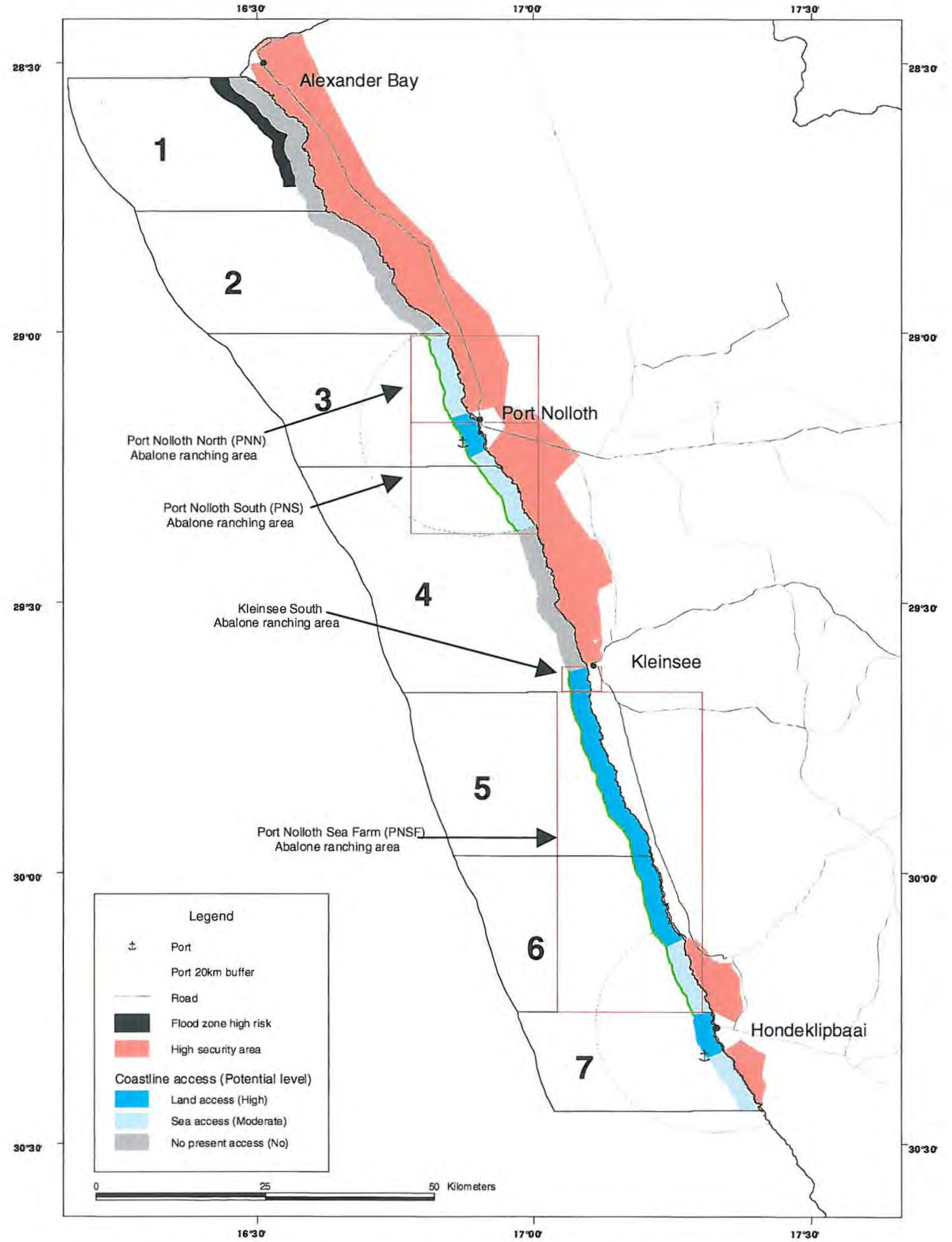

Figure 5.7: The three levels of coastline accessibility (high, moderate and no access) determined by high security land mining zones and port/jetty, which provide about 20km radius access to the sea. The three potential ranching areas (PNN, PNS, and KS) and the existing ranching area (PNSF) were further evaluated in term of kelp bed availability for ranching abalone.

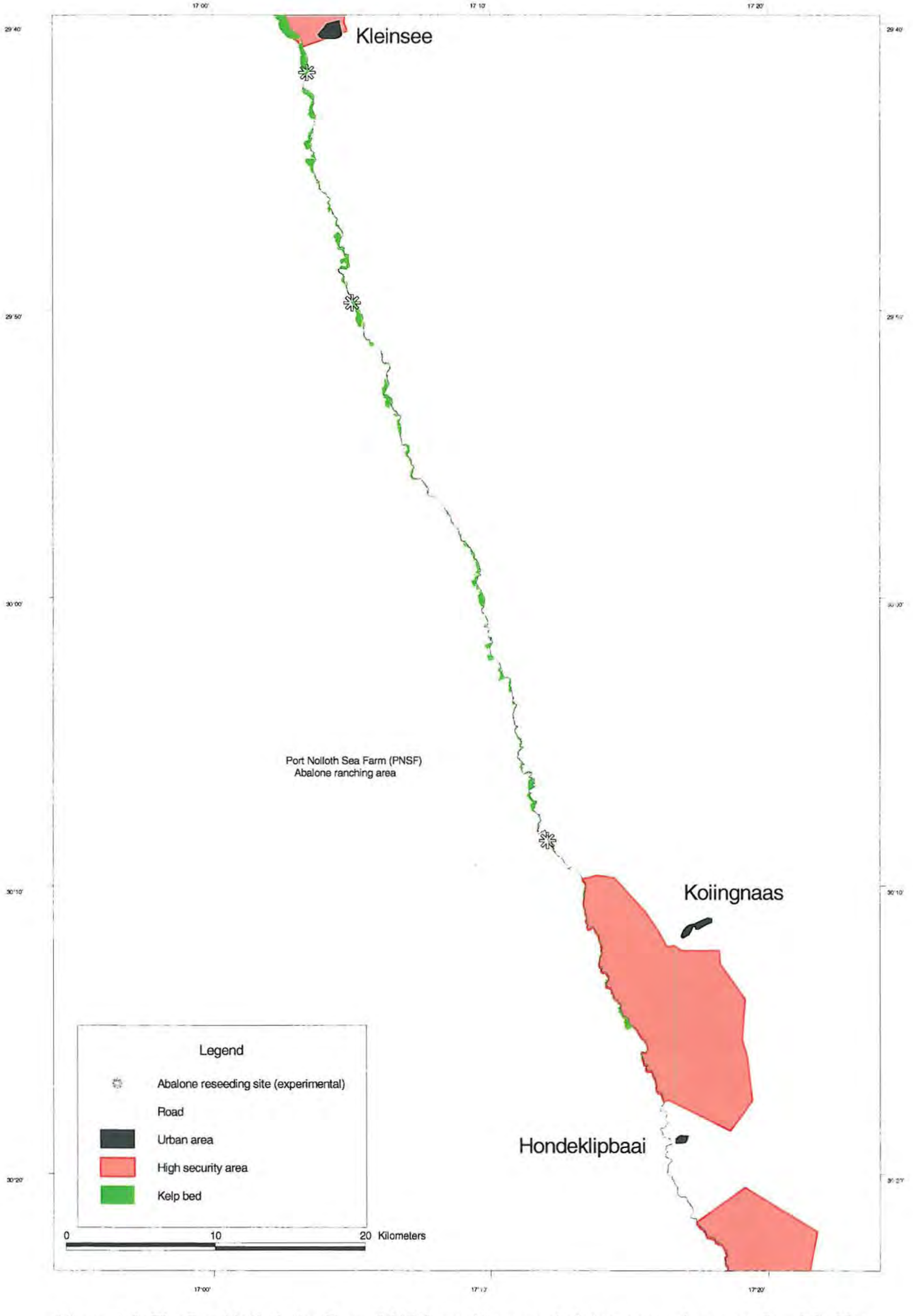

Figure 5.8: The Port Nolloth Sea Farm (PNSF) ranching area (mining concession areas 5 and 6). Note the decline in kelp beds surface area along the coastline from north to south.

