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**EMPIRICAL EVALUATION OF THE EFFECTIVENESS OF  
SOUTH AFRICA'S MARINE PROTECTED AREA NETWORK  
IN REPRESENTING FISH COMMUNITIES**

**by**

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## **PLAGIARISM DECLARATION**

I know the meaning of plagiarism and declare that all the work in the dissertation, save for that which is properly acknowledged, is my own.

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## ABSTRACT

The World Summit 2002 on Sustainable Development (WSSD) as well as the IUCN's fifth World Parks Congress recommended the establishment of a *representative* network of marine protected areas by 2012. South Africa as a signatory Party is expected to comply with these recommendations. Previous studies have assessed the representation of fish species throughout South Africa's MPA network. However, none of these studies considered quantitative survey data. In this study, fish community structure as sampled by shore angling, trawling, boat-based line-fishing and seine netting (in estuaries), was compared across the EEZ of South Africa, including sites in designated MPAs. Multivariate statistics were used to assess the extent to which MPAs represent the full range of fish communities in South African waters. Results show there is an increase in fish diversity from west to east along the South African coast. Three major biogeographic zones were described based on fish communities; the West Coast, South Coast together with the East Coast and the north East Coast. South African MPAs currently collectively represent less than 50 percent of the fish community structure as measured by fourth root transformed Bray-Curtis similarity. The percentage of representativity in MPAs of the fish communities sampled by each fishing technique was as follows: 44 percent of the communities sampled by shore angling, 41 percent of the communities sampled by boat based line-fishing, nine percent of estuarine communities sampled by seine netting and four percent of the communities sampled by trawling. The West Coast fish communities had the lowest level of representation in MPAs. Estuarine protection is also very low in South Africa. Testing for representativeness through quantitative, multi-gear data seems to be more appropriate, since that it is based on discrete sampling methods, it allows for repetition and it gives a quantitative measure to representativity.

## CHAPTER I

### **General introduction to marine conservation planning in South Africa**

A review of the state of the marine fishery resources by the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) in 2007 estimated that 19 percent of the world's fish stocks were overexploited and nine percent were depleted or in the process of recovery from depletion; 52 percent were fully exploited, thus close to their maximum sustainable limits. According to the FAO at least 548 marine species groups are exploited globally (FAO 2005). In 2006, global marine capture (includes all fishing types) was 81.9 million tons, in addition marine aquaculture production added up to 20.1 million tons (FAO 2008). The review concluded that of the world's fish stocks, for which information was available, 80 percent were fully exploited or overexploited (FAO 2008). It is clear that over-exploitation has become the greatest threat to the oceans' ecosystems and it has been recognized by many authors as a mayor issue which has to be dealt with as soon as possible (Attwood et al. 1997a; Attwood et al. 1997b; Crain et al. 2009; Dee Boersma & Parrish 1999; Hockey & Branch 1997; Jackson et al. 2001; Pauly et al. 2002; Rosenberg 2003; Sumaila et al. 2000).

There is a high degree of trophic connectivity between organisms in the marine environment. Most fisheries target larger individuals due to their economic value, thus removing high trophic level organisms, consequently altering the structure of the food web, causing increases of some species and potential decline in others (Bascompte et al. 2005; Law 2000). Removing a large amount of top predators from the food chain is not the only alteration that fishing causes to the oceans' ecosystems, there is also habitat transformation that accompanies certain fishing practices, which changes the ecosystems' structure and functioning (Auster et al. 1996; Collie et al. 2000; Crain et al. 2009; Pauly et al. 2002). The

various kinds of fishing techniques have different effects on the ecosystems, some more damaging than others, but all of them one way or another modify natural ecosystems (Auster et al. 1996; Collie et al. 2000; Dee Boersma & Parrish 1999; Kura et al. 2004; Sumaila et al. 2000). For example, bottom trawling has been reported to have negative effects on benthic communities, such as decreasing diversity, density and abundance of benthic fauna, changing the physical habitat structure, usually by reducing complexity, as well as causing changes in community composition (Jennings et al. 2001; Thrush & Dayton 2002; Watling & Norse 1998). Fishing can also have an impact on the evolution of phenotypic traits, such as growth and maturation in fish, due to directional selection (Law 2000).

Fishing however, is not the only threat. Coastal development also poses a great threat to the world's oceans; with coastal populations growing, the pressure on the marine environment increases (Crain et al. 2009; Griffis & Kimball 1996). Draining of coastal wetlands, exploitation and destruction of mangroves, pollution, and in general habitat loss or degradation have put many coastal ecosystems in great danger (Crain et al. 2009; Whitfield 1999). High levels of tourism can also deteriorate the ecosystems, for example intensive diving and its related activities has been shown to have significant ecological impacts on coral reefs (Harriott et al. 1997; Zakai & Chadwick-Furman 2002). In addition, as development continues, pollution becomes harder to control. There are many point sources of pollution, which deposit chemical and biological pollutants into the ocean. A few examples are sewage waste, heavy metals, chemicals used for agriculture and oils (Dee Boersma & Parrish 1999; Williams 1996). The world's oceans are also affected by regional and global pollutants which are very difficult to control due to their distant origin (Dee Boersma & Parrish 1999). Various mining practices have been found to have a large impact on the marine environments, causing deterioration of the environment, as well as mortality

of sensitive species and other ecological effects (Castilla & Nealler 1978; Correa et al. 1999).

Marine alien invasive species can also be added to the factors that place the marine ecosystems at high risk (Molnar et al. 2008). They can compete with local communities, or potentially introduce diseases, thus diminishing the resilience of those local communities, making them more susceptible to other environmental disturbance (Bax et al. 2003). With an increasing amount of trade and tourism around the globe, the number of alien species that can potentially be introduced, for example via ship ballast water, is growing, and so does the risk of them establishing and altering the natural functioning of the ecosystems (Bax et al. 2003). In addition, aquaculture practices places marine ecosystems under immense pressure. It has been shown that organic matter from aquaculture farms can alter the conditions on the sea bed, such as the oxygen and nutrient availability, causing a decrease in benthic diversity. The creation of fish-farms has also resulted in destruction of important coastal habitats (Tovar et al. 2000; Wu 1995; Wu et al. 1994).

One approach to marine conservation that has grown in popularity is the creation of Marine Protected Areas (MPAs). The use of MPAs has been recommended by several conservation organizations as a conservation and management tool for marine ecosystems. The International Union for Conservation of Nature (IUCN) defines an MPA as 'any area of intertidal or sub tidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment'(Kelleher & Kenchington 1992). There is a high degree of variation among MPAs, they can differ in the types and levels of protection, management goals and objectives, size and public support, among many others (Lubchenco et al. 2003; Palumbi 2001). Palumbi (2001) recognizes three broad kinds of MPAs: those designed to enhance fisheries, those that focus on maintaining biological diversity within the

marine ecosystems, and “special-feature” MPAs, which aim to conserve specific areas important for certain life history stages or for cultural reasons. MPAs can be categorized according to the IUCN’s categories described in the *Guidelines for Protected Area Management Categories* (IUCN 1994) (Table 1). Not every MPA fits exactly within a category, however, the categories can be applied generally and can help clarify the objectives of the MPAs (Dudley 2008; Kelleher & Recchia 1998).

According to Hockey and Branch (1997), MPAs have three main functions: protection of the ecosystems, fisheries management, in order to improve stock status in adjacent areas, and utilization by humans which do not compromise the conservation objectives. Kelleher (1999) recognizes two main reasons to declare an MPA: for the protection of habitat and biodiversity and to sustain viable fisheries. Attwood *et al.* (1997a) argue that MPAs are key for the preservation of diverse and functional ecosystems, by excluding development from representative areas and by managing the utilization of sensitive habitats. However, as Kelleher (1999) and Lubchenco *et al.* (2003) stress, MPAs should be used in conjunction with integrated management regimes, in order to successfully conserve the marine ecosystems.

There are approximately 5 000 MPAs around the world, covering about 2.58 million km<sup>2</sup> of the world’s oceans, which amounts to 0.717 percent of the oceans. The number of MPAs continues to grow around the globe. However, only 0.08 percent of the world’s ocean area is within ‘no-take’ areas. In addition, the existing MPAs are not evenly distributed across regions and their distribution is biased towards coastal areas (Laffoley *et al.* 2008; Spalding *et al.* 2008; Wood *et al.* 2008). Spalding *et al.* (2008) found that more than half of the world’s 232 ocean ecoregions (according to the biogeographic classification for the world’s coastal and shelf areas by Spalding *et al.* (2007)), contain less than 1 percent of their area under protection with MPAs.

The South African network of MPAs consists of 22 gazetted MPAs with different types of management including 'no-take' areas, as well as areas in which certain kinds of extraction and uses are permitted (Lombard et al. 2004). The marine component of the National Spatial Biodiversity Assessment by Lombard et al. (2004) presented a spatial evaluation of the existing MPAs in South Africa. The results showed that of the total surface area within the exclusive economic zone (EEZ), which covers an area of 1 071 883 km<sup>2</sup>, only 0.16 percent falls into 'no take' MPAs, 0.23 percent is under other types of MPAs and 98.65 percent is not under protection by an MPA. The South African coastline is 3 650 km long, of which 23 percent is under MPAs; however, only nine percent of this is 'no-take' MPAs (Lombard et al. 2004).

At the Conference of the Parties to The Convention on Biological Diversity's (CBD) sixth meeting in April 2002 in The Hague, Netherlands, of which South Africa is a signatory Party, a target was set to have "at least 10 per cent of each of the world's ecological regions effectively conserved", in order to achieve the objective to reduce the rate of biodiversity loss by 2010. This suggests an increase in ecological regions represented in protected areas, as well as improving the effectiveness of existing protected areas (CBD 2002). The World Summit on Sustainable Development (WSSD), convened by the United Nations (UN) in Johannesburg, South Africa, in August-September 2002, recognized the need to promote conservation and management of the ocean's biodiversity and to maintain their productivity. In order to achieve this, they recommend the "establishment of marine protected areas consistent with international law and based on scientific information, including *representative* networks by 2012" (UN 2002). In addition, the IUCN's fifth World Parks Congress held in Durban, South Africa, in September 2003, as part of the recommendations, following the targets set by the WSSD, called for the establishment by 2012 of "a global system of effectively managed, *representative* networks of marine and coastal protected

areas, consistent with international law and based on scientific information... these networks should be extensive and include strictly protected areas that amount to at least 20-30 percent of each habitat” (IUCN 2003). South Africa is expected to comply with these recommendations, thus there is a need to monitor and evaluate the effectiveness of the MPA network in terms of conserving the country’s marine biodiversity, as well as looking at future directions to achieve those targets.

South Africa’s national legislation follows the international agreements for which the country is a signatory party. Chapter one of the National Environmental Management: Biodiversity Act 57 of 2003, which applies to the sea as well by the Protected Areas Amendment’s insertion of section 14 in Act 57 of 2003, has as an objective ‘to provide for a *representative* network of protected areas in state land, private land and communal land’. Additionally, the National Environmental Management: Biodiversity Act 10 of 2004 calls for the development of a National Biodiversity Framework, which must ‘identify priority areas for conservation action and the establishment of protected areas’.

The term *representative* is used in most of the agreements mentioned before; however, no clear definition is given for its use in official documents. What is really meant by representative networks, and how do we assess if they are in fact representative? According to the Conference of the Parties to the Convention on Biological Diversity’s ninth meeting, ‘representativity is captured in a network when it consists of areas representing the different biogeographical subdivisions of the global oceans and regional seas that reasonably reflect the full range of ecosystems, including the biotic and habitat diversity of those marine ecosystems’ (CBD 2008). However, in practice things are not that simple. There is a lack of practical ways of measuring the ecosystem, biotic and habitat diversity outside and within MPAs. Thus, the problem remains as to how we measure representativity in an MPA network, in order to meet the conservation targets. Should we measure the amount of

bioregions present in MPAs? Or should we look at the different habitats they protect? Or should we be looking at species composition in our MPA networks?

There have been several approaches to address the issue of measuring representativity and assessing the state of South Africa's MPA network. According to a survey by Attwood et al. (1997b), fish species, including economically and ecologically important species, were well represented in South Africa's MPAs. However, in many cases the populations were in critical state according to the managers, which suggested poor or ineffective protection. The authors mention as an important finding that the knowledge of biota in MPAs at the time was poor. The survey was based on expert opinion, not on a set of comprehensive field surveys, thus, the authors considered the species information to be only a "rough guide". Hockey and Branch (1997) defined the objectives to be achieved by MPAs in South Africa, and they also described a methodology, which they named COMPARE (Criteria and Objectives for Marine Protected Area Evaluation), to be applied to South Africa's existing and proposed MPAs. This methodology was designed to evaluate and determine how well, and if, MPAs are achieving or could potentially achieve their objectives (Hockey & Branch 1997).

Turpie et al. (2000) used existing fish distribution data in an approach to identify and select priority areas for conservation of South Africa's coastal fish diversity. Using fish distribution ranges they included presence/absence data of 1239 fish species in 50-52 km long sections around the South African coastline. The study examined and compared different approaches to select MPAs in South Africa in order to conserve coastal fish diversity. While discussing the 'complementing existing protected areas' approach, the authors suggest that South Africa's coastal fish diversity is not fully represented in the existing MPAs. In this regard, the report concludes that to achieve full representation of fish species, conservation actions needed to be applied in several areas such as Port Elizabeth,

the Transkei and the west coast of South Africa (Turpie et al. 2000). However, the distribution data used from Smith and Heemstra (1986) is unclear regarding the collection of the records, sources and assumptions. Due to the fact that the data were not obtained through surveys, it is biased against the absent species. Finally big assumptions were made regarding the presence and abundance of fish species along the entire distribution range. As part of their conclusions, Turpie et al. (2002) state that ‘ground-truthing’ is required to make sure the protected areas can achieve their objectives and conserve the species that they are theoretically supposed to protect”.

The marine component of the National Spatial Biodiversity Assessment prepared by Lombard et al. (2004) included Turpie et al.’s (2000) fish distribution data for their species analyses, in order to perform gap analyses and to report their conservation status. The results, which should be considered as preliminary according to the authors, showed that 98 percent of the fish species that were included in the analyses fell within MPAs. However, as mentioned in the report, these results do not suggest that those fish species are adequately protected or that they are in viable populations. In the assessment, South Africa’s EEZ was divided into bioregions based on large-scale biological variability and habitat differences, as well as biogeography, and it was found that the existing MPAs are not well distributed among bioregions. The authors concluded that South Africa’s marine biodiversity is not fully represented in its MPA network (Lombard et al. 2004). Regarding fish species, this assessment has similar limitations as Turpie et al. (2000), since many assumptions had to be made concerning fish distributions and open ocean fish species were not considered. Thus, there is a need for actual survey data analyses to confirm that the fish species are indeed present and represented in South Africa’s MPAs (Lombard et al. 2004).

In order to evaluate how representative South Africa’s MPA network is and how, or if, the global targets are being met, every aspect needs to be considered; including habitats and

bioregions, as well as species and communities. Previous studies have assessed the presence of fish species and their representation throughout South Africa's MPA network; however, none of these studies considered actual survey data. No one survey can accurately measure the entire species composition in a particular part of the ocean. Different kinds of fishing gear and techniques target specific areas and fish sizes, thus generally catching different species of fish. Among the fishing gears utilized in South Africa, for which survey data exist, are trawling, shore angling, boat based line-fishing, and seine netting. Existing quantitative data sets of fish species can be from scientific or monitoring surveys, as well as from commercial fishing. In this study we aim to look at the value of multigear quantitative data sets of fish abundance to examine how well South Africa's fish communities are represented in its MPA network.