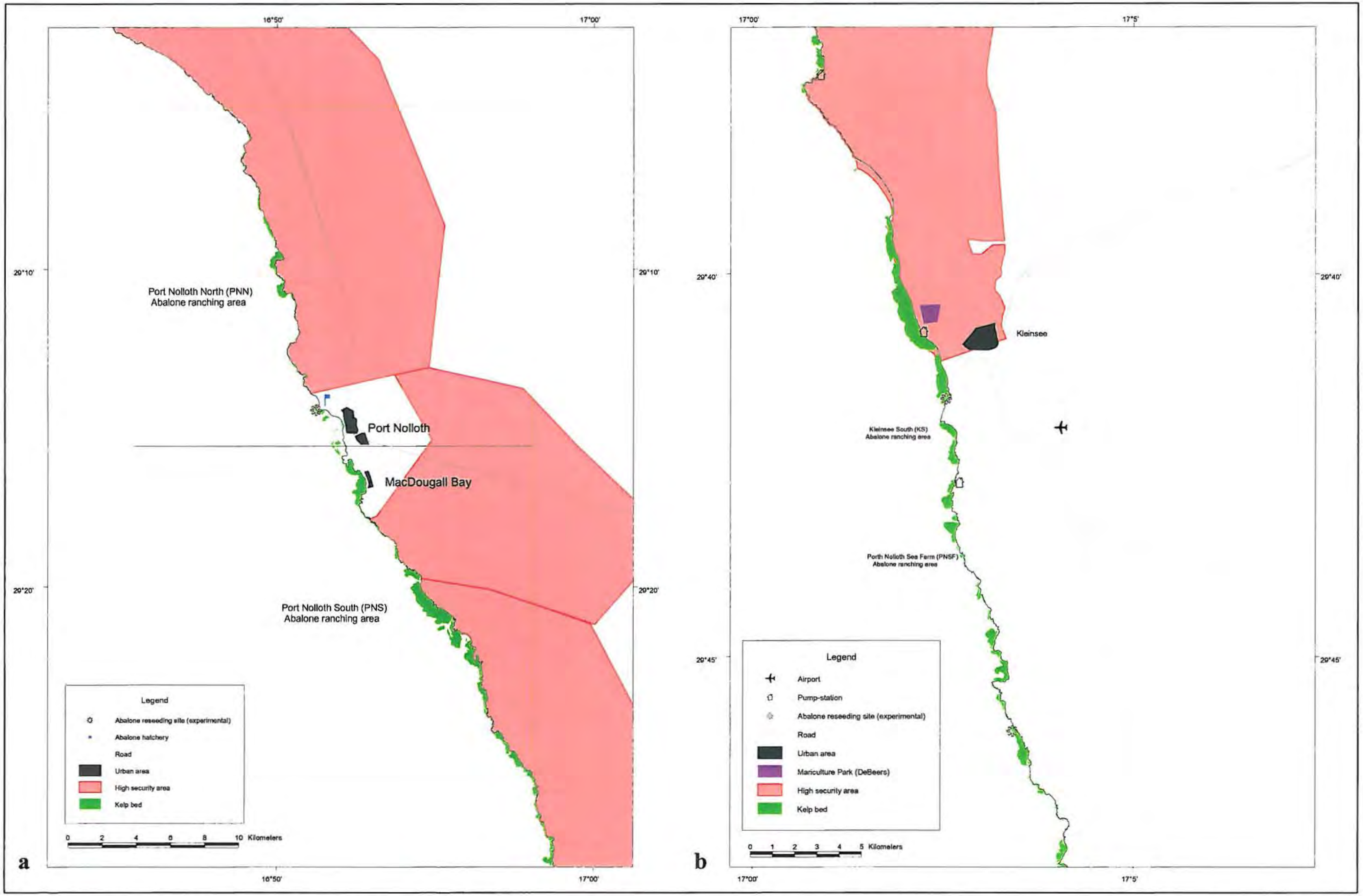

Figure 5.9: The accessible potential abalone ranching areas showing kelp bed locations and abundance at (a) Port Nolloth North (PNN) and Port Nolloth South (PNS), and at (b) Kleinsee South (KS).

Phase 3 (Conflict evaluation)

Two potential ranching areas were included in this evaluation: Port Nolloth North (PNN) and Port Nolloth South (PNS). This evaluation was based on the Abalone Ranching Model (ARM) and provided an insight into the potential conflict between marine mining and potential abalone ranching activities. The ARM is based on two inputs: kelp bed area and the marine Mining Intensity Model (MIM). The MIM reveals the localized, uneven distribution, and clustered patterns of marine mining intensity along PNN and PNS coastlines (areas "a" and "b" in Figure 5.10). The total percentage of high and very high marine mining intensity areas (>= 20m distance from any mining production point) in the PNN and PNS areas (1km zone) were found to be 16% and 7%, respectively. In addition, the ARM results showed that overlaps between intensive marine mining areas and kelp beds are localized and clustered (areas "a", "b", and "c", Figure 5.11). A small spatial overlap between kelp beds and marine mining of about 2-3% was recorded in each of the potential ranching areas (PNN and PNS). However, in total, PNS was found to have a larger non-conflict area (kelp bed with no mining impacts) than PNN (Table 5.2). Furthermore, results showed that the ratio of intensive mining located in kelp beds to total mining was more substantial in PNS (43%) then in PNN (10%). Lastly, PNN and PNS had similar ratios of kelp bed areas affected by mining to total kelp bed area (Table 5.2).

Table 5.2: Summary of outputs from the Mining Intensity Model (MIM) and Abalone Ranching Model (ARM) for Port Nolloth North (PNN) and Port Nolloth South (PNS) potential abalone ranching areas.

Measurement (%)	Port Nolloth North (PNN)	Port Nolloth South (PNS)
Total high intensity mining area in ranching area	16	7
Total conflict area (kelp & mining) in ranching area	2	3
Total non-conflict area (kelp & no mining) in ranching area	9	16
Ratio of mining found in kelp bed area ((Mining + kelp) / Mining)	10	43
Ratio of kelp bed area affected by mining ((Mining + kelp) / kelp)	15	16

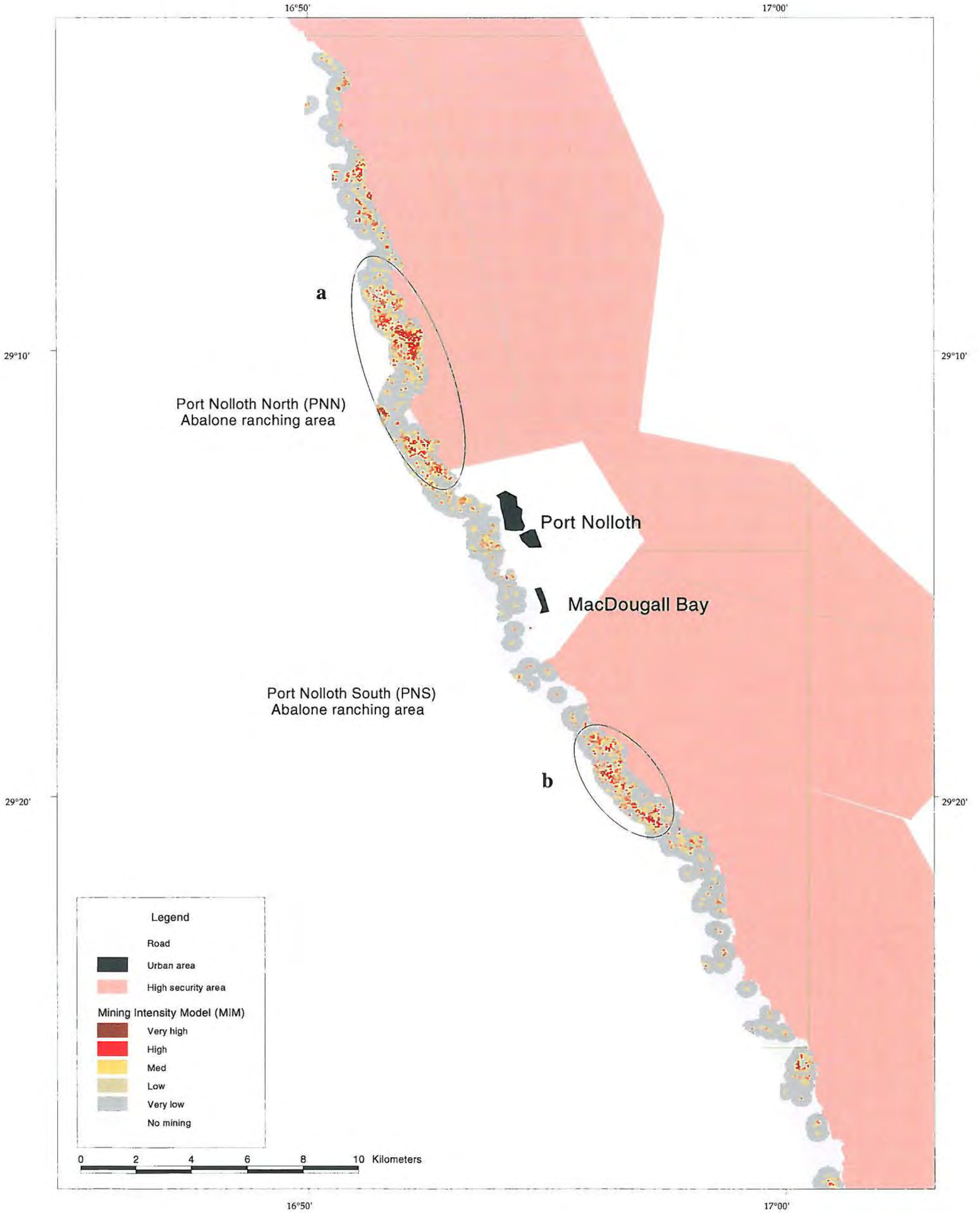

Figure 5.10: The marine Mining Intensity Model (MIM) for Port Nolloth North (PNN) and Port Nolloth South (PNS). The localized and cluster pattern of high and very high mining intensity is marked with circles (areas "a" and "b").

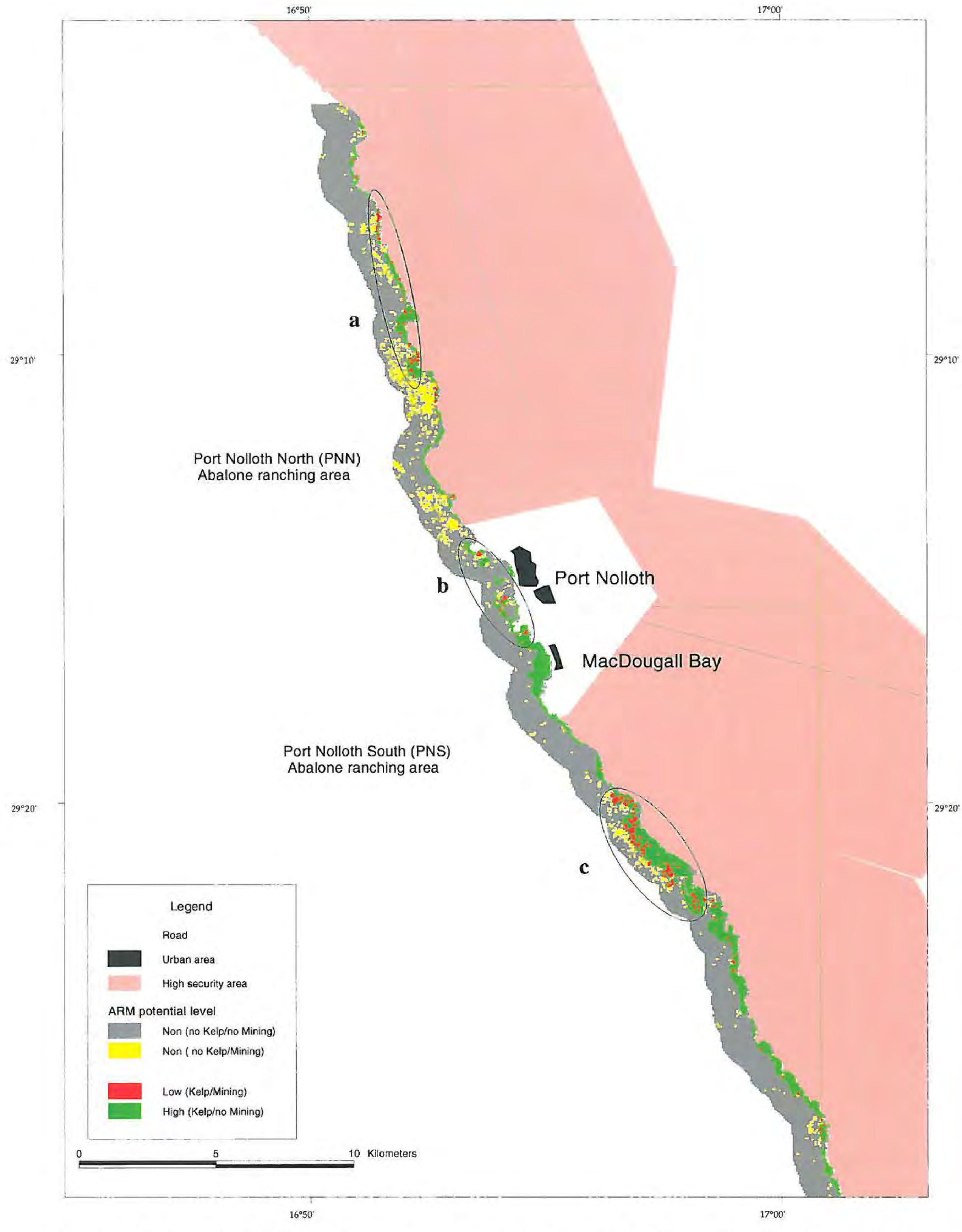

Figure 5.11: Conflict evaluation between marine mining activities and potential abalone ranching areas (kelp beds) within the Port Nolloth North (PNN) and Port Nolloth South (PNS) potential ranching areas, using Abalone Ranching Model (ARM). Note the localized and minimal potential conflict between the marine mining and kelp bed locations (marked in red within areas "a", "b", and "c").

Discussion

The following discussion contains two sections: land-based and marine-based analyses.

1. Land-based analysis

Alexander Bay development area

Alexander Bay, owned by Alexander Bay Development Corporation (Alexkor Ltd), is situated in the most developed mining area along the Namaqualand coastline (Scott Wilson Planning and Development Resources 1998). This includes an airport that can support large cargo planes with regular international flights. Furthermore, the mining infrastructure includes power lines, which extend up to 30km south of Alexander Bay town connected to 5 pump stations (pump stations no. 1-5). An extensive mined out area of 667ha exists within a 2km radius of the pump stations (Figure 5.3). This includes several water storage ponds (converted from mining excavations and used by the nearby diamond sorting plants), which offer unique opportunities for mariculture development. One existing mariculture operation entails the production of the Pacific Oyster (*Crassostrea gigas*) at the Rietfontein storage dam (Figure 5.3, Plate 5.8). Nevertheless in the Alexander Bay area, the expansion of the present oyster operation is limited by the high security zone (Figure 5.4b). The inaccessibility of the coastline in this area is a major constraint for any form of further mariculture development. In addition, the short section of the accessible coastline along the mouth of the Orange River is located within the high–risk flood zone (Figure 5.3).

Lastly, the lack of a designated area by an alternative land-use development plan in the Alexkor Bay development area minimises the current potential for mariculture development. The land-based mariculture development potential in Alexander Bay area will remain low unless the security level is reduced, allowing for more free access to the coast, preferably near developed infrastructure in the southern part of the area (i.e. pump stations no. 3-5).

Port Nolloth development area

Port Nolloth is the largest centre along the Namaqualand coast, and its economy is based on the mining economy and the marine living resources including hake and associated bycatch, lobster, seaweed and subsistence fishing (Mather 1999, Britz *et al.* 2002b).

In contrast to the coastal area owned by the mining companies, Port Nolloth consists of about 2100ha of municipal and privately owned land (excluding the Port Nolloth residential area). The pump station and the abalone hatchery (pump station no. 6) at Port Nolloth Sea Farm (PNSF) (privately owned-land, Snethlage, pres. Comm.), could provide supporting infrastructure and technology for new mariculture development, when necessary land-use permits from local (e.g.: PNSF, Port Nolloth municipal) and national (DEAT/MCM) agencies are granted. However, the increase in the demand for coastal housing in the area, such as in MacDougall Bay for seasonal tourism within this limited space (Scott Wilson Planning and Development Resources 1998), could imply that residential expansion is favoured over mariculture establishment. Hence, mariculture development in this area is limited in terms of space and has the potential to cause conflict with property development.

The additional pump station, located at Oubeep (pump station no. 7, Plate 5.9), provides an alternative potential suitable location for mariculture development in Port Nolloth development area. It has recently been proposed that this area to the south of Port Nolloth at Oubeep be allocated for mariculture development. This will, however, require a change in security level in that location, which at present is a major development constraint.

In conclusion, the combined high level of unemployment in this area, the available infrastructure and the accessible coastal area at Port Nolloth make this an attractive development area for land-based mariculture among the four development areas (Table 5.3).

Kleinsee development area

The Kleinsee area is privately owned by DeBeers consolidated Mines Ltd, Namaqualand Mines. This area has been subject to intense mining activity with 310ha of mined out area, which is second only to the Alexander Bay area. As a result, Kleinsee area is dominant by high security zone and inaccessible coastline.

However, a coastal area to the south of Kleinsee is zoned as a low security area (680ha) and provides access for other activities such as tourism, recreation and mariculture (Figure 5.4c). DeBeers mining infrastructure in Kleinsee area, which includes four pump stations (i.e. pump 8-10), could specifically enhance mariculture development by saving initial capital of about R1-5 million (Peter Britz, pers. comm. DIFS, Rhodes University, 2003). A site with particularly high mariculture development potential has been identified by DeBeers north of Kleinsee (pump station no. 10, known as AK3 station, Plate 5.10). Subsequently, an area of about 50ha has been zoned by DeBeers as a potential "mariculture zone" and a pilot development of oyster culture in an earthen pond system has been established. However, like the oyster farm at Alexkor, this zone is located within a high security area, where the issue of security is a constraint to operation. Since the "mariculture zone" boundary is adjacent to the low security area, an obvious solution could be a change in the high security demarcation. The pump station no. 11 located south of Kleinsee in the low security area[19] provides an additional potential site for development (Figure 5.3). Consequently, Kleinsee is among the most suitable development areas (Table 5.3).

Hondeklipbaai development area

Hondeklipbaai is a small island of private and public owned land surrounded by the DeBeers Namaqualand Mining area. The two pump stations (pump stations no. 12 and 13) and the limited mined out area are all situated within a high security area (Figure 5.3). This suggests potential conflict between mining and any proposed mariculture development. The limited access to the coast confined to the municipal area, does not reveal much potential for mariculture. However, infrastructure at the old lobster factory

[19] Also known as the "yacht club".

in Hondeklipbaai might provide a potential site for an operation. Thus, the overall potential for mariculture development in Hondeklipbaai is limited, due to mining security issues.

Plate 5.9: Pump station no. 7 (i.e. Oubeep) located south to Port Nolloth.

Plate 5.10: Pump station no. 10 (i.e. AK3) located north of Kleinsee.

Table 5.3: A Comparison of land-based mariculture potential between the four development areas in Namaqualand, based on equally weighted criteria. The main constraining criteria, namely mining activity, and supporting infrastructure (pump station), have been assigned an equal score. The scores simplify each criterion's advantages (+) or disadvantages (-) for mariculture development. Based on this, total score and associated ranks were given for each development area. Note Kleinsee and Port Nolloth's outstanding potential as compared to Alexander Bay and Hondeklipbaai.