**Table 1.** IUCN protected area management categories (IUCN 1994).

<b>Category I A: Strict Nature Reserve</b>	protected area managed mainly for science
<b>Category I B: Wilderness Area</b>	protected area managed mainly for wilderness protection
<b>Category II: National Park</b>	protected area managed mainly for ecosystem protection and recreation
<b>Category III: Natural Monument</b>	Protected area managed mainly for conservation of specific natural features
<b>Category IV: Habitat/Species Management Area</b>	Protected area managed mainly for conservation through management intervention
<b>Category V: Protected Landscape/Seascape</b>	Protected area managed mainly for landscape/seascape conservation and recreation
<b>Category VI: Managed Resource Protected Area</b>	Protected area managed mainly for the sustainable use of natural ecosystems

## CHAPTER II

### **Empirical evaluation of the effectiveness of South Africa's Marine Protected Area network in representing fish communities**

#### **INTRODUCTION**

Threats such as over-exploitation, coastal development, pollution, mining, marine alien invasive species and aquaculture are placing the world's oceans at great risk (Auster et al. 1996; Bascompte et al. 2005; Bax et al. 2003; Collie et al. 2000; Correa et al. 1999; Dee Boersma & Parrish 1999; Kura et al. 2004; Law 2000; Molnar et al. 2008; Sumaila et al. 2000; Tovar et al. 2000; Whitfield 1999; Williams 1996; Wu 1995; Wu et al. 1994). According to the Food and Agriculture Organization (FAO) eighty percent of the world's fish stocks are fully exploited or overexploited (FAO 2008). These issues have been addressed by many researchers in search for possible solutions (Attwood et al. 1997a; Attwood et al. 1997b; Crain et al. 2009; FAO 2008; Hockey & Branch 1997; Lombard et al. 2004; Pauly et al. 2002).

One recommended approach to marine conservation and management has been the implementation of Marine Protected Areas (MPAs). An MPA is defined by the International Union for Conservation of Nature (IUCN) as 'any area of intertidal or sub tidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment' (Kelleher & Kenchington 1992). Among others, MPAs can differ in their levels of protection, objectives, size and management (Lubchenco et al. 2003; Palumbi 2001). MPAs have been designed mainly for the protection of marine ecosystems; however, some have also been implemented for fisheries management (Attwood et al. 1997a; Hockey & Branch 1997; Kelleher 1999). Nevertheless, in order to conserve marine biodiversity

successfully, MPAs should be part of an integrated management approach (Kelleher 1999; Lubchenco et al. 2003).

South Africa's MPA network consists of 22 Gazetted MPAs which includes 'no-take' areas, as well as areas that allow certain kinds of extraction (fig 1). These MPAs cover 0.35 percent of the 1 071 883 km<sup>2</sup> of exclusive economic zone (EEZ), and 0.23 percent of the 3 650 km long coastline. Conversely, 98.65 percent of the EEZ and 77 percent of the coastline remains unprotected (Lombard et al. 2004). Whereas there is broad agreement that protection should be extended to more areas, the location of new protected areas is contentious.

International conventions, to which South Africa is a signatory Party, have set several targets to increase the protection of marine ecosystems. The World Summit 2002 on Sustainable Development (WSSD) as well as the IUCN's fifth World Parks Congress, recommended the establishment by 2012 of a *representative* network of marine protected areas, which should be consistent with international law and based on scientific information (IUCN 2003; UN 2002). 'Representativity is captured in a network when it consists of areas representing the different biogeographical subdivisions of the global oceans and regional seas that reasonably reflect the full range of ecosystems, including the biotic and habitat diversity of those marine ecosystems' according to the Conference of the Parties to the Convention on Biological Diversity's ninth meeting (CBD 2008). In addition, South Africa's national legislation through chapter one of the National Environmental Management: Biodiversity Act 57 of 2003, which applies to the sea as well by the Protected Areas Amendment's insertion of section 14 in Act 57 of 2003, provides for 'a *representative* network of protected areas in state land, private land and communal land'. Furthermore the National Environmental Management: Biodiversity Act 10 of 2004 calls for the identification of priority areas for conservation action and the establishment of protected

areas. The problem lies in how to measure representativity in an MPA network, as well as which features should be measured in order to meet the conservation targets.

One of the recent approaches to measure representativity and identify priority areas for conservation of marine biodiversity in South Africa, is the study by Turpie et al. (2000). The data source for this study was the comprehensive book on Southern Africa's marine fishes, Smith's sea fishes (Smith & Heemstra 1986). This book lists the end points of distribution of each species. This information in turn was derived from a variety of sources accumulated over long periods by several specialists. Turpie et al. (2000) used the fish distribution data as presence/absence of the species in 50-52 km long sections around the South African coastline, and compared different approaches for MPA selection for the conservation of coastal fish diversity.

A more recent approach to measure representativity in South Africa's MPA network was the marine component of the National Spatial Biodiversity Assessment prepared by Lombard et al. (2004). The same fish species distribution data as Turpie et al.'s (2000) study used was included in this study; but it was augmented by several other sources of biological and geological information. Lombard et al.'s (2004) analysis provided a solution of MPAs on presence/absence data as well as broad habitat and biogeographic zonation. Neither study was based on community structure data, as such information was neither widely available nor standardised (Lombard et al. 2004; Turpie et al. 2000).

The objectives of this research were to identify the different fish communities in South Africa as measured by the relative abundance of each species. Given that marine fish are widely distributed by marine currents during the egg and larval stages, fish may settle and be detected in marginal or sub-optimal habitats. Whereas, the use of actual frequencies should give a better indication of community types.

The problem encountered in measuring community structure among fish species is that no method gives an accurate representation. All of the sampling methods are biased. In this study I examine community structure as sampled by shore-angling, trawling, boat-based line-fishing and seine-netting (in estuaries) and measure the similarities in community structures among areas throughout South Africa's EEZ. In addition the study intended to examine fish communities in MPAs, in order to assess the extent to which they represent the full range of fish communities in South African waters. Finally this study aimed to look at the value of multigear quantitative data sets of fish abundance for MPA network representativity evaluations.

## **METHODS**

### *Data sources*

Species composition data from different sites around exclusive economic zone (EEZ) of South Africa were used for this study. These data were collected through different types of fishing techniques. Four different fishing methods were used, namely, shore-angling, boat-based line-fishing, seine-netting (for estuaries) and trawling. Data were obtained from surveys of recreational and commercial fishing records, and scientific surveys (fisheries independent data). A brief description of the data's source, area, methods of collection, fishing type and sample size per area is given in table 2. The MPAs for which data were available per sampling method are presented in table 3, as well as the total area protected by each MPA.

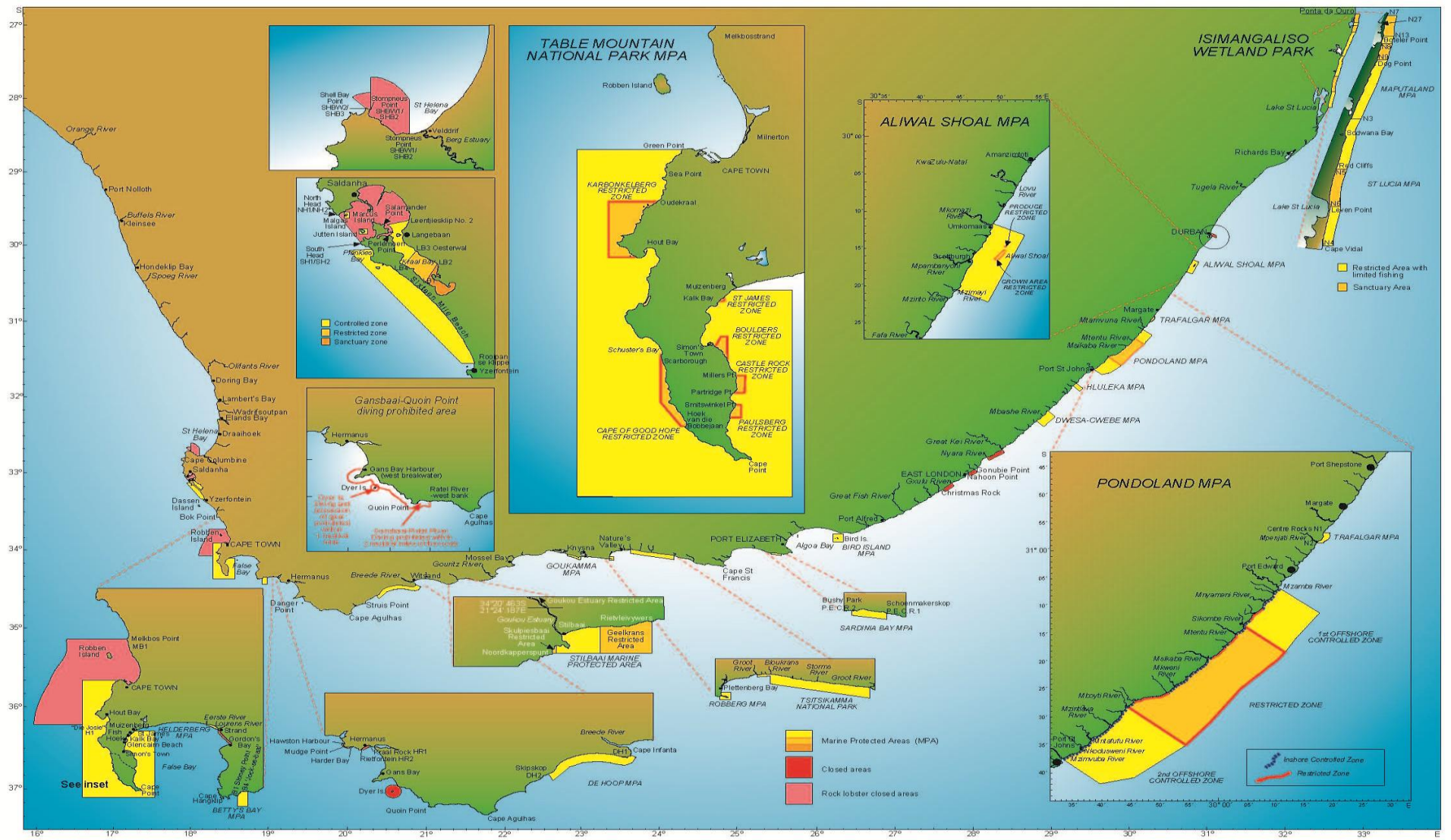


Figure 1. Map showing the location of South Africa's MPAs.

**Table 2.** Source, area, methods of collection, fishing type and sample size for the data used for this study.

Source	Year	Description	Area	Sample size (N)*	Methods
(Götz et al. 2009)	2000-2003	Boat-based line-fishing survey	Goukamma	2496	Standardised angling survey
Götz A unpublished data (SAEON <sup>‡</sup> )	2006-2008	Boat-based line-fishing survey	Tsitsikama	907	Standardised angling survey
(Coetzee & Baird 1981)	1975-1978	Boat-based line-fishing survey	St Croix	3544	Standardised angling survey
Götz A unpublished data (SAEON)	2006-2008	Boat-based line-fishing survey	Woody Cape	1235	Standardised angling survey
Götz A unpublished data (SAEON)	2006-2008	Boat-based line-fishing survey	Bird Island	1835	Standardised angling survey
Smale, M. unpublished data	2004	Boat-based line-fishing survey	East London	1963	Standardised angling survey
(Mann et al. 2006)	2006-2008	Boat-based line-fishing survey	Mtentu	596	Standardised angling survey
(Mann et al. 2006)	2006-2008	Boat-based line-fishing survey	Mkambati	395	Standardised angling survey
(Mann et al. 2006)	2006-2008	Boat-based line-fishing survey	Casino	260	Standardised angling survey
(Mann et al. 2006)	2006-2008	Boat-based line-fishing survey	Mnyameni	393	Standardised angling survey
NMLS <sup>Δ</sup>	2000-2008	Boat-based line-fishing commercial	Bettys Bay	354 799	Commercial catch return
NMLS	2000-2008	Boat-based line-fishing commercial	Western Cape	9 608 722	Commercial catch return
NMLS	2000-2008	Boat-based line-fishing commercial	Southern Cape	170 780	Commercial catch return
NMLS	2000-2008	Boat-based line-fishing commercial	KwaZulu Natal	755 251	Commercial catch return
(Fennessy et al. 2003)	1997-1999	Boat-based line-fishing survey	Northern Transkei (recreational and commercial)	7 783	Access point survey and Roving creel survey
(Fennessy et al. 2003)	1997-1999	Boat-based line-fishing survey	Southern Transkei (recreational and commercial)	739	Access point survey and Roving creel survey
NMLS	2000-2008	Boat-based line-fishing commercial	Struisbaai	11 281 450	Commercial catch return
National Parks unpublished	2005-2007	Boat-based line-fishing commercial	West Coast National Park	8 909	Access point survey
(Harrison et al. 2000)	1993-1999	CSIR <sup>□</sup> estuarine survey	South Africa	274 492	Seine net surveys
Attwood unpublished survey data	2005-2008	Shore-angling recreational fishing	Langebaan	2 461	Roving creel survey
(Hutchings et al. 2008)	2002-2005	Shore-angling recreational fishing	Berg River	2 839	Roving creel survey
Lamberth, S unpublished data	2004-2005	Shore-angling recreational fishing	Breeder River	575	Roving creel survey
(Pradervand et al. 2003)	2000	Shore-angling recreational fishing	Durban Bay	740	Roving creel survey
(Pradervand et al. 2003)	2000	Shore-angling recreational fishing	Mgeni River	255	Roving creel survey
(Pradervand & Baird 2002)	1996-1997	Shore-angling recreational fishing	Eastern Cape estuaries	2 238	Boat- based creel survey

**Table 2** (continued)

Source	Year	Description	Area	Sample size (N)*	Methods
(Brouwer et al. 1997)	1994-1996	Shore-angling recreational fishing	Eastern Cape	1 325	Roving creel survey
(Brouwer et al. 1997)	1994-1996	Shore-angling recreational fishing	KwaZulu Natal	97	Roving creel survey
(Brouwer et al. 1997)	1994-1996	Shore-angling recreational fishing	South Coast	94	Roving creel survey
(Brouwer et al. 1997)	1994-1996	Shore-angling recreational fishing	West Coast	100	Roving creel survey
(Mann et al. 2002)	1986-1999	Shore-angling recreational fishing	St Lucia estuary	163 089	Commercial catch return
(Beckley et al. 2008)	2001- 2002	Shore-angling recreational fishing	Richards Bay	1 298	Roving creel survey
Tintlet, S. 2005-2008	2005-2008	Shore-angling recreational fishing	Table Mountain	294	Roving creel survey
(Mann et al. 2003)	1997-1998	Shore-angling recreational fishing	Transkei	657	Roving creel survey
(Coetzee et al. 1989)	1978-1982	Shore-angling recreational fishing	East Coast	4 381	Roving creel survey
Mann, B. Q. unpublished data (ORI <sup>o</sup> )	2008-2009	Shore-angling survey	St Lucia	6 279	Standardised angling survey
Mann, B. Q. unpublished data	2002-2007	Shore-angling survey	Pondoland	1 486	Standardised angling survey
(Bennet & Attwood 1993)	1984-2009	Shore-angling survey	De Hoop	55 662	Standardised angling survey
(Pradervand & Hiseman 2006)	1993-2003	Shore-angling survey	Goukamma	5 644	Roving creel survey
Götz A unpblished data (SAEON)	1998-2005	Shore-angling survey	Tsitsikama	10 042	Standardised angling survey
Götz A unpblished data (SAEON)	2006-2008	Shore-angling survey	Woody Cape	1142	Standardised angling survey
(Clarke & Buxton 1989)	1985-1986	Shore-angling survey	Port Elizabeth	1187	Roving creel survey
(Wallace et al. 1984)	1980	Trawl survey	Cape South Coast	113 181	Inshore trawl survey
DAFF South Coast Trawl Survey	1987-2007	Trawl survey	South Coast inshore	2 330 129	Inshore trawl survey
Offshore resources observer program (DAFF)	2002-2006	Trawl commercial observer	West Coast/South Coast offshore	2 334 198	Ship based observer data
DAFF, South Coast Trawl Survey	1987-2007	Trawl survey	Tsitsikama	5 405	Inshore trawl survey
DAFF, South Coast Trawl Survey	1987-2007	Trawl survey	De Hoop	28 772	Inshore trawl survey
ORI	2003-2006	Trawl commercial observer	KwaZulu Natal	930 590	Prawn trawl survey

\* When the sample size was obtained by weight, the assumption of one kilogram per fish was made.

† Department of Agriculture Forestry and Fisheries

\* South African Environmental Observation Network

△ National Marine Line-fish System

° Oceanographic Research institute

□ Council for Scientific and Industrial Research

**Table 3.** List of MPAs for which data were available for each sampling method.

<b>MPA</b>	<b>Area (Km<sup>2</sup>)</b>	<b>Shore- angling</b>	<b>Boat-based line-fishing</b>	<b>Trawling</b>	<b>Estuarine seine-netting</b>
Langebaan Lagoon	47.16	x	x		
Table Mountain National Park	953.2	x			x
Betty's Bay	12.1		x		
De Hoop	288.9	x		x	
Stilbaai	33.74				x
Goukamma	33.97	x	x		x
Tsitsikama National Park	323	x	x	x	x
Bird Island	70.38		x		
Pondoland	1 238	x	x		x
St Lucia	414	x			x
East London closed areas*			x		

\* Only shore-angling is allowed in these areas, however these sites are not declared MPAs. The areas extend three nautical miles seawards from the high-water mark and are located: between Nahoon Point and Gonubie Point, Between Christmas Rock and Gxulu River and between Nyara River and Great Kei River (fig 1).

### Shore-angling

Shore-angling involves the capture of fish from a shore stance with a rod and reel. A baited hook on a single line is cast into the surf or estuary. Shore-angling is practiced by recreational and subsistence fishers. Shore-angling recreational fishing data are usually collected through interviews with the fishermen and either by access point surveys or roving creel census (Pollock et al. 1994). Data are also collected by scientists through standardized shore-angling surveys. Shore-angling data were obtained at 29 sites (Appendix 1).

### Boat-based line-fishing

Boat-based line-fishing is a technique in which a single line with a baited hook, usually hand held or operated by means of a rod and reel is used to catch fish. It can be used from a moving or stationary boat. This technique is used by commercial or recreational fishers who operate mostly in coastal waters. Two sets of data are available. The first constitutes line-fishing surveys and surveys of fishermen's catches. The second constitutes the monthly

records submitted by commercial skippers, and stored in the National Marine Line-fish System (NMLS).

These two data sets were analysed separately. The NMLS data has records for the entire South African coast. For this study the coast was divided in 100 km-blocks. The blocks that had MPAs within those 100 km were considered as having communities partly protected. The location of line-fishing surveys and NMLS data are listed in appendices 2 and 3 respectively.

### Seine-netting

Seine-netting is practiced with a fishing net called a seine net, which is a net used to surround and catch fish. This method is effective for catching shallow water fishes. In this study a single data set of estuarine seine-netting surveys was used (Harrison 2003). There were a large number of estuaries included in the analyses (217) from around the coast of South Africa (Appendix 4).

### Trawling

Trawlers drag a net held open by doors along the sea bottom. It is a fairly indiscriminate method of capturing fish and, despite environmental concerns associated with this fishing method, can provide a useful record of fish fauna in environments otherwise difficult to sample. Catch composition data from commercial trawling are obtained by observers, who record catch information from the boats. Scientific data are also collected in standardised random-stratified trawl surveys.

Commercial offshore trawling data were obtained from the South and West Coast by ship based observers and grouped by grid cell. Shallow and deep water trawling data from KwaZulu Natal were also obtained by ship based observers and grouped by grid cell as well. Survey inshore trawling data were obtained from De Hoop MPA and Tsitsikama National Park MPA. These data were aggregated in 20° x 20° blocks. Shallow inshore trawling

surveys were also conducted along the Cape South Coast (Wallace et al. 1984) and these stations were grouped into longitudinal degrees (22° to 26° E). Longitudinal degrees 23° E and 26° E were considered as partially protected due to the fact that within those degrees lie the Goukamma and Robberg MPAs, as well as the MPAs located in Algoa Bay.

### *Preliminary tests*

#### General approach

The statistical package PRIMER (Plymouth Routines in Marine Ecological Research) (Clarke & Gorley 2006) was used to test for similarity between fish communities in different areas along the South African coast to measure the extent to which fish communities in MPAs collectively represent all fish communities. Multi-gear data were used in an attempt to reduce the error due to sampling bias. However, there were several other possible sources of error, namely sampling error, temporal variation and the effects of fishing.

#### Sampling error

In order to test for the effects of sampling error on diversity and similarity a hypothetical community was modelled. Samples of 500 fish were drawn from the community. The fish community estimated by various numbers of samples (one to ten) was then compared with the fish community estimated by an infinitely large sample size (i.e. assuming the entire area was completely sampled by that method) in a cumulative curve.

#### Temporal variation

Dissimilarity caused by temporal variation, was tested with shore angling data from 1989 to 2005 from De Hoop MPA. After standardisation and fourth root transformation was performed, the Bray-Curtis similarity index, among species composition per year, was used to perform a group average hierarchical clustering analysis. Sample size was on average 3000

fish per year, however it ranged from 232 to 5 140 individuals per year, implying that the observed variation was a combination of sampling error and temporal variation.

### Effects of fishing

The effect of fishing on similarity among communities was tested through a group average hierarchical clustering analysis of the Bray-Curtis similarity index of the species composition from five hypothetical communities. Three of the hypothetical communities were composed of the same primal community; however to represent the effects of exploitation, one of them was left unexploited, one of them had 50 percent of its species being exploited (the abundance of 50 percent of the species was reduced to half) and the third one had 50 percent of its species being reduced to 10 percent, thus representing an overexploited community. The other two communities had 41 percent and 23 percent of the species of the original unexploited community respectively; these communities were modelled to represent geographic differences.

### *Data analysis*

Multivariate analysis of species composition data was used to examine fish community structure and diversity along the South African coast. The analyses were performed for each fishing technique independently.

The Shannon-Wiener diversity index was calculated for each site and compared among sites. The total number of species sampled, as well as the percentage of those species that are represented in MPAs, was calculated for each sampling method (fishing technique). In addition, as a measure of redundancy, the number of MPAs in which each species was present was calculated for each sampling method. The species composition data were first standardised to get a percentage of the total abundance for each species at every site. A fourth root transformation was performed in order to down-weight the common, highly abundant,

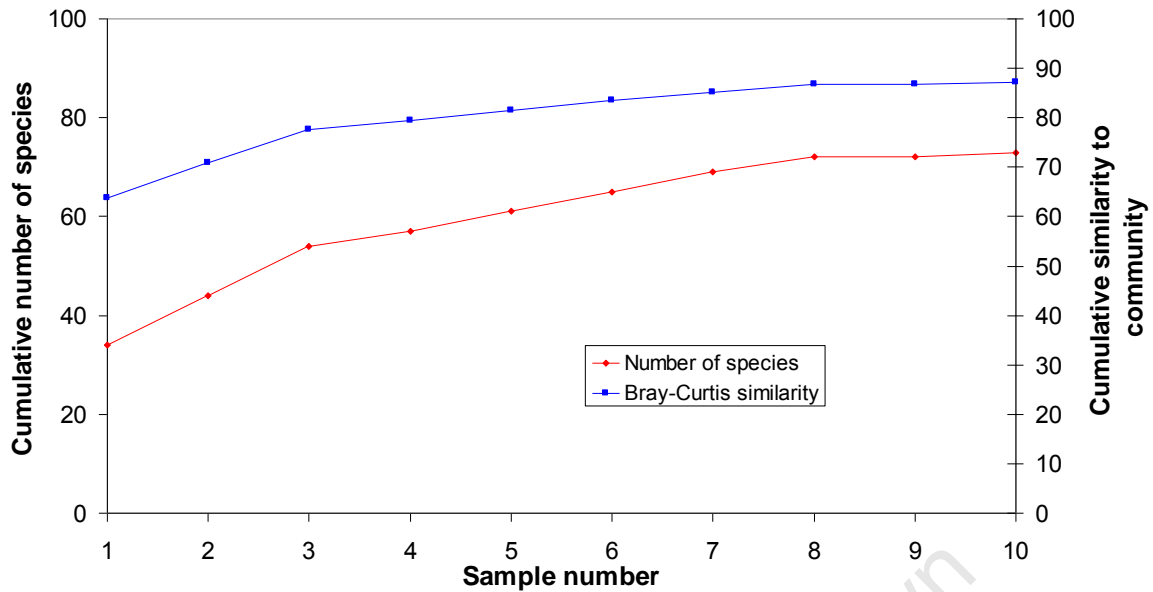
species and allowing for the rare, less abundant, species to influence the analysis (Clarke & Warwick 2001). The Bray-Curtis similarity index was used to perform a group average hierarchical clustering analysis, in order to identify groups of areas with similar community assemblages and assess representativity. In addition, a two dimension non-metric multidimensional scaling (MDS) ordination technique was used to display community similarities among sites in a two-dimensional space.

## **RESULTS**

### *Preliminary analysis*

#### Sampling error

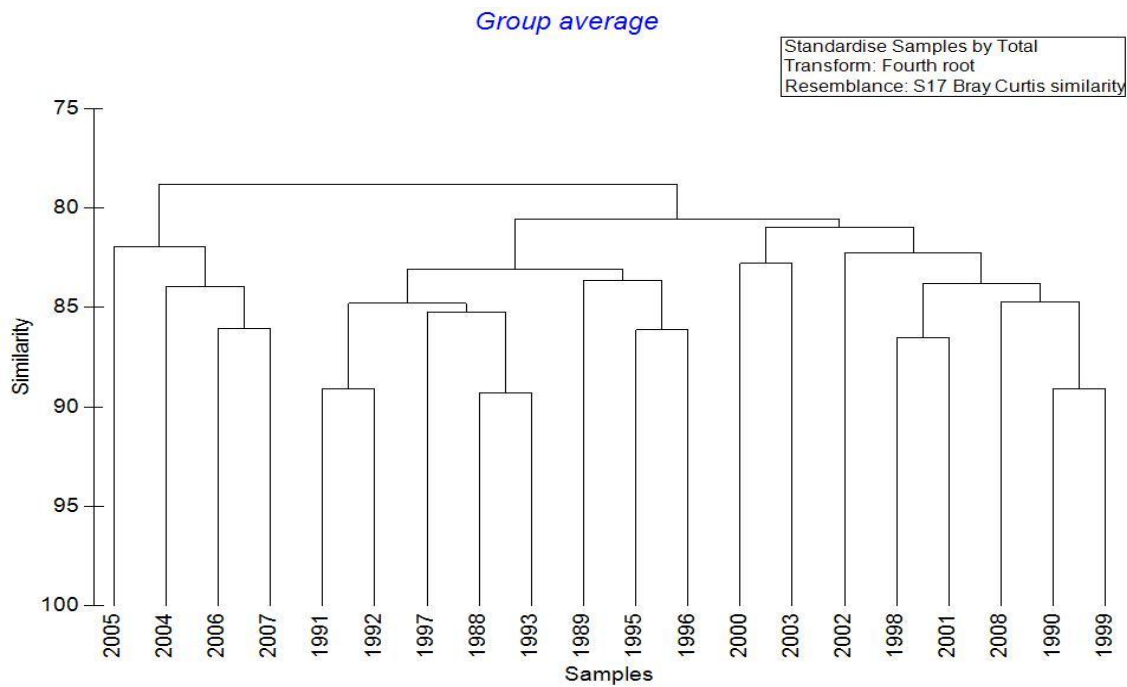
Results from the preliminary analysis show that as the number of samples (of n=500 fish) increases initially the cumulative number of species as well as the cumulative similarity to the completely sampled community increases. However, the line reaches a plateau at around seven samples, after which the cumulative similarity to the completely sampled community does not increase substantially with an increase in the number of samples (fig. 2). A sampling effort of 5000 fish will result in approximately 15 percent dissimilarity from the completely sampled community simply due to sampling error.



**Figure 2.** Cumulative curve showing the cumulative number of species and the cumulative similarity to the completely sampled community per sample. Each sample draws 500 fish.

### Temporal variation

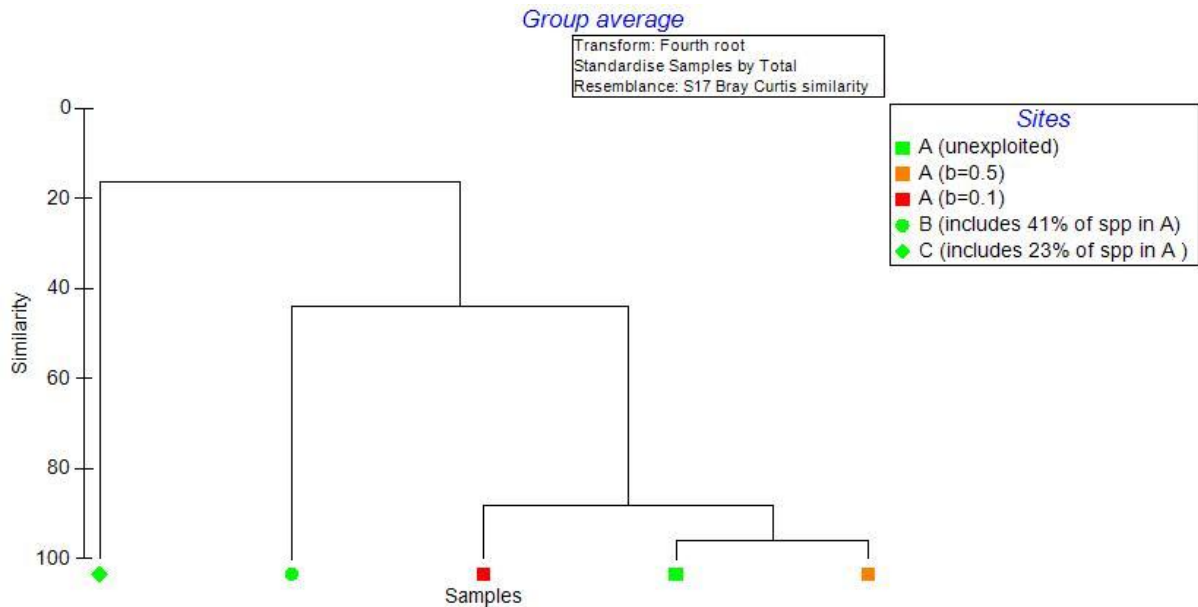
Figure 3 shows the results for the cluster analysis for the De Hoop MPA angling survey data. The group average similarity across all years was 78 percent. None of the years have community samples which were more than 90 percent similar. Annual variation and sampling error together can account for approximately 20 percent dissimilarity among fish communities in this example, which was taken as typical of fish sampling for the purpose of this study.



**Figure 3.** Dendrogram showing similarities between the community samples obtained on each sampling year for the De Hoop MPA angling survey data.

### Effects of fishing

The results for the cluster analysis performed for the five hypothetical communities modelled are shown in figure 4. The exploited community is 95 percent similar to the unexploited community. The overexploited community is 90 percent similar to the unexploited and the exploited communities. The three biogeographically separate communities are less than 50 percent similar to the other two communities which represents the difference attributed to different, but overlapping, species assemblages. Five to ten percent dissimilarity can be caused by the effects of fishing alone, which is small relative to the effects of changing species assemblages.



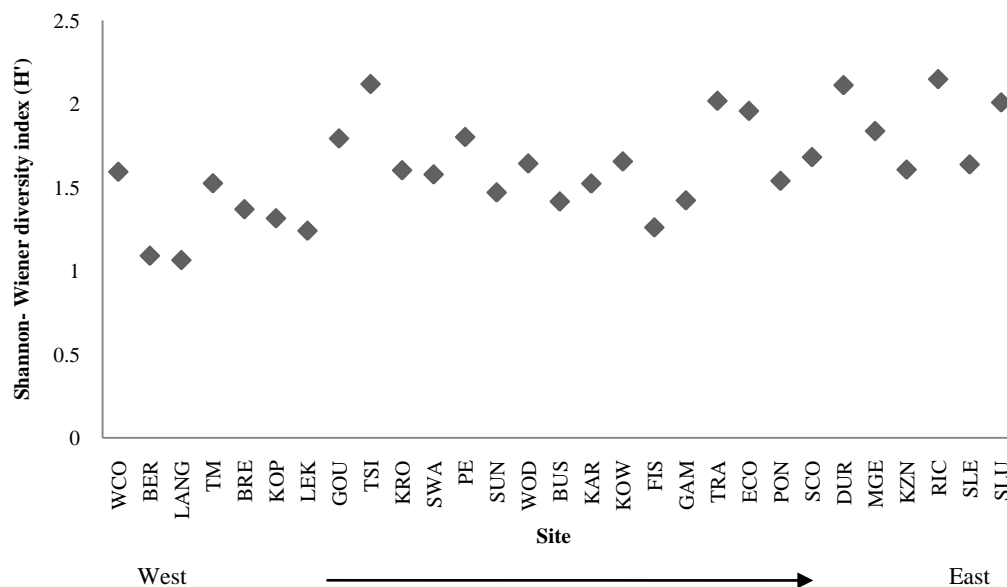
**Figure 4.** Dendrogram showing similarities between five hypothetical communities. A (unexploited) represents an unexploited fish community, A ( $b=0.5$ ) has 50 percent of the species reduced to half the unexploited abundance in A to simulate the effects of fishing at maximum sustainable yield, and A ( $b=0.1$ ) has 90 percent of the species in A's abundance reduced to 10 percent of the unexploited abundance in A to simulate over-fishing. B and C represent hypothetical fish communities with different but overlapping species assemblages.