Criteria		**Alexander Bay**	**Port Nolloth**	**Kleinsee**	**Hondeklipbaai**
Mining Activities	*Mined out area*	+	-	+	-
	High security zone	-	+	-	-
	Low security zone	-	+	+	-
Supporting infrastructure	*Number of potentially suitable pump stations*	(1) +1	(2) +2	(2) +2	(1) +1
Total overall score		0	+3	+3	-2
Final ranking		**2**	**1**	**1**	**3**

2. Marine-based analysis

Regional evaluation

The regional potential of abalone ranching was evaluated on the basis of the marine mining concession areas. Based on Tarr (1993), the low kelp bed density along the northern concessions of the coast suggests a low potential for abalone production (Figure 5.6). The potential of mining concession area 1 is lowered by a high conflict potential with the intense marine mining activity and the limited land access to the coast. The high-risk flood zone (20km south the Orange River mouth) poses an additional limitation for development in the north.

A significant increase in kelp bed density along mining concession areas 3 and 4 suggests an estimated potential annual abalone production of 337 and 1094 tons, respectively. This reveals an enormous potential for abalone ranching in the centre of the coastal region of Namaqualand. However, the intense marine mining activity in mining concession area 3, and the limited land access to the coast along mining concessions 1-4, could introduce a potential conflict between mining and abalone ranching. Land access from Port Nolloth, and sea access based on a 20km cruise range of small vessels, could provide an alternative solution for seeding abalone in this restricted part of coastline (Figure 5.7).

An additional high potential area for abalone ranching exists along the southern coastal region (mining concession areas 5 and 6). This region, allocated to Port Nolloth Sea Farm (PNSF), contains an overall high density of kelp beds, with a particularly high estimated production capacity (of about 430 tone abalone) at mining concession area 5. Additionally, land access to the coast and to these resources across most of mining concessions 5 and 6 reveals an ideal location for ranching activities. Although no quantitative data was available on marine mining activities in this region, limited marine mining activities have been observed (Snethlage Pers. Comm.). Although more marine mining data is required, this observation might suggest that the potential conflict between ranching and marine mining would be low in this area. Furthermore, access to the jetty at Hondeklipbaai offers additional access from the sea in the southern part of mining concession area 6 (Figure 5.7).

Abalone ranching areas evaluation

The experimental ranching area assigned to Port Nolloth Sea Farm (PNSF) along mining concession areas 5 and 6 was found to have the highest potential for abalone ranching production along the Namaqualand coastline (Table 5.4). This is mainly due to the extensive kelp bed resources, access by both land and sea, and the low level of potential conflict with mining. Divers could use the existing jetty at Hondeklipbaai for launching their boats for abalone ranching and harvesting procedures. Such activities could enhance the economy of the Hondeklipbaai development area, which has the highest unemployment level in the region (Mather 1999). Based on the estimated abalone production potential of the kelp beds (Tarr 1993), the total estimated production capacity of the Port Nolloth Sea Farm (PNSF) abalone ranching area is estimated at over 600 tones of abalone per year. This is about equal to the full combined potential production of the South African abalone farming industry (Hecht 1999). Distribution of the kelp beds resources reveals that large kelp bed areas are mostly located along the northern section of PNSF ranching area (Figure 5.9), implying that the abalone ranching potential is more limited in the south than in the north. Furthermore, the temporal dynamic of kelp beds abundance and location, which has been demonstrated by Bushing (1997), requires that aerial surveys should be an ongoing process. When such a database of kelp is established, GIS could be used to model temporal changes of kelp beds biomass and assist in resource management, and consequently, with planning and management of ranching abalone.

Additional potential for abalone ranching was identified within Port Nolloth North (PNN), Port Nolloth South (PNS), and Kleinsee South (KS) areas. PNN and PNS potential areas include access by the sea from Port Nolloth and the close proximity of rich kelp beds (Figure 5.9a). The experimental abalone ranching site at Port Nolloth used by Cook *et al.* (1999) validated the result. The high abundance of kelp beds, specifically in Port Nolloth South (PNS) area, suggests that habitat and food availability are not a limiting factor for abalone ranching activities (i.e. potential yield projection of abalone estimated for PNS areas is about 597 tons).

The Kleinsee South (KS) area has a short section of coastline of about 7km between the Port Nolloth Sea Farm north boundary and the high security-mining zone at Kleinsee (Figure 5.9b). Kleinsee South's potential area includes good supporting infrastructure (i.e. Kleinsee mining town) and access to a large portion of kelp bed situated in a small-protected bay. An experimental abalone ranching site within KS area, chosen by De Waal (2002), confirms the potential of this area for ranching abalone.

Table 5.4: A comparison of the potential for abalone ranching between the six mining concession areas, based on equally weighted criteria. Each criterion has been assigned an equal score, which is represented as an advantage (+) or disadvantage (-) for abalone ranching development. A total score and associated rank is then provided for each mining concession. Note the outstanding potential of mining concession areas 5 and 6 for abalone ranching.

Location	Region	North		Centre		**South**	
	Concession number	1	2	3	4	5	6
Criteria	Kelp bed availability	-	-	+	+	+	+
	Marine mining intensity (An indicator for potential conflict)	-	+	-	+	+*	+*
	Accessibility level (land/sea)**	-	-	0	0	+	+
	Flood risk	-	+	+	+	+	+
Output	Total score	-4	0	+1	+3	+4	+4
	Final ranking	5	4	3	2	1	1

* Snethlage pers. comm.

** Accessibility level score is presented by: land access (+), sea access only (0), no access (-)

Potential conflict evaluation

The need to integrate the ecological and economic factors is recognized as an essential element in the planning of an abalone ranching operation (Cook and Sweijd 1999, De Waal 2002). One essential economic factor in Namaqualand is associated with the impact of the marine mining activities on the environment. Hence, the aim of this analysis was to model the spatial dynamics of marine mining activities and its potential impact on kelp beds in Port Nolloth North (PNN) and Port Nolloth South (PNS) ranching areas.

Marine mining operations are localized and opportunistic activities, which unlike the land-based mining does not have clear geophysical boundaries for mining (i.e. such as "mined-out" areas) (Lane and Carter 1999). In the process of mining, marine habitats are modified (i.e. the shift and removal of sediments, and the cutting of kelp), which could lead to loss of the seeded abalone. The Mining Intensity Model (MIM) output demonstrated the cluster and uneven distribution of marine mining activities along the coastline. The MIM reveals that mining intensity is higher in PNN than in PNS abalone ranching areas. However, according to the Abalone Ranching Model (ARM) output, the ratio of intense marine mining found in kelp beds was much higher in PNS (43%) than in PNN (10%) area. Considering that PNN area has more mining and less kelp bed than PNS, this suggests that the marine mining activity is not related directly to kelp bed location.

The spatial impact of marine mining on the environment has been estimated to be minimal, with less then 0.01% per year of total marine mining concession being mined (Barkai and Bergh 1992, Lane and Carter 1999). Similarly, this study revealed minimal impact of marine mining within PNN and PNS near shore (i.e. surf zone and concession "A") areas on kelp beds. However, the localised nature of mining regardless of kelp bed positions implies that potential spatial conflict between mining and abalone ranching might be much higher in certain parts of the coastline then was previously suggested by Barkai *et al.* (1992) and Lane & Carter (1999).

Finally, although the ARM provides a simplified output of ecological and economic factors, this model, comprised of national natural resources and provincial mining activity data, is the first attempt to provide an insight into the spatial dynamics of this region.

In conclusion, abalone ranching in Namaqualand has high potential for development due to vast kelp bed areas along mining concessions 3-6. These concessions' potential abalone production is enormous, and is equal to the total production of land-based abalone farms in the country. Specific high potential areas identified along mining concessions 5 and 6 has been allocated to Port Nolloth Sea Farm (PNSF). Additional potential areas for abalone ranching identified along Port Nolloth town (Port Nolloth North and South) was found to be limited as a result of mining activity and the restricted access to the coast. Potential conflicts between marine mining activity and abalone ranching along Port Nolloth coastline were found to be minimal but very localized. This suggests that in some locations abalone ranching could result in a major conflict with marine mining activity. Hence, additional aerial surveys and fieldwork for habitat suitability assessments, and updated information on marine mining operations would be required to manage abalone ranching activity.

CHAPTER 6
General Discussion

The diverse conditions and needs of the South African mariculture sector provided a good setting for the development of the GIS. These conditions and needs were represented by the three case studies (i.e. chapter 3, 4, and 5), and resulted in three independent GIS analyses. Hence, the aims of this chapter were three-fold. Firstly, to evaluate the GIS outputs and their relevance for the South African mariculture sector planning process; secondly, to consider data and GIS method limitations; and thirdly, to provide some suggestions on how this GIS may be further developed and used as a planning tool for the development of mariculture in South Africa.

The relevance of the GIS outputs for mariculture planning in South Africa

The evaluation of the relevance of the GIS outputs for mariculture sector planning in South Africa was based on the ability of GIS to identify suitable areas for mariculture development. This in turn, is highly dependent on the GIS ability to evaluate the spatial constraints (i.e. biophysical, social, and economic) to development that have been identified by planners. Based on the South African coastal management policy, and a review of the literature, two important spatial constraints for developments were identified and addressed. They were competition among coastal users and access to the coast. These constraints were evaluated in each of the three case studies.

On the national scale (chapter 3), strong competition for space was most apparent along the KwaZulu-Natal coastline. About 75% of the provincial coastline is occupied - the north dominated by conservation areas and the south by urban development. As a result, KwaZulu-Natal Province was identified as having little potential for land-based mariculture development. Access to the coastline was the dominant constraint along the southern part of the Northern Cape Province coastline, the Wild Coast along the Eastern Cape Province coastline, and Maputaland along the KwaZulu-Natal Province coastline. The restricted access to these coastal areas implies additional limited potential for mariculture, and the need for appropriate development plans. An example of such plans is the recent Wild Coast Spatial Development Area plan of the Department of Economic

Affairs of the Eastern Cape Provincial government (Anon 2001), which may yet lead to a significant mariculture development along the Wild Coast.

The results of this GIS case study, therefore, provided the first holistic overview of the potential for land-based mariculture development along the entire South African coast. Ten potentially suitable areas were identified for land-based mariculture development. However, only three areas were identified with exceptionally high potential for mariculture development. These areas were in the vicinity of the urban centres of East London (Area 3) and Port Elizabeth (Area 4) in the Eastern Cape Province, and at Mossel Bay (Areas 5) in the Western Cape Province, and characterised by low spatial competition, and a minimal risk level for Harmful Alga Blooms (HAB) (Figure 3.6).

The main constraints evaluated in the national abalone ranching GIS analysis included the rocky coastline, Sea Surface Temperature (SST), conservation areas, and infrastructure availability. The final output in this case study revealed that the Western and Eastern Cape Provinces coastlines are prime areas for abalone ranching. Additional potential, identified within Areas 8 and 9 along the Northern Cape Province's coastline, was attributed to the lack of a natural abalone population and competing coastal uses (Figure 4.6). These results, confirmed by the present experimental abalone ranching activity and the proposed development areas for ranching in the west and east coasts, illustrate GIS' ability to evaluate specific mariculture development.

The ability of GIS to address constraints to mariculture development and to evaluate potential user conflict on a regional basis was further demonstrated for the Namaqualand coastline of the Northern Cape Province. The constraints and opportunities for development were identified by Britz *et al.* (1997) and Britz *et al.* (2002). Two independent analyses for potential land and marine-based mariculture development were undertaken to address these specific constraints and opportunities for development. These analyses were based on high-resolution data of the mining activities, security zones, and location of relevant infrastructure. The GIS successfully identified two high potential land-based development areas at Kleinsee (AK3 pump station) and Port Nolloth (Oubeep pump station). This result, in line with the mariculture sector development strategy plans by Britz *et al.* (2002), confirmed the suitability of GIS as a planning tool. Furthermore, marine-based analysis aimed to address the potential conflict between mining and abalone ranching, as identified by Lane and Carter (1999). This was based on the assumption that marine mining is not compatible with ranching abalone (i.e. mining has a negative impact on the kelp bed area, which is abalone habitat). As a result of available comprehensive marine mining and kelp bed databases, an Abalone Ranching Model (ARM) was developed in two potential abalone ranching areas. The ARM revealed a minimal and localised pattern of mining impact on kelp bed areas. This analysis illustrated how GIS can provide a compatible database framework into which different data can be integrated on a geo-referenced basis. In conclusion, this case study has shown that GIS is a valuable tool during the implementation phase of the Northern Cape regional mariculture sector development plan.

Mariculture development in South Africa has been strongly hampered by lack of institutional support and organizational capacity (Hecht 1996, Hecht 1999, Britz and Hecht 1999). This has resulted in the limited integration of social and economic data for mariculture development. Comprehensive databases and the use of GIS as an integrated planning tool have therefore been identified as a crucial requirement for South African mariculture planning (Anon 1998). The evaluation of the country's mariculture development potential based on an integrated database was therefore a fundamental principal for land-based and abalone ranching analyses in both national and provincial scales.

Overall, it can be concluded that GIS is a relevant and compatible tool for South African mariculture sector planning. However, several limitations were also identified in this study and are discussed next.

Data and method limitations

The quality of GIS output information is primarily determined by the quality of the input data. Evaluating data quality is therefore essential. Data quality can be evaluated in terms of accuracy. Accuracy is the degree with which recorded data positions and their attributes represents the true or real-world value (Chrisman 1991, Jones 1997, Von Meyer *et al.* 2000). In this study, the data quality limitations were attributed to low-resolution data and outdated information. Additional limitations in this study included oversimplification of the analysis, and the limited data for verifying the GIS results.

The national database (Chapters 3 and 4) contains various data with different resolution levels. This database was suitable for the assessment of the mariculture potential on the national scale. However, the use of the low-resolution data was also limiting. GIS is capable of incorporating different resolution levels of data. Nevertheless, any use of GIS must always be confined to the lowest-resolution scale of data, to ensure a meaningful output. Similarly, in this study the low-resolution data of Harmful Algal Bloom (HAB) outbreaks in South Africa are of little use on a scale below 1:3,000,000, which implies that if HAB data is used, this GIS database is limited only for the national scale. The use of the Sea Surface Temperature (SST) database is also restrictive. SST records do not provide continuous coverage but only present a general understanding of temperature patterns along the South African coastline. Although this was found to be sufficient for the national scale analysis, these records cannot provide sufficient detail for provincial planning on a local scale (i.e. below 1:3,000,000).

Data quality was further limited by outdated data. This includes the database on the recreational activity locations, which was published in 1984. Recreational activity is a dominant coast user along the entire South African coastline, and has a major impact on coastal development including mariculture. Since this data is outdated and yet fundamental, the data was only used to compare the proportion of recreational activity among the four coastal provinces. Hence, in order to perform a more accurate analysis, there is an urgent need to update this database by means of a comprehensive national survey.

Two analytical limitations of this GIS need to be discussed briefly. The first limitation includes the use of Boolean logic and arithmetic operations to analyse the interactions among coastal users, which is often characterised by fuzzy and indeterminate range. An example is the exclusion of all urban areas and their surrounding 2km buffer zone as non-compatible with mariculture, regardless of urban location and size. However, the abalone farming industry, which is the main land-based mariculture activity in South Africa, is established within some of the urban areas along the Western Cape Province coastline. This was the result of historical land ownership, and available infrastructure for development (e.g. such was the case with abalone farms established within the harbour area of Hermanus). Urban areas and their surroundings are therefore not all unsuitable for mariculture development. Some urban areas could offer potential opportunities for land-based mariculture provided they are located within compatible industrial areas, which will have a minimal impact (e.g. pollution) on mariculture. Hence, in this study, the interactions between urban areas and mariculture activities were oversimplified. This analysis therefore requires an improved model of interaction between urban areas and mariculture activities. An improved model could be based on an integration of additional data such as land zonation (provided by town planners), land unemployment levels, as well as land and property values (provided by estate agencies). An example of such an improved model could include a variable buffer zone size for each urban area, which is a function of population size (i.e. a potential indicator for low water quality due to sewage pollution).

The second limitation concerns confining of the analysis to a narrow coastal strip. Comprehensive analysis of the coastal zone includes not just the immediate coastal areas, but also the surrounding zones, also known as the Zone of Influence (ZOI) (Clark 1995). This is due to the coastline being influenced by the surrounding catchments. Nevertheless, most coastal zone analyses (including mariculture) have only been concerned with the immediate coastal areas. The scope of this study was limited to a 2km coastal zone strip, without any consideration of the upper catchments activities such as agriculture and/or industry and their impacts (e.g. river pollution runoff) on the coast.

Additional ZOI for mariculture development such as distance to the local market, and associated cost of transportation, could improve the national GIS analysis.

The final major limitation in this study concerns the verification of the GIS outputs. Ideally, GIS outputs require verification by ground truthing or independent surveys. Since ground truthing was beyond the scope of this study, the outputs were verified using previous published surveys (Cowley *et al.* 1998), and the location of existing mariculture operations (e.g. abalone, prawn and oyster farms). Although this information provided only a very basic verification, a comprehensive regional ground exercise is still required to verify the relevance of the GIS outputs for future mariculture development plans.

Conclusions and future suggestions

In conclusion, this study has established a GIS that provides information for planners on the mariculture development potential along the South African coastline. This includes primary information on potential conflicts between mariculture development and other coastal users. Furthermore, this study addressed the diverse requirements of mariculture planning in South Africa. These conditions included the early stage of a national development plan, and the development of a comprehensive regional mariculture sector plan in the Northern Cape Province. The results of this study successfully demonstrated the capacity of GIS to address the requirements and scale of both the national and regional plans (Figure 6.1). This included the GIS preliminary spatial information for the future national mariculture stocktaking and diagnostic survey (Figure 6.1 **a** and **b**), and specific information to assist in the choice of development strategy for Namaqualand mariculture sector planning (Figure 6.1 **c**).