No attempt was made to assess the cumulative impact of all three sources of error as they are unlikely to be purely additive. This analysis serves only as a rough guide to the magnitude of errors that could be obtained. On the basis of these results it can be expected that no more than 70 to 75 percent similarity between MPAs and exploited areas can be expected from conventional surveys which might cover different time periods.

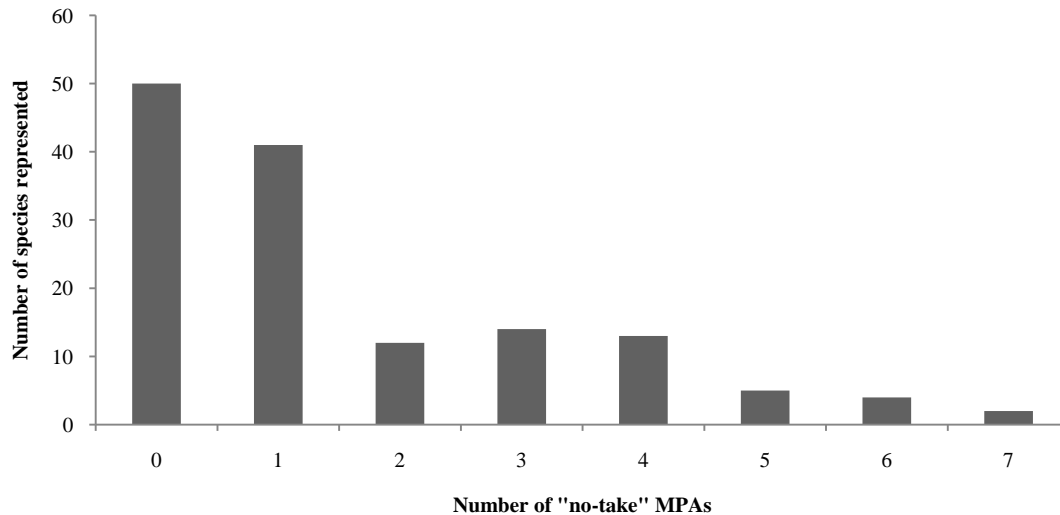
Cut off points were drawn on the cluster analyses at 70 percent and also at the highest level of similarity at which there was full representativity (i.e. all the groups formed had an MPA within them). Seventy percent was chosen to show the representation of fish communities at a reasonable level of similarity measured by conventional surveys, following results from the preliminary analysis.

### Shore-angling sampling method

A total of 208 fish species were recorded from the 29 areas sampled on the littoral zone. The average number of species recorded per site was 31 with a standard deviation of  $\pm 18$  species, however the number of species recorded per site ranged between a minimum of 8 and a maximum of 77 species. An increasing trend in diversity was found from west to east along the coast of South Africa (fig 5). Of the total number of species recorded 158 were present in MPAs, which accounts for 75.96 percent of the total species sampled. However, of the 208 species only 91 were recorded in “no-take” MPAs, which accounts for 43.75 percent of the total number of species. The redundancy in the MPA network is measured by the number of MPAs which include each species. *Pomatomus saltatrix* and *Diplodus sargus* are the most widespread species, occurring in seven MPAs. Of the 91 species recorded in “no-take” MPAs, almost half (41 species) occur in only one MPA. A total of 50 species were not recorded in any “no-take” MPA (fig 6).

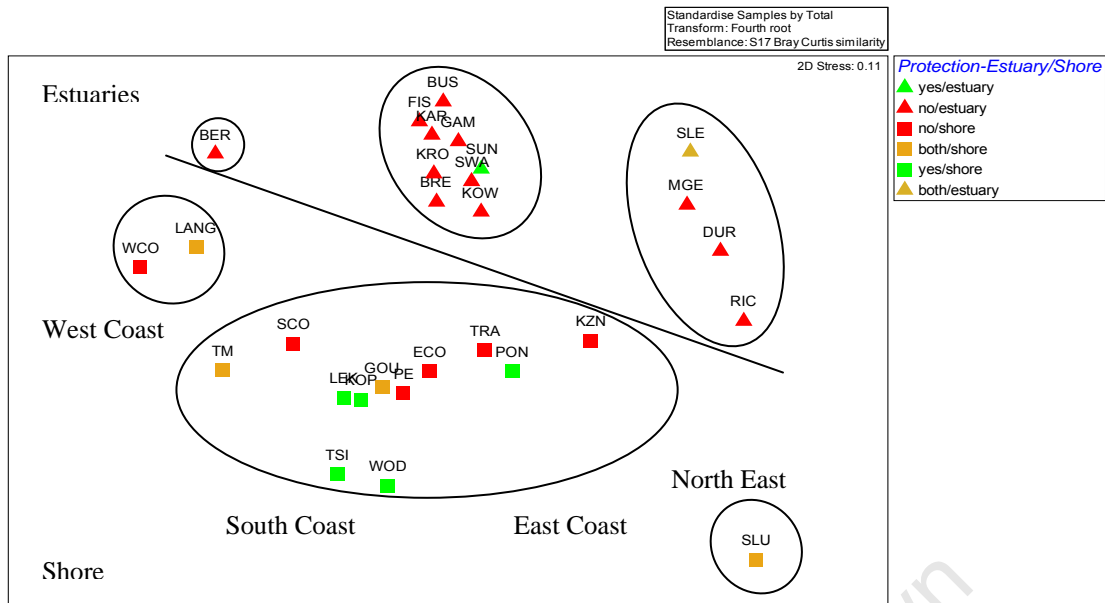


**Figure 5.** Shannon-Wiener diversity index for the shore-angling sampled sites arranged from west to east along the South African coast (see appendix 1 for site key).

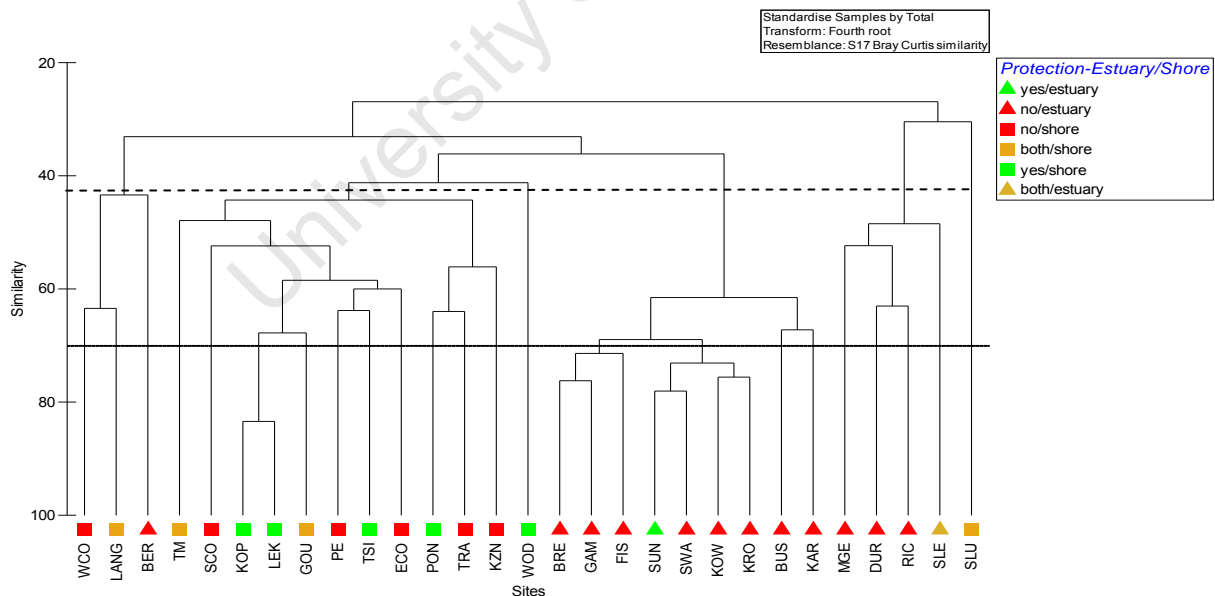


**Figure 6.** Histogram showing the number of fish species represented in the given number of “no-take” MPAs based on shore-angling samples.

Two distinct groups form along the lines of sea shore and estuarine habitat (fig 7). Three major groups form among the estuarine habitats, showing differences between fish communities from sites on the west coast (from the Namibian border to the Cape Peninsula), the south coast (from Cape Peninsula to Cape Agulhas) together with the east coast (from Cape Agulhas to Durban) and the north-east coast (from Durban to the Moçambican border). The sea shore habitat sites form similar groups, differentiating between the west, south and east and north-east coasts. According to the cluster analysis, at 70 percent similarity there are 23 clusters of fish communities. Of the 23, 10 have a MPA, of which only five are “no-take” MPAs. The remaining 13 groups of sites at the 70 percent similarity level have no form of protection. Forty four percent is the highest similarity level at which all groups have an MPA(fig 8).



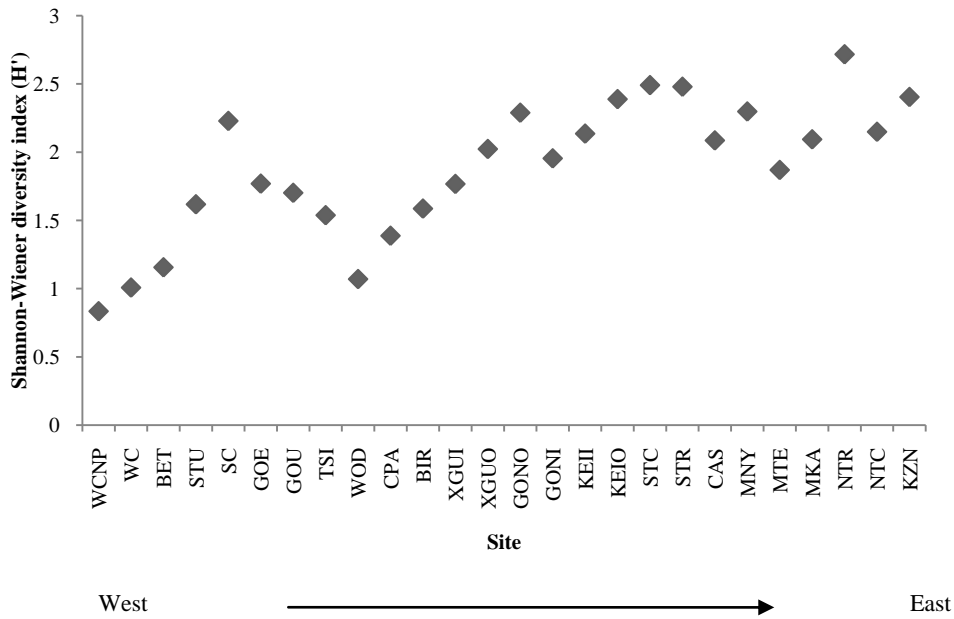
**Figure 7.** Two-dimensional MDS plot showing similarities between fish communities in the different shore-angling sites along the South African coast. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, both = data obtained from a site in an MPA where certain kinds of fishing are allowed. Estuary/Shore factor: estuary = data obtained from an estuary, shore = data obtained from shore angling along the coast. The line marks the division between estuary and shore habitat. The circles represent the three major zones with similar fish communities identified (see appendix 1 for site key).



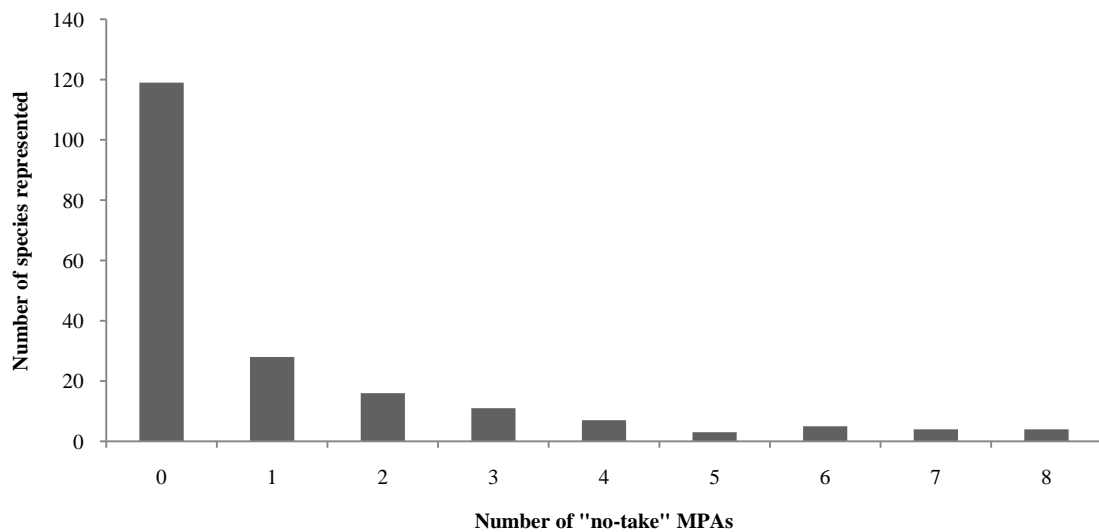
**Figure 8.** Dendrogram showing similarities between fish communities in the different shore-angling sites along the South African coast. Cut off points were drawn at 70 and 44 percent similarity. Protection factors: no= data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, both = data obtained from a site in an MPA where certain kinds of fishing are allowed. Estuary/Shore factor: estuary = data obtained from an estuary, shore = data obtained from the shore along the coast (see appendix 1 for site key).

### *Boat-based line-fishing sampling method*

A total of 197 fish species were recorded from the 26 sites sampled on the continental shelf. On average 34 species were recorded per site with a standard deviation of  $\pm 24$  species, however the number of species recorded ranged between 12 and 122 species per site. There was an increasing trend in diversity found from west to east along the coast of South Africa. However there is a slight decrease in diversity around the Tsitsikama National Park and Woody Cape, Cape Padrone and Bird Island MPAs, after which diversity keeps increasing along the East Coast (fig 9). Forty-five percent (89 species) of the total number of species recorded were present in MPAs. However, of the 197 species only 78 were recorded in “no-take” MPAs, which amounts to 39.59 percent of the total number of species. The number of MPAs which include each species measures the redundancy in the MPA network. The species that were represented in the highest number of MPAs were *Boopsoidea inornata*, *Cymatoceps nasutus*, *Diplodus sargus* and *Mustelus mustelus*, which occurred in eight MPAs. A total of 119 species from the continental shelf were not recorded on any “no-take” MPA, 28 were recorded in only one MPA (fig 10).



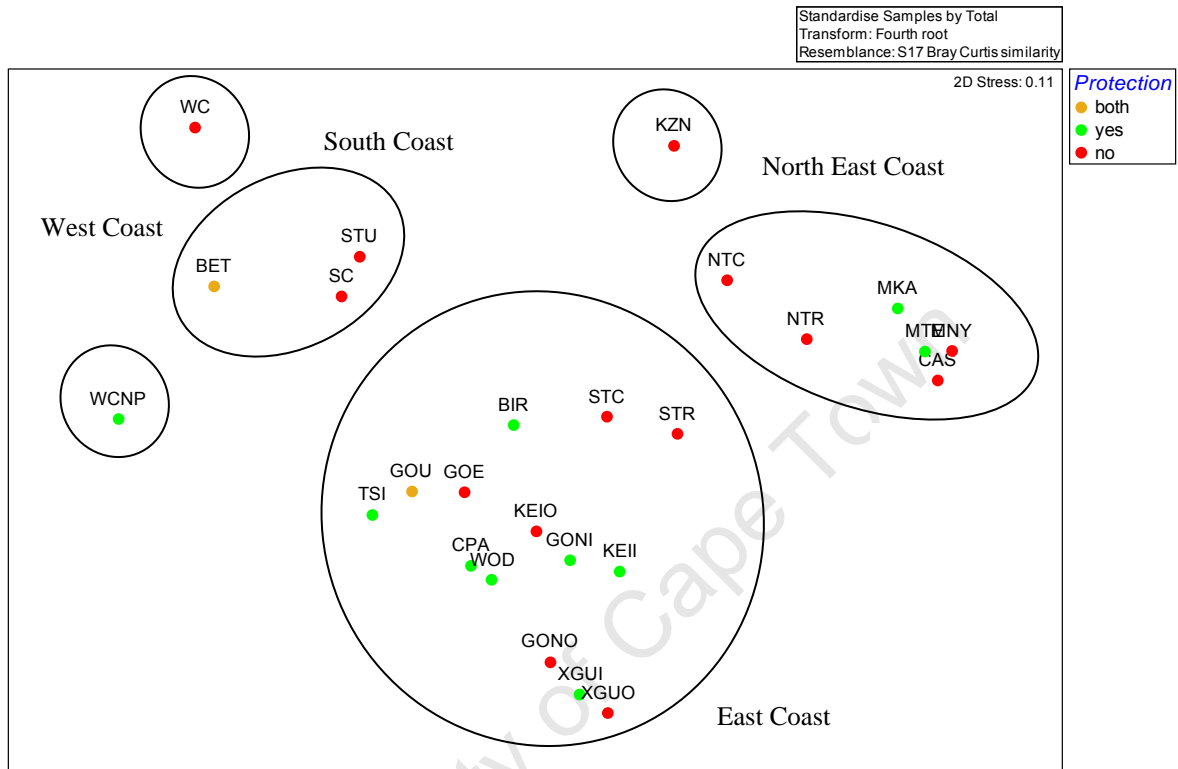
**Figure 9.** Shannon-Wiener diversity index for boat-based line-fishing sampled sites organized from west to east along the South African coast (see appendix 2 for site key).



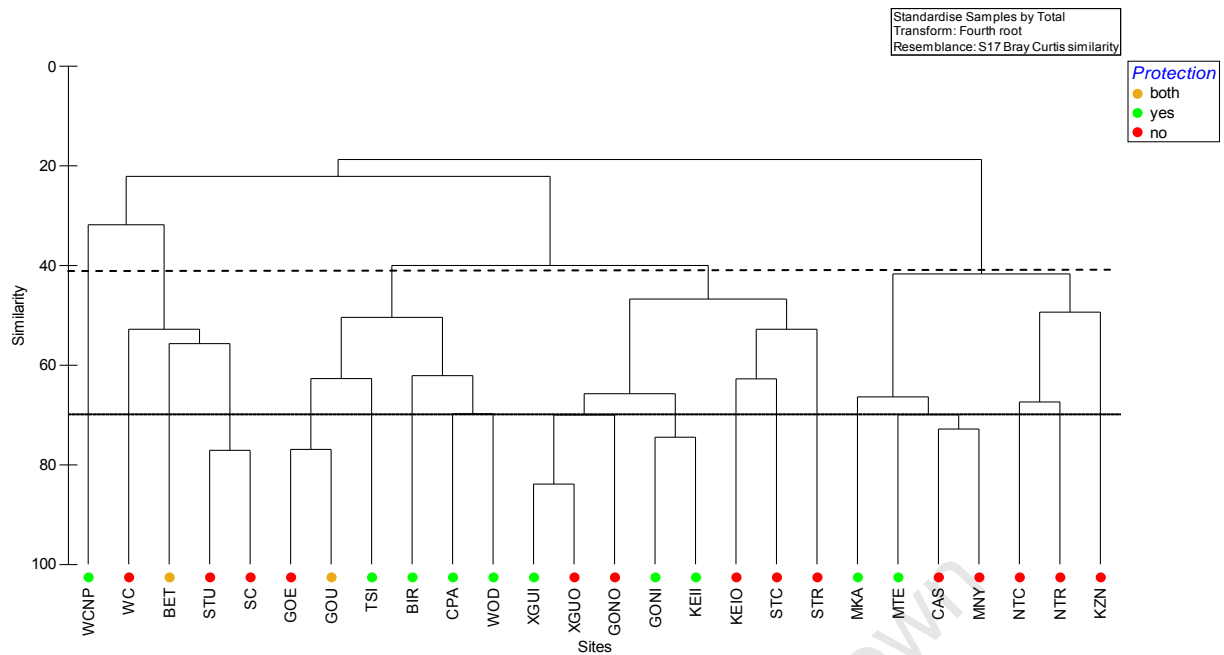
**Figure 10.** Histogram showing the number of fish species represented in the given number of “no-take” MPAs based on boat-based line-fishing samples.

Six groups of sites form among the 21 samples conforming to the different geographic zones, the west coast, south coast, east coast and north east coast. West Coast National Park and KwaZulu Natal separate from the rest of the sites (fig 11). At 70 percent similarity, there are 21 clusters of fish communities. Of the 21, 11 have an MPA, however only nine clusters have

a “no-take” MPA. There are 10 groups of sites with similar communities that have no form of protection at this level of similarity. Above 41 percent similarity not all the communities are represented in MPAs (fig 12).



**Figure 11.** Two-dimensional MDS plot showing similarities between fish communities in the different boat-based line-fishing sites along the South African coast. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, both = data obtained from a site in an MPA where certain kinds of fishing are allowed. The circles represent the major zones with similar fish communities identified (see appendix 2 for site key).

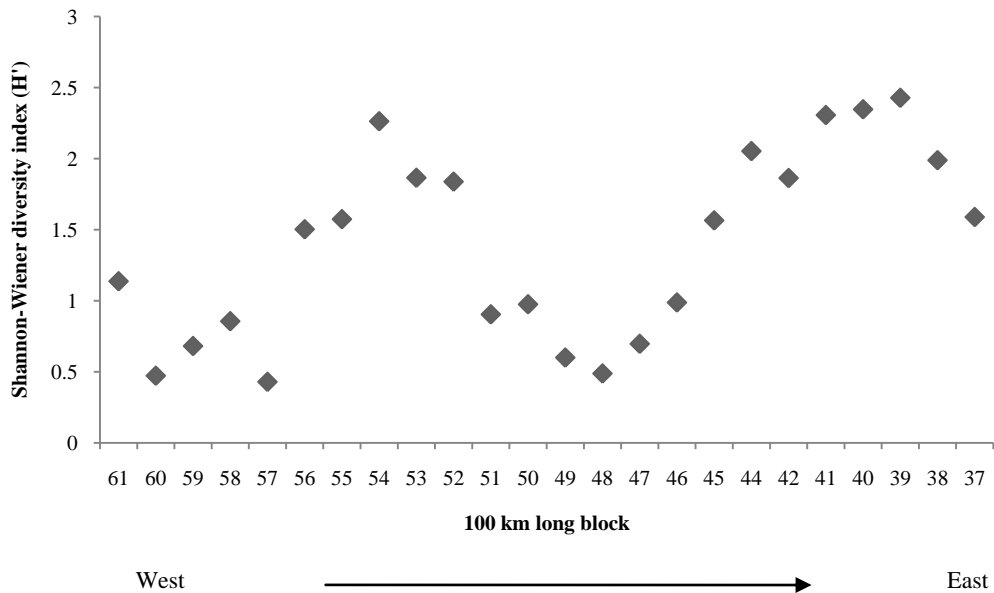


**Figure 12.** Dendrogram showing similarities between fish communities in the different boat based line-fishing sites along the South African coast. Cut off points were drawn at 70 and 41 percent similarity. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, both = data obtained from a site in an MPA where certain kinds of fishing are allowed(see appendix 2 for site key).

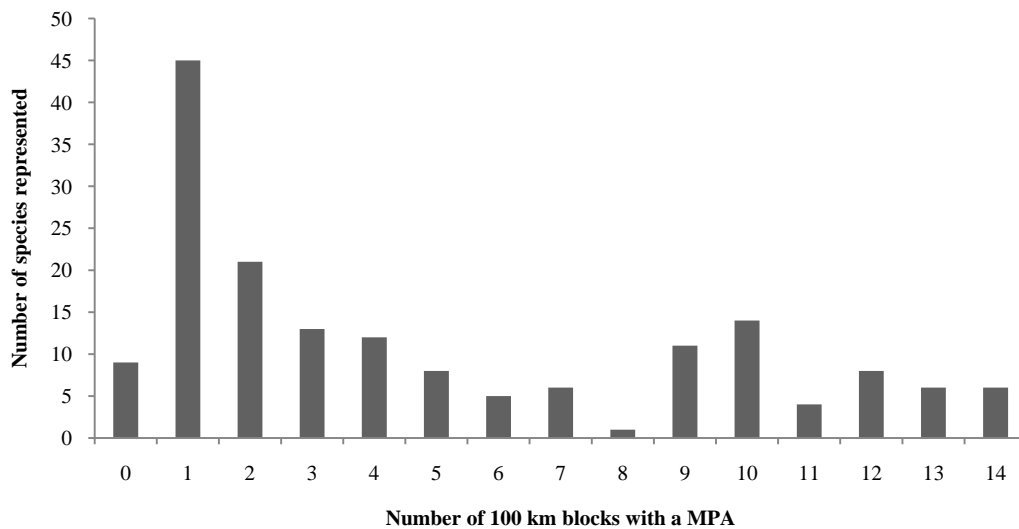
#### *NMLS boat-based line-fishing catch return data*

A total of 24 100 km-blocks were analysed from the NMLS data, of which fourteen had an MPA. A total sample of 330 742 968 kg of fish were obtained from around the coast of South Africa. In total there were 169 fish species from the continental shelf recorded. On average 58 species were recorded per site with a standard deviation of  $\pm 20$  species, however the number of species ranged between 20 and 99 species per site. Diversity initially increased from west to east along the South African coast. However there is a marked decrease in diversity around the Knysna area (blocks 50 to 46) (fig 13) after which it increases again. One hundred and sixty species were recorded in blocks which had MPAs, which represents 94.67 percent of the total number of species. The number of MPAs in which a species is represented measures the redundancy of the MPA network. *Argyrosomus inodorus*,

*Atractoscion aequidens*, *Chrysoblephus gibbiceps*, *Epinephelus marginatus*, *Petrus rupestris* and *Scomber japonicus* were the species that were represented in the highest number of 100 km blocks with a MPA (14). Forty five species were represented in one MPA, and only nine species were not represented on any 100 km blocks with an MPA (fig 14).

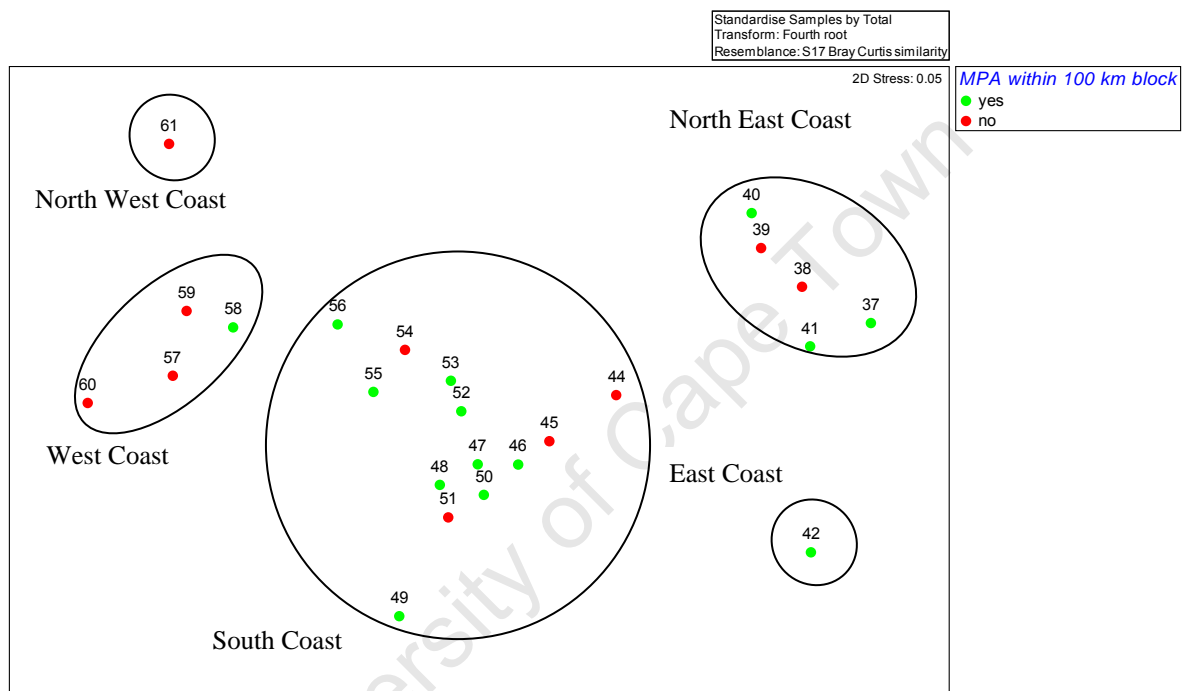


**Figure 13.** Shannon-Wiener diversity index for boat-based line-fishing NMLS sampled 100 km blocks organized from west to east along the South African coast (see appendix 3 for site key).

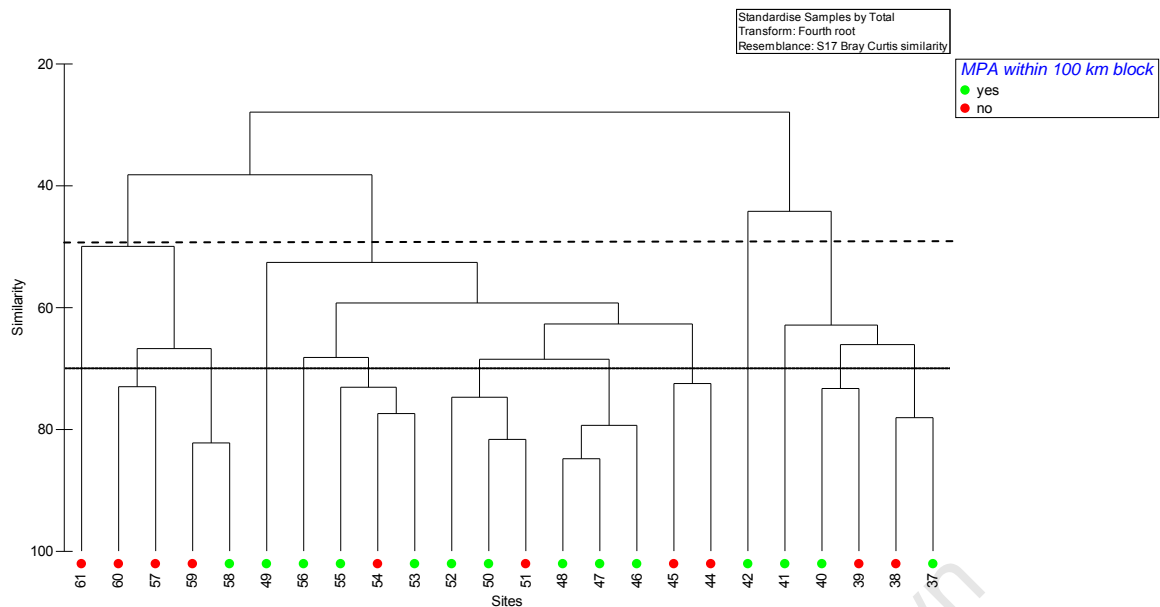


**Figure 14.** Histogram showing the number of fish species represented in the given number of 100 km blocks with MPAs based on NMLS catch return data.

Five general groups form, corresponding to the north-west, south-west, south-east, east and north-east areas of the coast of South Africa (fig 15). At 70 percent similarity, 13 groups of blocks with similar fish communities form. Of the 13 groups, 10 have a MPA within the 100 kilometers block. There are 3 groups of sites with similar communities that have no form of protection. Forty eight percent is the highest similarity at which all the groups have 100 km blocks with MPAs within them (fig 16).