Case study 1
(Chapter 3)

a

Case study 2
(Chapter 4)

b

Case study 3
(Chapter 5)

c

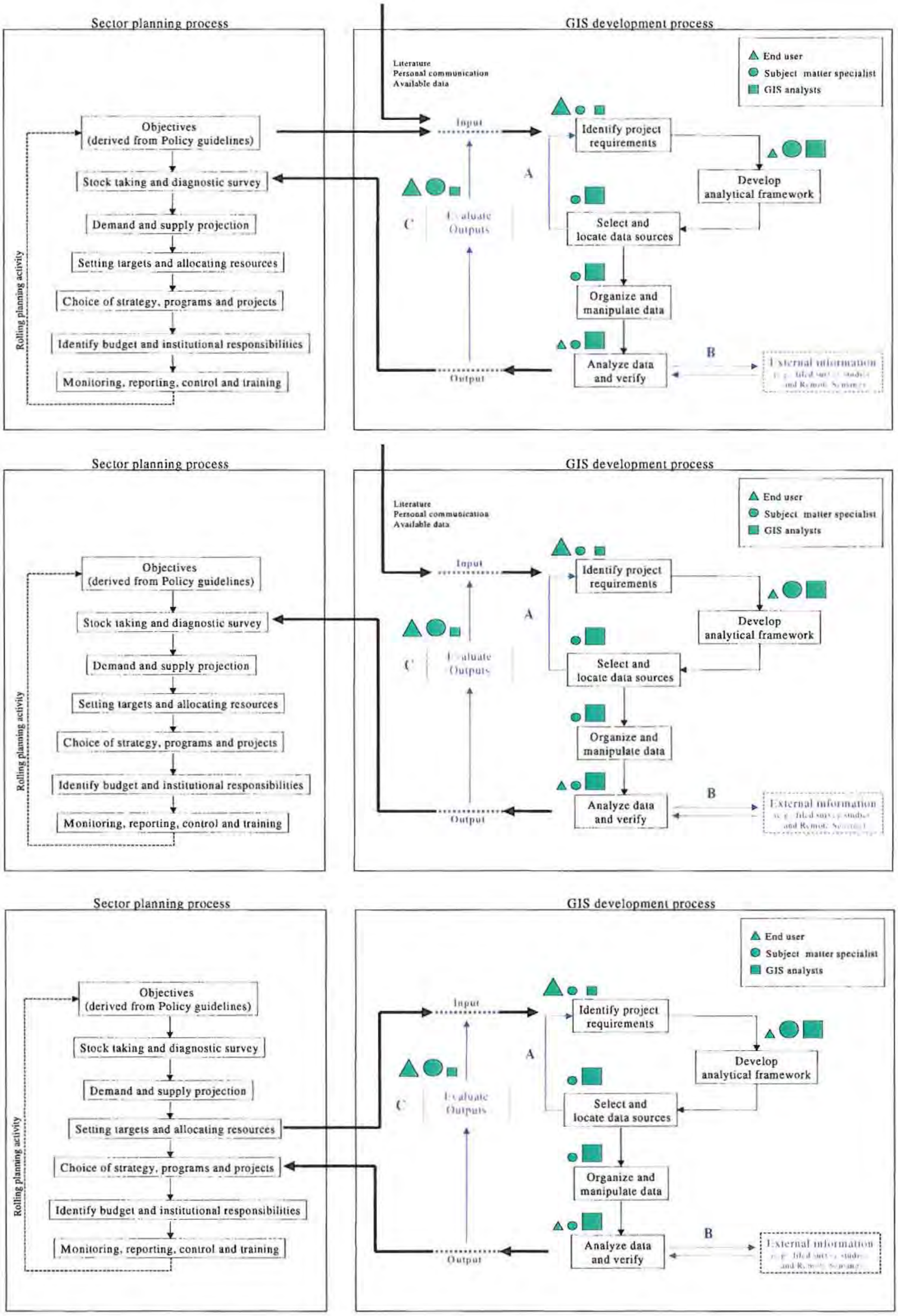

Figure 6.1: The interactions between the processes of sector planning and the development of GIS in: a) National land-based mariculture (chapter 3), b) National abalone ranching (chapter 4), and c) Namaqualand land and marine-based mariculture (chapter 5).

Hence, this study has successfully demonstrated the compatibility, and adaptability of GIS as a Spatial Decision Support System (SDSS) tool for South African mariculture sector planning.

However, for GIS to become a successful application in the South African mariculture sector planning, it is vital that the GIS is not developed in isolation but is integrated with planning processes. This should be based on national and provincial governments' long-term commitments for developing GIS as a planning and management tool, including institutional, resources, and budget allocations. GIS should therefore be developed through continuous interactions between all mariculture sector stakeholders, including the national mariculture decision-makers group and coastal zone planners (i.e. Coastal Management Policy Program (CMPP) office, Department of Environmental Affairs and Tourism), provincial government planning authorities, farmers associations (e.g. Mariculture Association of South Africa (MASA) and Abalone Farmers Association of South Africa (AFASA)), and mariculture specialists.

Successful use of GIS would therefore be much dependent on the incorporation of GIS outputs in the decision-making procedure for mariculture development, and its ability to be part of a comprehensive South African Integrated Coastal Zone Management GIS from which it can receive and provide data.

REFERENCES

AGUILAR-MANJARREZ, J. and NATH, S. S. 1998. A strategic reassessment of fish farming potential in Africa. *CIFA Technical Paper 32.* Roma; FAO: 170 pp.

AGUILAR-MANJARREZ, J. and ROSS, L. G. 1995. Geographic information systems (GIS), environmental models for aquaculture development in Sinaloa, Mexico. *Aquaculture International.* 3; 103-115

ALI, C. Q., ROSS, L. G., and BEVERIDGE, M. C. M. 1991. Microcomputer spreadsheets for the implementation of geographic information systems in aquaculture: a case study on carp in Pakistan. *Aquaculture.* 92; 199-205

ANON. 1994. Alexkor Environmental Management Programme. *Vol. 2. Specialist study report.* EMAS-C94037 (2). Stelenbosch. CSIR

ANON. 1998. *Northern Cape Development Strategy.* Department of Economic Affairs and Tourism, Northern Cape. Kimberley. 82 pp.

ANON. 1998. The Sea and the Coast Programme. *The fifth meeting of the Trust Advisory Panel to assess research plans within the Mariculture Thrust.* South African Network for Coastal and Oceanic Research (SANCOR)

ANON. 1999. *Information update for the TNT products.* MicroImages. Lincoln, Nebraska

ANON. 1999. *White Paper for Sustainable Coastal Development in South Africa.* Department of Environmental Affairs and Tourism (DEAT). 134 pp.

ANON. 2000 Government gazette regulation no. 6978 vol. 426. Pretoria

ANON. 2000. *South African airways (SAA), express, and airlink timetable.* Johannesburg

ANON. 2001. *Application: establishment of an abalone grow-out facility on farm Pringle cove no. 559/95, Caledon, an identified activity in term of section 21 of the environment conservation act, 1989 (Act no. 73 of 1989).* DECAS, Western Cape Province.

ANON. 2001 Eastern Cape Provincial gazette No. 720 vol.18. 20 pp.

ATTWOOD, C., MANN, B. Q., BEAUMONT, J., and HARRIS, J. M. 1997. Review of the state of marine protected areas in South Africa. *South African Journal of Science.* 18; 341-367

BAILLY, D. and PAQUOTTE, P. 1996. Aquaculture and Environmental Interactions in the Perspective of Renewable Resource Management Theory. *Coastal management.* 24; 251-269

BARG, U. C. 1992. Guidelines for the promotion of environmental management of coastal aquaculture development. *FAO Fisheries Technical Paper.* 328; 1-43

BARKAI, A. and BERGH, M. O. 1992. *The effects of marine diamond pumping operations on the littoral and shallow sublittoral benthos along the South African west coast, Namaqualand region, with special attention to possible effects on the rock lobster resource: a pilot study.* Department of Zoology University of Cape Town. Cape Town. 43 pp.

BARKAI, R. and GRIFFITHS, C. L. 1986. Diet of the South African abalone *Haliotis midae. South African Journal of Marine Science.* 4; 37-44

BARTLETT, D. 1993. Space, time, chaos and coastal GIS. *Proceedings International Cartographic Congress.* Cologene, Germany: 539-551.

BARTLETT, D.1994. *GIS and the coastal zone: Past, present and future.* Information and Education Committee publication. Cork. 36 pp.

BARTLETT, D. 2000. Working on the frontiers of science: Applying GIS to the coastal zone. In *Marine and coastal Geographic Information Systems.* Wright, D. J. and Bartlett, D. (Eds.). Taylor and Frances. Cork: 11-21

BEVERIDGE, M. C. M., ROSS, L. G., and MENDOZA, Q. M. 1991. Geographic Information systems (GIS) for coastal aquaculture site selection and planning. In *Ecology of marine aquaculture: a workshop in marine aquaculture.* Koop, K. (Eds.). International Foundation For Science. Stockholm: 26-47

BLACK, E. A. and TRUSCOTT, J. 1994. Strategies for regulation of aquaculture site selection in coastal areas. *Journal of Applied Ichthyology.* 10; 295-306

BRANCH, G. M., EEKHOUT, S., and BOSMAN, A. L. 1990. Short-term effects of the 1988 Orange River floods on the intertidal rocky-shore communities of the open coast. *Transactions of the Royal Society of South Africa.* 47(3); 331-354

BRANCH, G. M., GRIFFITHS, C. L., BRANCH, M. L., and BECKLEY, L. E. 1994. *Two oceans: A guide to the marine life of Southern African.* National Book Printer. Cape Town. 359 pp.

BRINK, D. 2002. Aquaculture production in South Africa. Afma matrix 11(2); 26-31

BRITZ, P. J., DE WAAL, S. W. P., and GODFREY, B. P. 2002. Management Plan for the Eastern Cape Abalone Resource. Rhodes University. Grahamstown. 50 pp.