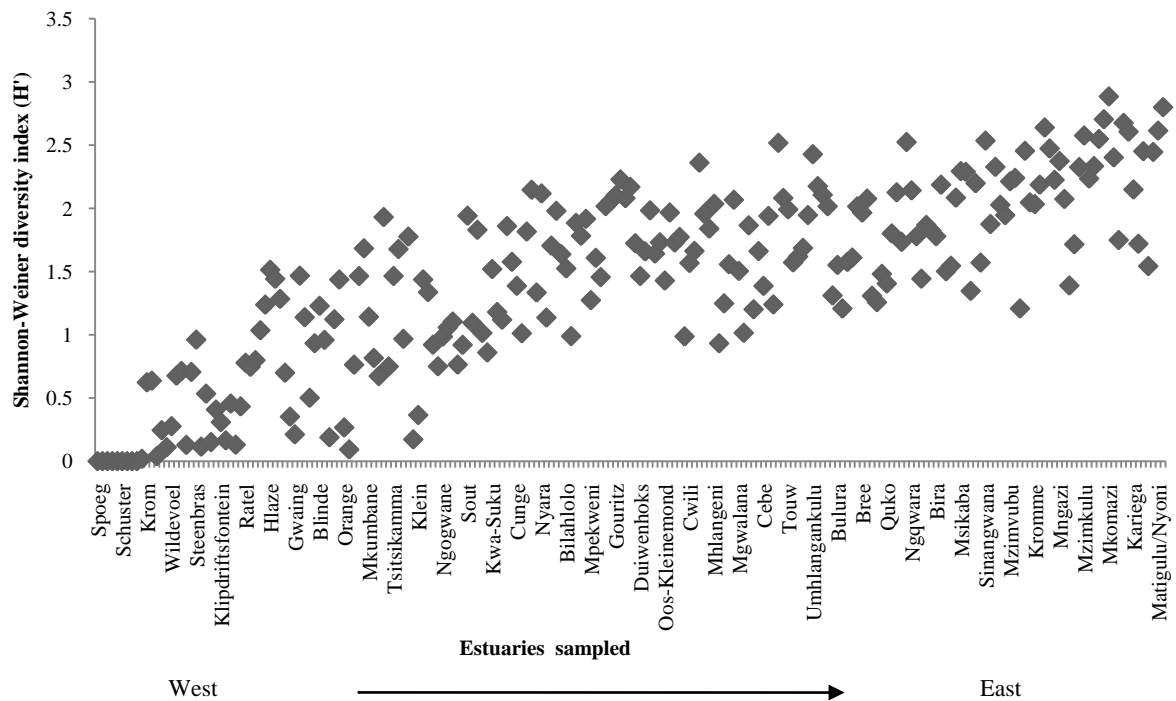
**Figure 15.** Two-dimensional MDS plot showing similarities between fish communities in the different NMLS boat-based line-fishing 100 km blocks along the South African coast. Protection factors: no = no MPAs within 100 km long block along the coast, yes = There is an MPA within the 100 km long block along the coast. The circles represent the major zones with similar fish communities identified (see appendix 3 for site key).



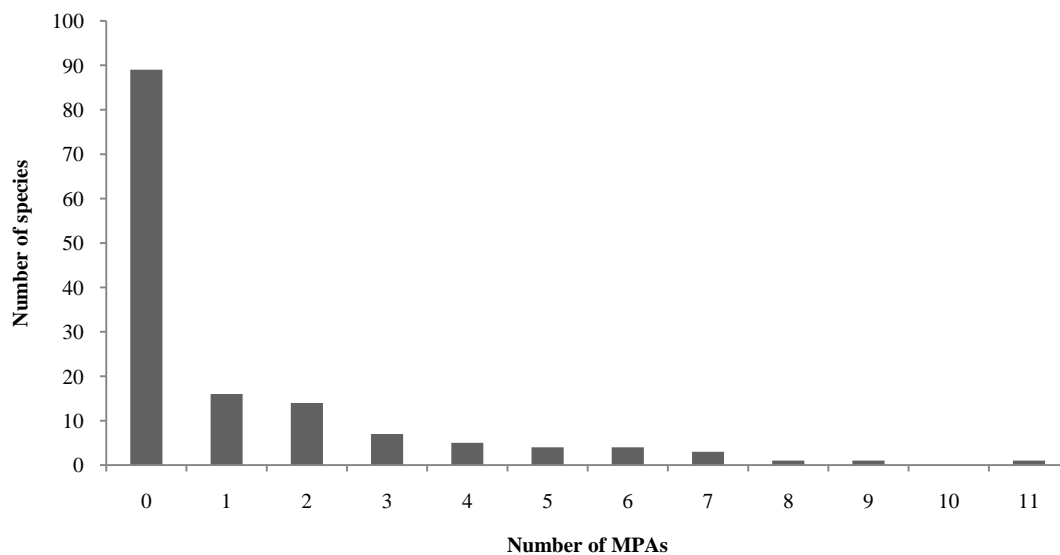
**Figure 16.** Dendrogram showing similarities between fish communities in the different NMLS boat-based line-fishing 100 km blocks along the South African coast. Cut off points were drawn at 70 and 48 percent similarity. Protection factors: no = no MPAs within 100 km long block along the coast, yes = There is an MPA within the 100 km long block along the coast (see appendix 3 for site key).

### *Estuarine seine-netting*

In total 274 492 individuals were sampled from 145 fish species in the 217 estuaries sampled. The average number of species recorded per estuary was 17 with a standard deviation of  $\pm 11$  species, however the number of species recorded per site ranged from 1 and 58 species. A consistent trend in diversity was found from west to east along the coast of South Africa (fig 17). Of the total number of estuarine associated species recorded 56 were present in MPAs, which accounts for 38.62 percent of the total number of species recorded. Conversely, 89 species were not represented in MPAs. The greatest redundancy in protection was for *Liza richardsonii*, which was found in all 11 MPAs. Sixteen species were found in only one MPA (fig 18).



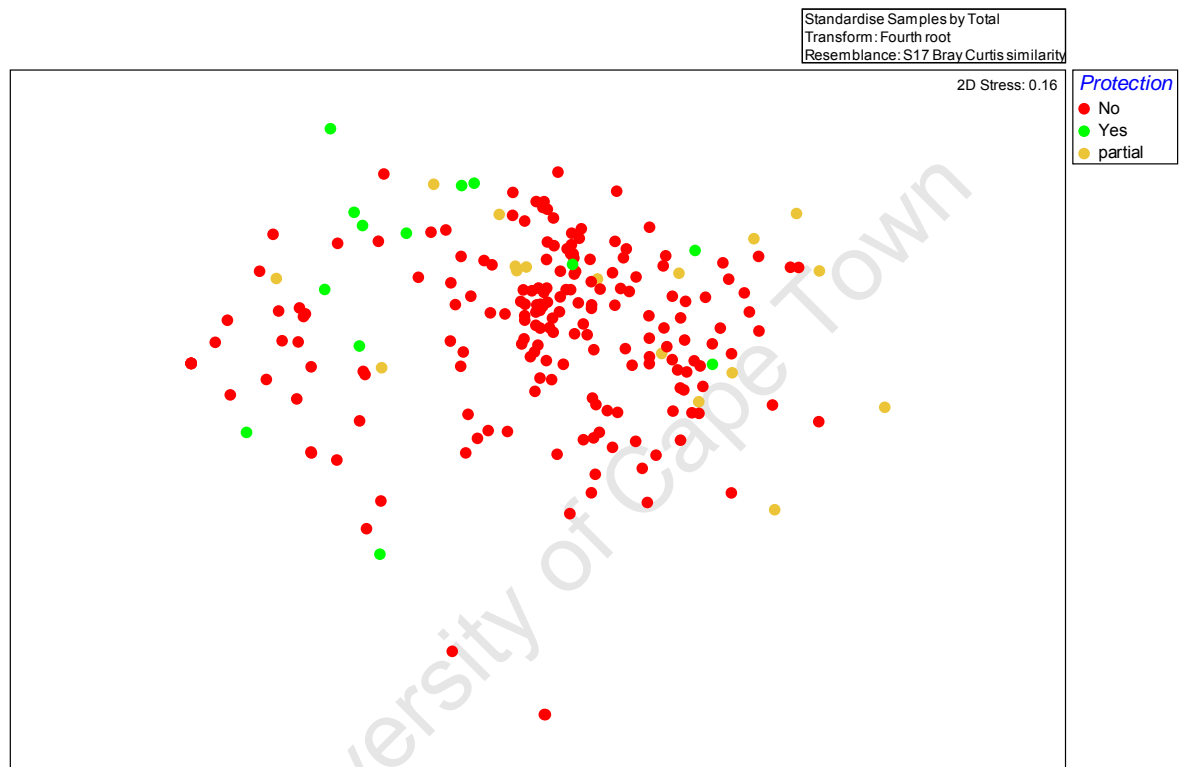
**Figure 17.** Shannon-Wiener diversity index for estuarine fish sampled by seine-netting. Sites from west to east along the South African coast (see appendix 4 for a list of estuaries sampled).



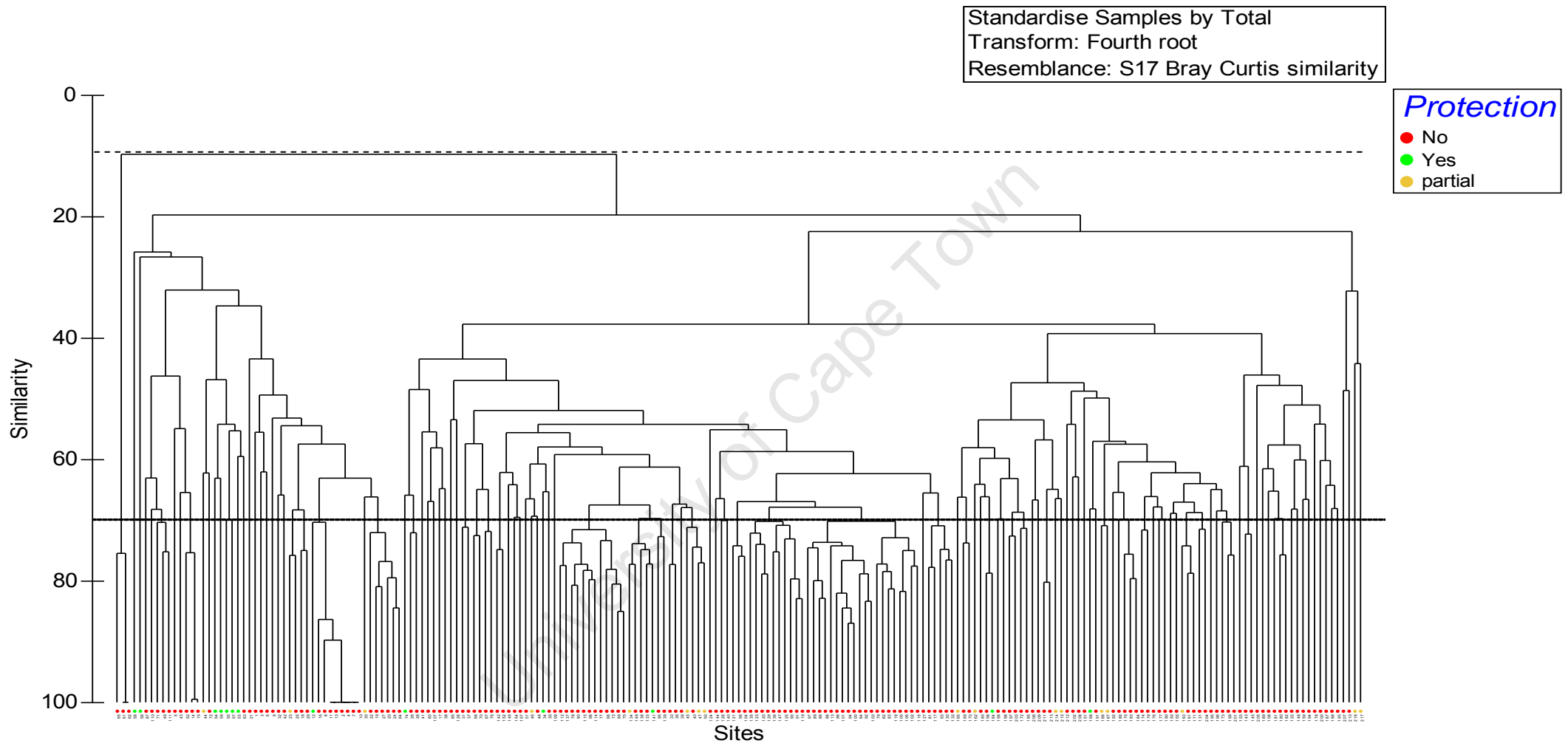
**Figure 18.** Frequency histogram showing the number of fish species represented in the given number of MPAs based on estuarine seine-netting samples.

There is no clear differentiation of sites on the basis of estuarine associated fish community structure (fig 19). At 70 percent similarity, there are 121 clusters of fish communities, of

which 25 have an MPA or some level of environmental protection. However, only 13 groups have a “no-take” MPA. There are 108 groups of sites with similar communities that have no form of protection at this level of similarity. Only at nine percent similarity do all the groups have protection, above that similarity level there are groups of communities that are not represented in MPAs (fig 20).



**Figure 19.** Two-dimensional MDS plot showing similarities between fish communities in the different seine-netting sampled sites along the South African coast. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, partial = data obtained from a site where there is environmental protection but fishing is allowed (see appendix 4 for information on the protection level of each estuary).

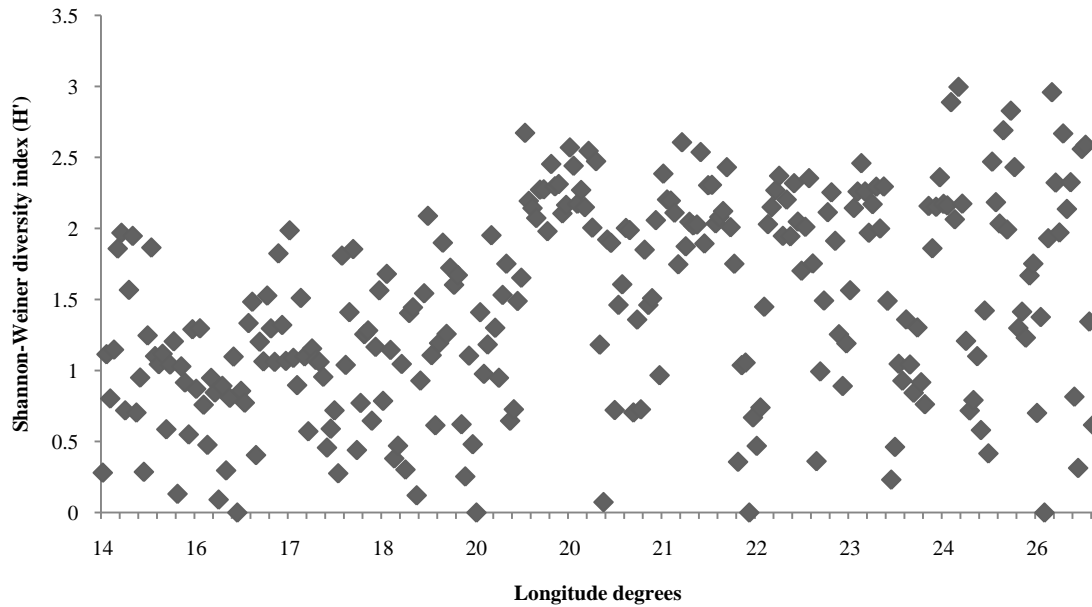


**Figure 20.** Dendrogram showing similarities between fish communities in the different seine-netting sampled estuaries along the South African coast. Cut off points were drawn at 70 and 9 percent similarity. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, partial = data obtained from a site where there is environmental protection but fishing is allowed.

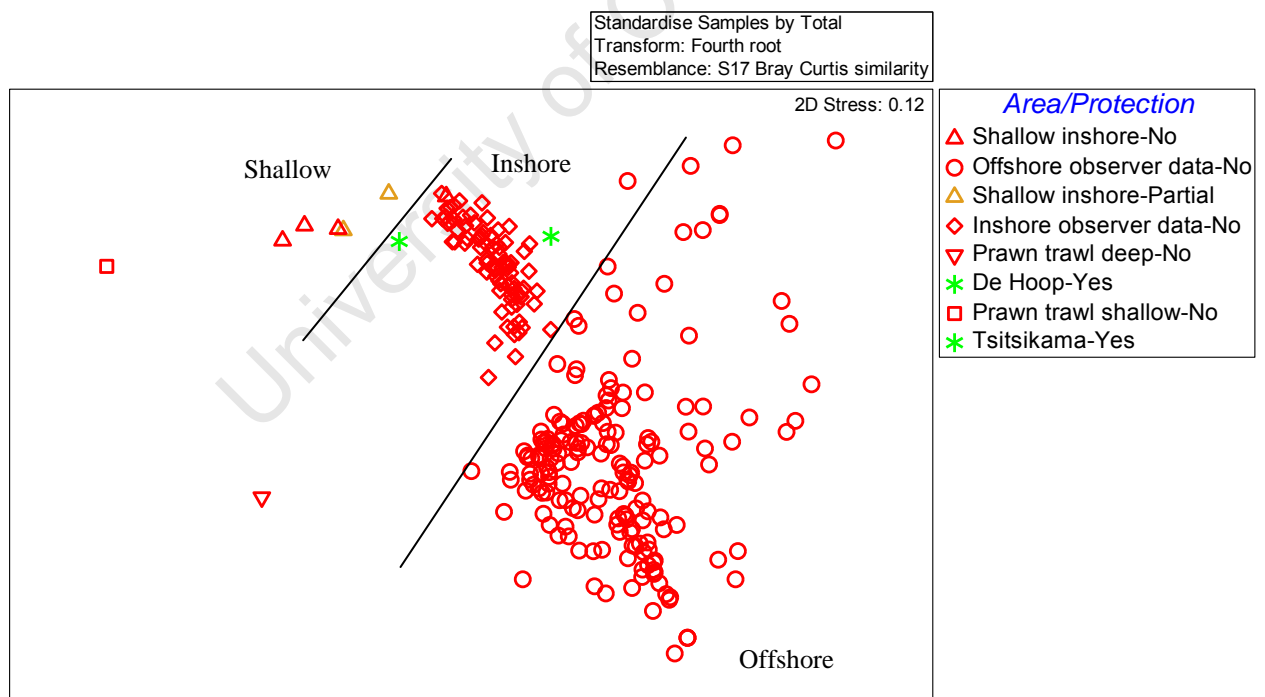
### *Trawling sampling method*

In total 446 fish species were recorded from the 269 sites sampled. On average 32 species were recorded per site with a standard deviation of  $\pm 28$  species, and the number of species recorded ranged between 1 and 113 species per site. There is an increasing trend in diversity along a longitudinal gradient (fig 21). Of the total number of species recorded, 138 were present in MPAs, which accounts for 30.94 percent. However, of the 446 species only 95 were recorded in “no-take” MPAs, which makes up 21.30 percent of the total number of species. A total of 308 species were not recorded in any MPA. Of the 95 species recorded in “no-take” MPAs, 56 species were recorded in one “no-take” MPA, and, 39 species were represented in two “no-take” MPAs.

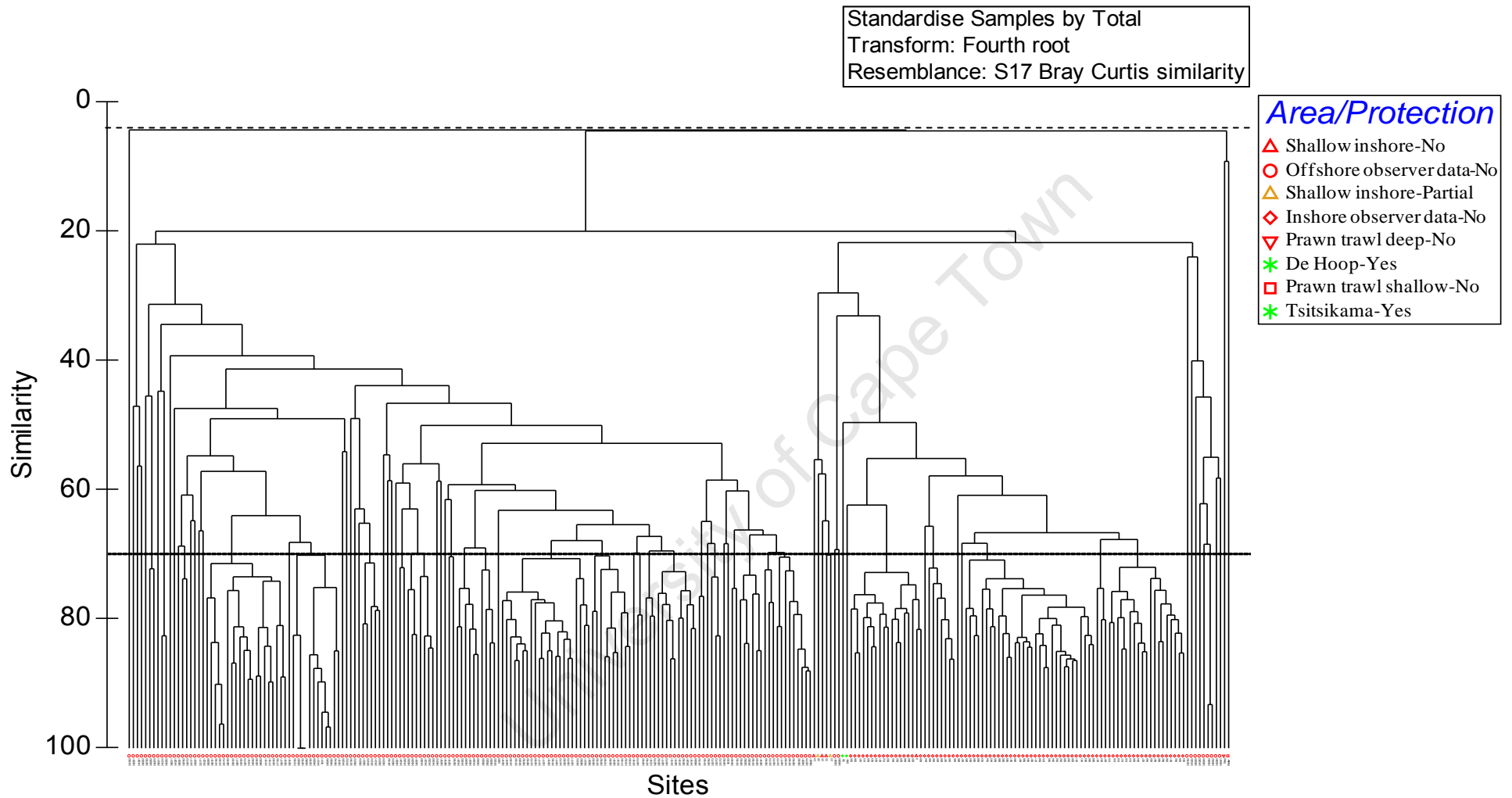
There is a distinction between offshore deep water fish communities, inshore fish communities, and shallow inshore fish communities (fig 22). At 70 percent similarity, there are 80 clusters of fish communities. Of the 80 clusters, four have an MPA site in them, however only two groups have a “no-take” MPA. There are 79 groups of sites with similar communities that have no form of protection at this level of similarity. Only at four percent similarity do all the groups have an MPA. Above that similarity level there are groups of communities that are not represented in MPAs (fig 23).



**Figure 21.** Shannon-Wiener diversity index for trawling sampled sites organized from west to east along a longitudinal gradient on the South African coast.



**Figure 22.** Two-dimensional MDS plot showing similarities between fish communities in the different trawling sites along the South African coast. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a site in a “no-take” MPA, partial = data obtained from an site where there is an MPA within the longitudinal degree.



**Figure 23.** Dendrogram showing similarities between fish communities in the different trawling sampled sites along the South African coast. Cut off points were drawn at 70 and 4 percent similarity. Protection factors: no = data obtained from a site not protected by MPA, yes = data obtained from a “no-take” MPA, partial = data obtained from a site where there is an MPA within the longitudinal degree.

## DISCUSSION

### *Trends in diversity*

Turpie et al. (2000) found an increase in species richness in coastal fish from the west to the north east along the South African coast. The same pattern has been shown for estuarine fish species in South Africa (Harrison 2002; Maree et al. 2000; Whitfield 1999). The increase in diversity along the longitudinal gradient on the coast of South Africa can be due to several influential factors such as sea temperature, productivity and habitat diversity; as well as the fact that the Indo-Pacific ocean is known to have a higher number of fish species than the Atlantic ocean (Lombard et al. 2004; McQuaid & Branch 1984; Turpie et al. 2000; Williams et al. 2001). Sea temperatures differ between the west and east coast of South Africa, with a decline in temperature from the north-east Coast to the south and west coast (Isaac 1937; Whitfield 1999). The Benguela current drifting northwards along the west coast is formed by cold productive waters brought to the surface by upwelling systems inshore (Branch et al. 2002; Isaac 1937; Lombard et al. 2004). On the opposite coast, the Agulhas current flows southwards along the east coast bringing warm, nutrient-poor waters from the subtropics (Branch et al. 2002; Isaac 1937). Intermediate temperatures and productivity occur in the region around the Agulhas bank in the South Coast where some upwelling take place (Lombard et al. 2004).

Changes in ocean temperatures affect the availability of nutrients for primary production, which may cause an inverse relationship between sea temperature and productivity (Behrenfeld et al. 2006). Previous studies have shown that there is an association between high fish diversity and low productivity and vice versa, as well as a relationship between species richness and water temperature (Maree et al. 2000; Rosenzweig 1992; Williams et al. 2001). This may explain why the fish species diversity that was found in this study increases

from the high productivity cold waters of the West Coast to the warm low productivity waters of the north East Coast. In addition, as found by Tupie et al. (2000), the number of tropical species from the Indo-Pacific and western Indian oceans decreases from the north East Coast southwards. The decreasing diversity around the Knysna area obtained from NMLS catch return data could be due to cold water associated with wind induced upwelling at capes between Knysna and Port Elizabeth (Hutchings et al. 2002). Yemane et al. (2010), in their study on demersal fish off the South Coast of South Africa (from 20°E to 27°E), found that diversity remained constant between degrees 20° to 24°. The lowest diversity was at 24°, after which demersal fish diversity slightly increased along the longitudinal gradient (Yemane et al. 2010).

The different results obtained from the commercial NMLS and the survey boat-based line-fishing data, could be explained by the way in which these data are collected. The commercial data obtained from catch return information is not as accurate and detailed as the data obtained from scientific surveys. Commercial fishers target several economically important species and in some cases may discard unwanted species. However, these commercial data can provide us with important information on the abundance and diversity of fish species around the entire coast. The number of species protected and sites of potential protection based on the NMLS data should not be considered as actual protection of those fish communities, since that data were not obtained from the MPAs, but rather in the immediate vicinity.

The number of fish taxa occupying estuaries is generally low, due to the unstable conditions and the high level of adaptation needed to survive in such environments (Whitfield 1994). Only 10 percent of the fish families described around the world are part of the estuarine ichthyofauna (Whitfield 1999). This may provide evidence of why in this study the estuaries had the lowest mean number of species per site, as well as the lowest total number of species.

### *Redundancy*

According to the Convention on Biological Diversity replication of ecological features means that ‘more than one site shall contain examples of a given feature in the given biogeographic area. The term “features” means “species, habitats and ecological processes” that naturally occur in the given biogeographic area’(CBD 2008). It is important to have replication of ecological features, or redundancy, in MPA networks in order to account for potential catastrophes or variability that can place these features at risk (CBD 2008). The South African MPA network has a low level of redundancy regarding fish communities, the majority of the species are only represented in one MPA or not represented at all, and if a stochastic event should occur those fish populations could be drastically affected.

### *Biogeography*

Lombard et al. (2004) described five inshore biogeographic regions as well as four offshore bioregions along South Africa’s EEZ based on an integration of existing biogeographic studies and expert opinion. The inshore bioregions are Namaqua, south-western Cape, Agulhas, Natal and Delagoa (Lombard et al. 2004). Branch et al (2002) recognized three broader marine biogeographic provinces around the coast of South Africa, the cold temperate Namaqua Province from the Namibian border to Cape Point, the warm temperate Agulhas Province from Cape Point to northern Transkei, and the subtropical Natal Province from northern Tanskei to southern Moçambique. These broad biogeographic regions coincide with the three major zones with similar coastal fish communities identified in this study, based on shore-angling and boat-based line-fishing data. These zones were also identified by other studies on South African marine fauna, although the boundaries and names of these broad biogeographic zones differ among studies (Emanuel et al. 1992; Harrison 2002; Prochazka 1994; Turpie et al. 2000).

Different fauna inhabit the areas south east and north west from Cape Point (Branch et al. 2002). A potential reason for the marked boundary found between coastal fish communities in the west coast and south-east coast around the Cape Peninsula may be that the area between the Cape Peninsula and Cape Agulhas is not influenced directly by the Agulhas or the Benguela currents. Instead this area is influenced by each of the currents at different times of the year; the sea temperature is higher in the area between the Cape Peninsula and Cape Agulhas than west of the Cape Peninsula (Griffiths et al. 2010; Isaac 1937).

The Cape Peninsula has also been found to be a boundary in other biogeographical studies of marine fauna. Emanuel et al. (1992) in their study on marine invertebrates found the boundary between the cool temperate south-west coast and the warm temperate south coast communities to be located around Cape Point. The study mentioned above also found a boundary between the two sub-provinces within the subtropical east coast to be close to Durban. This coincides as well with the second boundary found by this study between the south-east coast and the north-east coast. In addition, a study by Prochazka (1994) on the biogeography of intertidal fish species, found that the West Coast's limit was at Koppie Alleen. However the same study also found that the sites Koppie Alleen and False Bay appeared to be a transition zone for intertidal fish communities, and that sites between Lüderitz and the west coast of the Cape Peninsula clustered tightly together. Prochazka (1994) also found the boundary described by intertidal fish communities between the two east coast provinces to be somewhere close to Durban. The boundaries described by the fish communities included in this study are also in agreement with the boundaries found by Turpie et al. (2000) for coastal fish communities.

### *Representativity*

The representation of fish communities from the west coast of South Africa is the lowest in the MPA network. Similar results were found for marine invertebrates in Emanuel et al.'s (1992) study; the study concluded that the area between the Groen and the Spoeg rivers on the west coast has a high priority for conservation action. This, due to its representativeness of one of the major biogeographic provinces described by the authors (the Namaqua province), as well as the lack of overall protection for this region and its close to pristine state (Emanuel et al. 1992).

According to Lombard et al. (2004), the west coast biozones have the least amount of protection and experience the highest levels of threat. Thus, there is an urgent need of protection in this area. There is a proposed MPA in Namaqualand, which would cover 9 980 km<sup>2</sup> (Lombard et al. 2004); this MPA could greatly improve the representation of these communities in the MPA network.

In the marine component of the National Spatial Biodiversity Assessment by Lombard et al. (2004), the entire east coast was described as having a low priority status for conservation intervention, based on levels of threat and protection. In addition, the southern part of the east coast was found to have the lowest priority status. This coincides with this study's findings, which indicate that the fish communities from the south-east coast are of those that have the highest representation in South Africa's MPA network. Also, a larger portion of the coastline is protected in the east coast than in the west coast, hence the greater representation in MPAs of fish communities in the east coast.

Turpie (2004), as part of the estuarine component for the NSBA, describes the overall protection status of South Africa's estuaries to be very low. Tsitsikama National Park is the only area in which the estuaries enjoy complete protection against exploitation, i.e. any kind

of fishing or extraction is entirely banned (Turpie 2004). Of the 258 South African estuaries, which were included on the NSBA, 41 form part of protected areas, however of those 258 only 14 were found to have a high level of protection, which accounts to only 5,4 percent of the total number of estuaries (Turpie et al. 2002). Additionally, Turpie et al. (2002) found that 33 estuaries were under some kind of protection at the time, however they did not entirely represent estuarine biodiversity in South Africa. This coincides with the very low representation of estuarine fish communities in MPAs found in this study. Estuaries function as vital nursery and feeding grounds for many estuarine-associated fish species (Harrison 2002). Therefore, their protection is key for the conservation of marine fish communities and estuarine ecosystem functioning. Whitfield (1997) highlighted the need for conservation action in South African estuaries, starting from adequate river catchment management, as well as habitat restoration in some cases.