BRITZ, P. J. and HECHT, T. 1997 *Northern Cape Province Base Line Sectoral Studies: Fishing and Mariculture.* Rhodes University. Grahamstown. 64 pp.

BRITZ, P. J. and HECHT, T. 1999. Critical needs for aquaculture sector development in South Africa. In *Proceedings of National Workshop on Planning for Sustainable Development of Mariculture in South Africa.* Stenton-Dozey, J. (Ed.). DEAT. Cape Town; 18-23.

BRITZ, P. J., HECHT, T., and MANGOLD, S. 1997. Effect of temperature on growth, feed consumption and nutritional indices of *Haliotis midae* fed a formulated diet. *Aquaculture.* 152; 191-203

BRITZ, P. J., SAUER, W., and MATHER, D. 2002. *Northern Cape Province Fishing and Mariculture Sector Plan.* Rhodes University. Grahamstown. 48 pp.

BRITZ, P. J., SAUER, W. H. H., MATHER, D., OELLERMAN, L. K., COWLEY, P. D, TER MORSHUIZEN, L., and BACELA, N. 2002. Baseline study of the utilisation of living marine resources in the Eastern Cape province. Rhodes University. Grahamstown.

BROUWER, S. L., MANN, B. Q., LAMBERTH, S. J., SAUER, W. H. H., and ERASMUS, C. 1997. A survey of the South African shore-angling fishery. *South African Journal of Marine Science*. 18; 165-177

BRUTON, M. N. 1985. The Potential of Mariculture in South Africa. *Ecosystem Programmes: Water Quality Maintenance in Intensive Aquaculture*. Grahamstown; FRD: 16-18

BRUTON, M. N. and SAFRIEL, O. 1985 The selection and improvement of candidate species for aquaculture in South Africa. *Ecosystem Programmes: Water Quality Maintenance in Intensive Aquaculture*. Grahamstown; FRD: 8-16 pp.

BURBRIDGE, P., HENDRICK, V., ROTH, E., and ROSENTHAL, H. 2001. Social and economic policy issues relevant to marine aquaculture. *Journal of Applied Ichthyology*. 17; 194-206

BUSHING, W. W. 1997. GIS-Based Gap Analysis of an existing Marine Reserve Network around Santa Catalina Island. *Marine Geodesy: an international journal of ocean survey mapping and sensing*. 22 (2-3); 205-234

CANESSA, R. R. 1998 GIS decision support for integrated coastal management. *Oceans Conservation Report Series. Can. Tech. Rep. Fish Aquat. Sci. 2212*. Department of Fisheries and Oceans. Ottawa, Ontario

CHARISMAN, N.1997. *Exploring geographic information system*. John Wiley & Sons. New York.

CHO, Y. 2001. Building the information-based for aquaculture policy-making, planning, and management. In *Aquaculture in the Third Millennium: Technical Proceeding of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000*. Subasinghe, R. P., Bueno, P., Phillips, M. J., Hough, C., McGladdery, S. E., and Arthur, J. R. (Eds.). NACA & FAO. Bangkok, Thailand. 121-128.

CHRISMAN, N. R. 1991. The error component in spatial data. In *Geographic Information Systems: Principles and applications.* Maguire, D. J., Goodchild, M. F., and Rhind, D. W. (Eds.). John Wiley & Sons Inc. New York 165-174

CHUA, T. E. 1993. Environmental management of coastal Aquaculture development. In *Environment and Aquaculture in Developing Countries.* ICLARM: 199-212.

CLARK, J. R.1995. *Coastal Zone Management hand book.* CRC Press. Boca Raton. 694 pp.

COOK, P. 1996. Abalone farming in South Africa: Current research directions. In *Aquaculture '94. Proc. Aquacult. Assoc. sthn. Afr.* Cook, P. and Uys, W. (Eds.). Rhodes University. Cape Town. 154 pp.

COOK, P. and SWEIJD, N. 1999. The potential for abalone ranching and enhancement in South Africa. In *Stock enhancement and sea ranching.* Howell, B. R., Moksness, E., and Svasand, T. (Eds.). Fishing news books: 453-467

COWLEY, P. D, WHITFIELD, A. K., and HECHT, T. 1998 Estuarine mariculture in South Africa: strategic options for development and management. *South African Network for coastal and oceanic research: occasional report no. 4.* Pretoria; SANCOR. 80 pp.

DANGERMOND, J. 1990. A classification of software components commonly used in Geographical Information System. In *Introduction reading in GIS.* Pequet, D. J. and Marble, D. F. (Eds.). Taylor and Francis. New York: 30-51

DE WAAL, S. W. P. 2002. *Factors influencing the ranching of the abalone species Haliotis Midae along the Namaqualand coast of South Africa.* PhD thesis, University of Cape Town. 241 pp.

DURAND, H., GUILLAUMONT, B., LOARER, R., LOUBERSAC, L., HERAL, M., and PROU, J. 1994. An example of GIS potentiality for coastal zone management: preselection of submerged oyster culture areas near Marennes-Oleron (France). In *Earsel workshop on 'Remote sensing and GIS for coastal zone management'.* Rijkswaterstaat, Survey Department. Delft: 105-113.

EVANS, L. 1993. The establishment of a commercial *Penaeus monodon* prawn farm in Zululand, South Africa. In *Proceedings of the Aquaculture Association of southern Africa.* Hecht, T. and Britz, P. J. (Eds.). Rhodes University. Grahamstown: 109-116.

FIJEN, A. P. 1988 A review of marine disposal practice in South Africa. *Water Research Commission technical report no. 213/1/88.* CSIR: 1-51

FUCHS, J., DURAND, H., LOUBERSAC, L., PROU, J., and MOREL, Y. 1995. GIS potential for management of living resources in the coastal zone: examples in France and French Polynesia. In *The conference on Remote Sensing and GIS for Environmental Resources Management: June 6-8.* Jakarta: 1-10.

GENADE, A. B. 1984. The present status of mariculture in South Africa. *Aquaculture South Africa. Occ. Rep. Ser. Ecosystem Progs. Proceedings of a joint symposium by the Council for Scientific and Industrial Research and the South African Agriculture Union.* FRD, CSIR. Pretoria: 12-15

GODFREY, B. P. 2003. *The potential of abalone stock enhancement in the Eastern Cape Province of South Africa.* MSc thesis, Rhodes University. 163 pp.

GOULLETQUER, P. and HERAL, M. 1997. Marine molluscan production trends in France: from fisheries to aquaculture. *NOAA Tech. Rep. NMFS 129*; U.S. Dep. Commer.: 137-164

GREENWOOD, C. and TAUNTON-CLARK, J. 1994. *Time series of monthly mean sea temperatures around the South African coast.* Sea Fisheries Research Institution internal report

GRITA, F. 1997. GIS analysis for the assessment of fish farming potential in Latin America. *FAO technical report.* Roma

HAUCK, M and SWEIJD, N. 1999. A case study of abalone poaching in South Africa and its impact on fisheries management. *Journal of Marine Science*. 56; 1024-1032

HECHT, T. 1996. The need for an aquaculture development plan for South Africa. In *Aquaculture '94. Proc. Aquacult. Assoc. sthn. Afr.* Cook, P. and Uys, W. (Eds.). Rhodes University. Grahamstown. 154 pp.

HECHT, T. 1999. A perspective on South African Aquaculture. In *Proceedings of National Workshop on Planning for Sustainable Development of Mariculture in South Africa.* Stenton-Dozey, J. (Eds.). DEAT. Cape Town: 24-33.

HECHT, T. and BRITZ, P. J. 1990. *Aquaculture in South Africa: History, status, and prospective.* NMB Printers. Pretoria. 58 pp.

HECHT, T. and BRITZ, P. J. 1992. The current status, future prospects and environmental implications of mariculture in South Africa. *South African Journal of Science.* 88(June); 335-342

HOFFMAN, L.C., SWART, J. J., and BRINK, D. 2000. The 1998 production and status of aquaculture in South Africa. *Water South Africa* 26(1); 133-135

IBREKK, H. O., KRYVI, H., and ELVESTAD, S. 1993. National assessment of the suitability of the Norwegian coastal zone and rivers for aquaculture (LENKA). *Coastal management.* 21; 53-73

JACKSON, L. F. and LIPSCHITZ, S.1984. *Coastal Sensitivity Atlas of Southern Africa.* National Book Printers. Cape Town. 33 pp.

JONES, C. B.1997. *Geographic Information Systems and computer cartography.* Longman. Singapore.

KAPETSKY, J. M., MCGREGOR, L., and NANNE, E. H. 1987. A geographic Information system to plan for Aquaculture: A FAO-UNEP/GRID study in Costa Rica. *FAO fisheries technological paper no.287.* 287; 242-247

LANDMAN, R. 2001. Amatikulu prawns. *Aquaculture Association of Southern Africa Newsletter.* 2(4); AASA

LANE, S. B. and CARTER, R. 1999. *Generic environmental management programme for marine diamond mining off the west coast of South Africa.* Marine Diamond Mines Association. Cape Town

LEE, D. O. C. and WICKINS, J. F.1992. *Crustacean Farming.* Blackwell Scientific Publications. London. 392 pp.

LEVINGS, C. D., ERVIK, A., JOHANNESSEN, P., and AURE, J. 1995. Ecological criteria used to help site fish farms in Fjords. *Estuaries.* 18[1]; 81-90

LOUWRENS, K. 2001 Salmon farm at Gansbaai gets the green light. *Aquaculture Association of Southern Africa Newsletter.*2 (4): 9-9

MACKENZIE, A. G. 1996. Working towards closure: Environmental management at Namaqualand (diamond) mines. Internal report. Unpublished

MAGUIRE, D. J. 1991. An overview and definition of GIS. In *Geographical Information Systems: principles and applications.* Maguire, D. J., Goodchild, M. F., and Rhind, D. W. (Eds.). John Wiley & Sons Inc. New York: 9-43

MALAN, N. 1999. Coastal Management Policy Programme (CMMP): Draft White Paper for sustainable coastal development in South Africa. In *Proceedings of National Workshop on Planning for Sustainable Development of Mariculture in South Africa.* Stenton-Dozey, J. (Ed.). DEAT. Cape Town; 40-44.

MATHER, D. 1999. Socio-economic impact assessment and baseline study: Northern Cape Province fishing and mariculture sector development. Rhodes University, Grahamstown. 70 pp.

MEADEN, G. J. and DO CHI, T. 1996 Geographic information systems; applications to marine fisheries. *FAO fisheries technical paper no.* 356. FAO. Roma

MCHARG, I. L. 1969. *Design with nature.* Natural History Press. New York. 198 pp.

NASH, C. E.1995. *Aquaculture Sector Planning and Management.* Fishing News Books. Rome. 310 pp.

NATH, S. S., BOLTE, J. P., ROSS, L. G., and AGUILAR-MANJARREZ, J. 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquaculture Engineering.* 23; 233-278

PAP/RAC. 1996 Approaches for zoning of coastal area with reference to Mediterranean aquaculture. *PAP-10/EAM/GL.* Croatia. 35 pp.

PAYNE, J. L. 2000. Advancing coastal resource decision-making with information and technology. *GeoCoast*. 1(1); 1-14

PHENG, K. S., PAW, J. N., and LOO, M. 1992. The use of remote sensing and geographic information systems in coastal zone management. In *Integrative framework and methods for coastal area management: ICLARM Conf. Proc.* Chua, T. E. and Scura, L. F. (Eds.): 107-131.

PILLAY, T. V. R.1992. *Aquaculture and the Environment*. Fishing News Books. Oxford. 189 pp.

PITCHER, G. C. 1998 Harmful algal blooms of the Benguela current. National Book Printers. Cape Town 20 pp.

ROBINSON, A. R., MORRISON, J. L., MUEHRCKE, P. C., KIMERLING, A. J., and GUPTILL, S. C. 1995. *Element of cartography*. John Wiley & Sons. New York.

ROSS, L. G., MENDOZA, Q. M., and BEVERIDGE, M. C. M. 1993. The application of geographic information system to site selection for coastal aquaculture: an example based on salmonid cage culture. *Aquaculture*. 112; 165-178

SAMPSON, M. R., BRITZ, P. J., BOOTH, A. J., and ANDERSON, R. J. 2001. *A comparison of manual and GIS methods to estimate kelp biomass on the Northern Cape coast of South Africa.* Proceedings of the First International Symposium on Geographic Information System (GIS) in Fishery Science (Seattle, Washington, USA:2-4 March 1999). Nishida, T., Kailola, P. J., and Hollingworth, C.E. (Eds.). Seattle: 157-166

SCHUMAN, E. H. 1998. The coastal ocean off southeast Africa, including Madagascar coastal segment. In *The global coastal ocean: Regional studies and syntheses*. Robinson, A. R. and Brink, K. H. (Eds.). John Wiley&sons. New York

SCOTT WILSON PLANNING AND DEVELOPMENT RESOURCES. 1998. *Fourth interim report NCDC and EDU-DEAT*. 4; 37 pp.

SHAHID, M. A., SAYEED, A., HOSSAIN, T., RAHMAN, H., SARKER, M. H., and AHMED, A. N. 1997. Remote Sensing and GIS for Suitable Shrimp Farming Area Selection in Bangladesh. *Journal of Remote Sensing and Environment.* 1; 27-41

STENTON-DOZEY, J. 1999. Guidelines for Mariculture development. In *Proceedings of National Workshop on Planning for Sustainable Development of mariculture in South Africa.* Stenton-Dozey, J. (Ed.). DEAT. Cape Town; 131-143.

TARR, R. J. Q. 1993. *Stock assessment, and aspects of the biology of the South African abalone, Haliotis Midae.* MSc. thesis, University of Cape Town. 156 pp.

TARR, R. J. Q. 2000. The South African abalone *(H. midae)* fishery: a decade of challenges and change. In *Workshop on Rebuilding Abalone Stocks in British Columbia.* Cambell, A. (Ed.). Can. Spec. Publ. Fish. Aquat. Sci; 32-40.

TAUNTON-CLARK, J. and SHANNON, L. V. 1988. Annual and interannual variability in the South-east Atlantic during the 20th century. *South African Journal of Science.* 6; 97-106

VON MEYER, N., FOOTE, K. E., and HUEBNER, D. J. 2000. Information quality consideration for coastal data. In *Marine and Coastal Geographic Information Systems.* Wright, D. J. and Bartlett, D. (Eds.). Taylor & Francis; 295-308

WALKER, P. A. and YOUNG, M. D. 1997. Using integrated economic and ecological information to improve government policy. *International Journal of Geographical Information Science.* 11(7); 619-632

WOOD, A. D. and BUXTON, C. D. 1996. Aspects of the biology of the abalone Haliotis midae (Linne, 1758) on the east coast of South Africa. 1. Feeding biology. *South African Journal of Marine Science.* 17; 61-68

Appendix A: Boolean logic and arithmetic operations

The ability to search for locations characterized by a combination of phenomena is one of the fundamental features of GIS. The process of overlay analysis used in such searches to determine suitable sites for a particular purpose is primarily based on Boolean logic operators. Boolean logic operators consisting of AND, OR, NOT and exclusive OR (XOR) produces results of either true or false (Figure 1). These operations could be combined with arithmetic operators (Table 1). Additional spatial searches can be based on the relation database between the attributes (non-graphic) and their graphic features. This search can be generated with use of Spatial Manipulate Language (SML) and arithmetic operator.

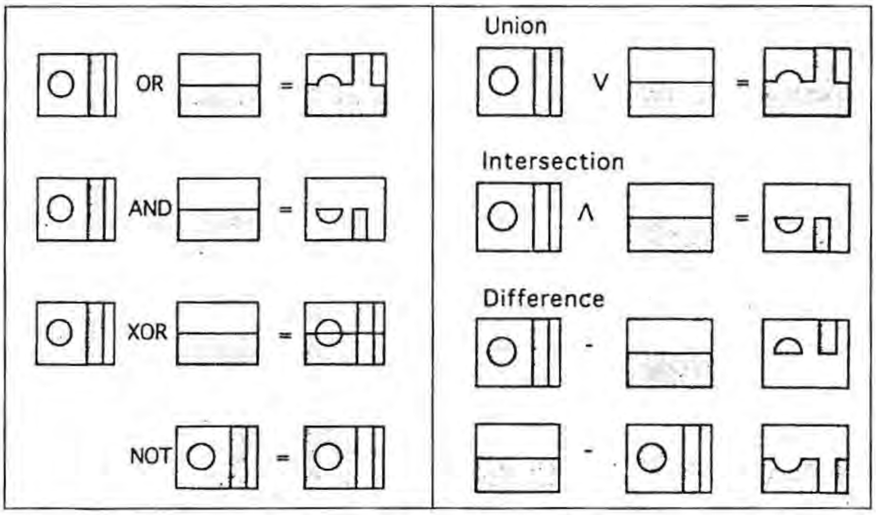

Figure 1: Boolean and set operators can be used to combine areas in spatial analysis. Note that these operators can be used in various combinations with arithmetic operators.

Table 1: Relation and algebraic operations that may be used to construct logical expression to search the GIS database.

Arithmetic operations	
Operation	Description
$a > b$	Greater than
$a < b$	Less then
$a = b$	Equals
$a \geq b$	Greater than or equal to
$a \leq b$	Less then or equal to
$a \neq b$	Not equal
$A + b$	Addition
$A - b$	Subtraction
$A \times b$	Multiplication
A / b	Division
b^a	Exponentiation

Appendix B: The Spatial Manipulation Language (SML) script used in the GIS program (TNTMips©) to generate the Abalone Ranching Model (ARM).

Spatial Manipulate Language (SML) is a programming language that allows writing scripts that operate on the spatial data objects. Using relational arithmetic operation (e.g.: equal "=" and greater then "><") in the SML basic relevant element were selected and extracted into a new layer. The following SML was used to generate the ARM:

```
GetInputRasters(Mining,Kelp)
GetOutputRaster(Result,Numlins(Mining),NumCols(Mining),"8-bit unsigned")
CopySubobjects(Mining,Result)

Dist1=20

foreach Mining
if (((Mining<=dist1) and (Kelp==0)) then Result=1
else
if (((Mining>dist1) and (Kelp==0)) then Result=2
else
if (((Mining<=dist1) and (Kelp==1)) then Result=3
else
if (((Mining>=dist1) and (Kelp==1)) then Result=1
else

Result=0

SetNull(Result,0)
CreatePyramid(Result)
CloseRaster(Result)
CloseRaster(Mining)
CloseRaster(Kelp)
```