Currently there is no MPAs in offshore bioregions of South Africa's EEZ (Lombard et al. 2004). There are only a few MPAs in trawlable grounds in South Africa, namely Tsitsikama, De Hoop, Pondoland and Bird Island (C. Attwood, pers. comm.). The two MPAs with trawlable grounds for which data were available, Tsitsikama and De Hoop MPAs, do not fully represent the offshore fish communities. There is a need for MPAs that extend offshore if we aim to represent South Africa's marine biodiversity (Lombard et al. 2004). Regarding offshore habitats, South Africa is far from meeting the conservation target of protecting more than 20 percent of each habitat (Lombard et al. 2004).

Currently, regarding all marine fish communities, based on this study South Africa's MPA network is at approximately 40 percent representativity for fish communities inhabiting the coastal shelf and the littoral, and less than 5 percent representativity for demersal fishes. However, there is no stipulation on how much of these communities should be represented in the MPA network. If we aim to represent all the fish communities present in South African

waters in the MPA network, more and larger protected areas need to be declared and properly enforced. These should be based on gap analyses such as the NSBA, in order to place them in areas where they would increase the representation of marine biodiversity in the MPA network.

### *Method*

This method to test for representativeness through quantitative data is advantageous over presence/absence records, since it is based on discrete sampling methods. It allows for repetition and provides a quantitative measure to representativity. Edgar et al. (1997) stress that 'a biological survey program is unavoidable when formulating an integrated MPA design'. The incorporation of various fishing techniques for monitoring programs has been recognized as a more effective practice (Coates et al. 2007; Lapointe et al. 2006). According to Tremain & Adams (1995) and Shoup et al. (2003) multigear collection methods are essential for an effective definition of fish diversity. Having a quantitative value for representativity of fish communities in South Africa's MPA network can help policy makers evaluate whether targets are being met, and where conservation action, in terms of fish species protection, needs to be focused.

## CHAPTER III

### SYNTHESIS AND CONCLUSIONS

This study aimed to identify similar fish communities along the South African coast. This was performed using long term data sets of shore angling, trawling, boat based line-fishing and seine netting (in estuaries) sampling methods. In addition, comparisons were made between communities within and outside MPAs. This study also assessed the value of multigear quantitative data sets of fish abundance for MPA network representativity evaluations.

Three major biogeographic zones were described regarding fish communities; the west coast, the south coast in a group together with the east coast, and the north-east coast. A distinction was found between estuarine and shore habitat sampled by shore angling. In addition, shallow water, inshore and offshore fish communities sampled by trawling also separated into different groups.

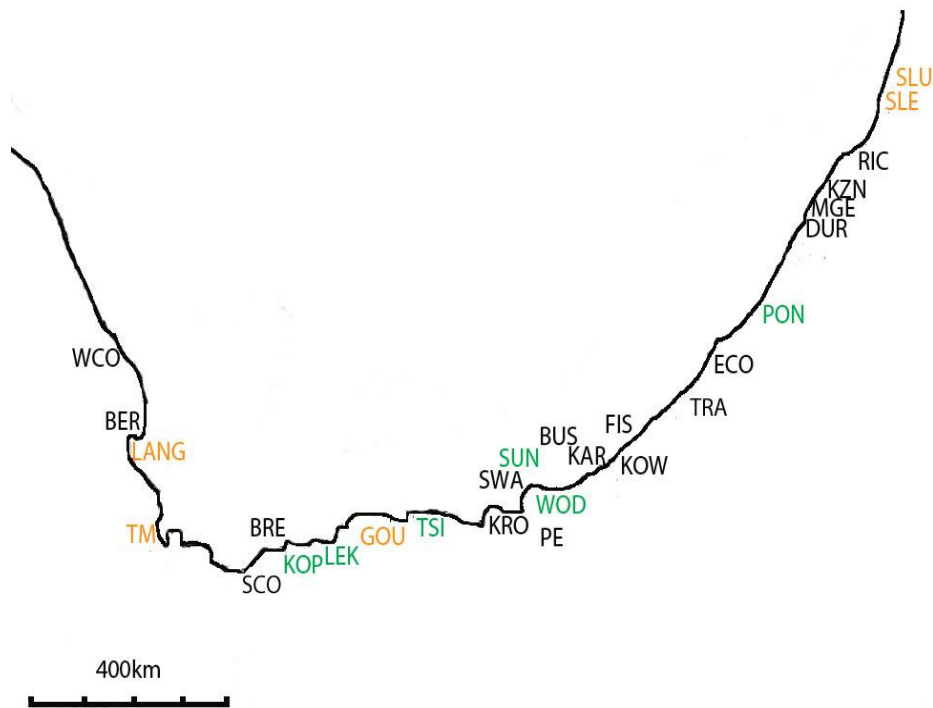
Low representativeness in MPAs was evident for the west coast fish communities, as well as for estuarine and offshore fish communities. The south-east coast is the area in which fish communities are best represented. The percentage of representativity in MPAs of the fish communities sampled by each fishing technique was as follows: 44 percent of the communities sampled by shore angling, 41 percent of the communities sampled by boat based line-fishing, nine percent of estuarine communities sampled by seine netting and four percent of the communities sampled by trawling. If South Africa desires a higher percentage of fish communities represented within its MPA network, there would need to be more and larger protected areas declared. These potential MPAs should be located based on gap analyses (such as the NSBA) so that they represent complementary areas in which biodiversity representation is low.

This study used a quantitative, multi-gear method of evaluating the representativity of an MPA network, which is advantageous over a simple presence/absence approach, as it provides a quantitative measure of representativity, is based on discrete sampling methods and also allows for repetition. This study included data on 10 of the major MPAs (out of 22 declared MPAs). Survey data for more MPAs would improve the coverage of the study and can potentially improve the overall results.

With a quantitative value for fish community representation in South Africa's MPA network, policy makers can evaluate whether targets are being met. This assessment can assist in the identification of potential MPA target areas by identifying areas for which priority conservation action is needed in terms of fish species protection.

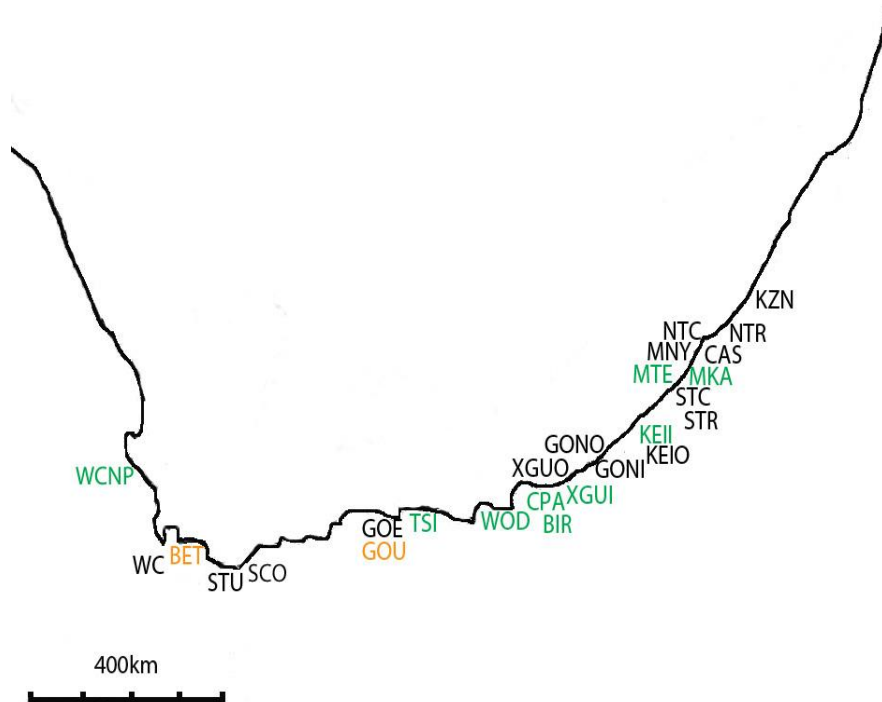
University of Cape Town

## APPENDICES



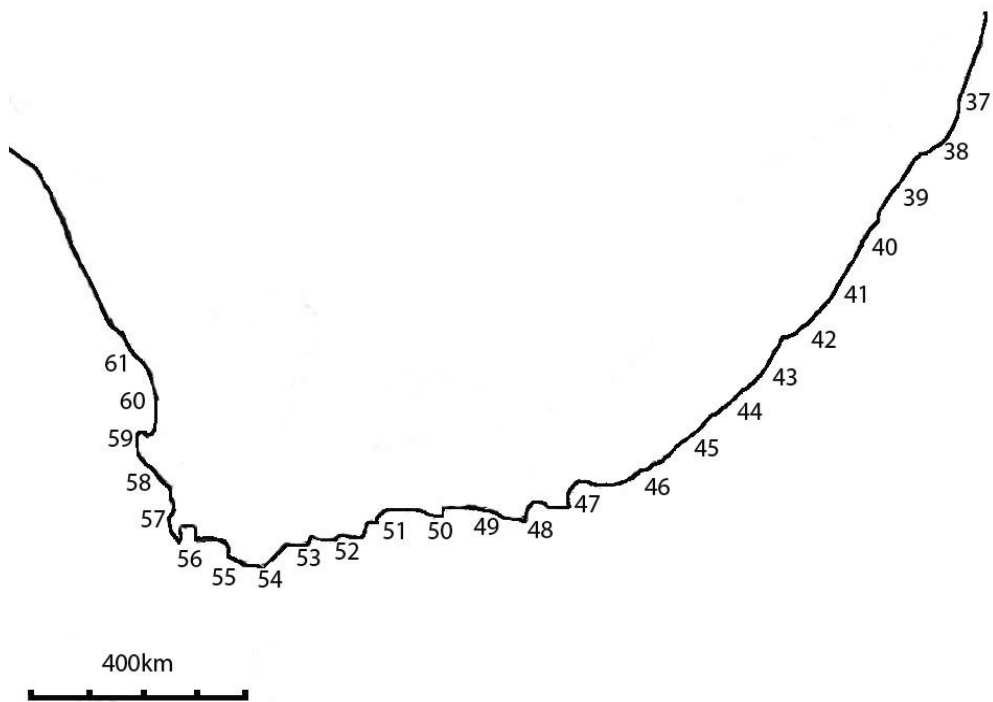
Code	Site name
BER	Berg river
BRE	Breede river
BUS	Bushmans
DUR	Durban bay
ECO	East Coast
FIS	Fish river
GAM	Gamtoos river
GOU	Goukama
KAR	Kariega river
KOP	Koppie Alleen
KOW	Kowie river
KRO	Kromme river
KZN	KwaZulu Natal
LANG	Langebaan
LEK	Leekerwater
MGE	Mgeni river
PE	Port Elizabeth
PON	Pondoland
RIC	Richards bay
SCO	South Coast
SLE	ST Lucia estuary
SLU	ST Lucia
SUN	Sundays river
SWA	Swartkops river
TM	Table Mountain
TRA	Transkei
TSI	Tsitsikama
WCO	West Coast
WOD	Woody Cape

**Appendix 1.** Map showing the sites where shore angling data was collected. Green means the data were collected from “no- take” areas in MPAs; orange means the data were collected from MPAs where some type of fishing is allowed, and black means data were collected from areas with no MPAs.



Code	Site name
BET	Bettys bay
BIR	Bird Island
CAS	Casino
CPA	Cape Padrone
GOE	Goukama exploited
GONI	Gonubi inside MPA
GONO	Gonubi outside MPA
GOU	Goukama MPA
KEII	Kei inside MPA
KEIO	Kei outside MPA
KZN	KwaZulu Natal
MKA	Mkambati
MNY	Mnyameni
MTE	Mtentu
NTC	Northern Tanskei commercial
NTR	Northern Tanskei recreational
SC	Southern Cape
STC	Southern Tanskei commercial
STR	Southern Tanskei recreational
STU	Struisbaai
TSI	Tsitsikama
WC	Western Cape
WCNP	West Coast National Park
WOD	Woody Cape
XGUI	Xgulu inside MPA
XGUO	Xgulu outside MPA

**Appendix 2.** Map showing the sites where boat-based line-fishing data were collected. Green means the data were collected from “no- take” areas in MPAs; orange means the data were collected from MPAs where some type of fishing is allowed, and black means data were collected from areas with no MPAs.



**Appendix 3.** Map showing the approximate location of 100 km long blocks where NMLS data were collected.

University of Cape

**Appendix 4.** Estuaries included in the analyses and the level of protection assigned.

No.	Estuary	Protection	No.	Estuary	Protection	No.	Estuary	Protection	No.	Estuary	Protection
1	Orange	partial	34	Duiwenhoks	No	67	Seekoe	No	100	Lilyvale	No
2	Spoeg	No	35	Goukou	Yes	68	Kabeljous	No	101	Ross' Creek	No
3	Olifants	No	36	Gouritz	No	69	Gamtoos	No	102	Ncera	No
4	Jakkals	No	37	Blinde	No	70	Van Stadens	No	103	Mlele	No
5	Verlore	No	38	Hartenbos	No	71	Maitland	No	104	Mcantsi	No
6	Berg	No	39	Klein Brak	No	72	Bakens	No	105	Gxulu	No
7	Modder	No	40	Groot Brak	No	73	Swartkops	No	106	Goda	No
8	Sout (S)	No	41	Maalgate	No	74	Koega	No	107	Hlozi	No
9	Diep	No	42	Gwaing	No	75	Sundays	Yes	108	Hickmans	No
10	Sout R.	No	43	Meul	No	76	Boknes	No	109	Buffalo	No
11	Houtbaai	No	44	Kaaimans	No	77	Bushmans	No	110	Blind	No
12	Wildevael	No	45	Touw	partial	78	Kariega	No	111	Hlaze	No
13	Schuster	Yes	46	Swartvlei	partial	79	Kasuka	No	112	Nahoon	No
14	Krom	No	47	Goukamma	partial	80	Kowie	No	113	Qinira	No
15	Booiskraal	No	48	Knysna	partial	81	Rufane	No	114	Gqunube	No
16	Silwermyl	No	49	Noetsie	No	82	Riet	No	115	Kwelera	No
17	Sand	No	50	Piesang	No	83	Wes-Kleinmond	No	116	Bulura	No
18	Eerste	No	51	Keurbooms	partial	84	Oos-Kleinmond	No	117	Cunge	No
19	Lourens	No	52	Matjies	No	85	Great Fish	No	118	Cintsa	No
20	Sir Lowry's	No	53	Sout	No	86	Old Woman's	No	119	Cefane	No
21	Steenbras	No	54	Groot (W)	Yes	87	Thatshana	No	120	Kwenxura	No
22	Rooiels	No	55	Bloukrans	Yes	88	Mpekweni	No	121	Nyara	No
23	Buffels (O)	No	56	Lottering	Yes	89	Mtati	No	122	Imtwendwe	No
24	Palmiet	partial	57	Elandsbos	Yes	90	Mgwalana	No	123	Haga-Haga	No
25	Kleinmond	No	58	Storms	Yes	91	Bira	No	124	Mtendwe	No
26	Bot	No	59	Elands	Yes	92	Gqutywa	No	125	Quko	No
27	Onrus	No	60	Groot (O)	Yes	93	Ngculura	No	126	Morgan	No
28	Klein	No	61	Boskloof	No	94	Mtana	No	127	Cwili	No
29	Uilkraals	No	62	Kaapsedrif	No	95	Keiskamma	No	128	Great Kei	No
30	Ratel	No	63	Tsitsikamma	No	96	Ngqinisa	No	129	Gxara	No
31	Heuningnes	partial	64	Klipdrif (O)	No	97	Kiwane	No	130	Ngogwane	No
32	Klipdriftfontein	No	65	Slang	No	98	Tyolomnqa	No	131	Qolora	No
33	Bree	No	66	Kromme	No	99	Shelbertsstroom	No	132	Ncizele	No

#### Appendix 4 (continued)

No.	Estuary	Protection	No.	Estuary	Protection	No.	Estuary	Protection	No.	Estuary	Protection
133	Kobonqaba	No	156	Sinangwana	No	179	Mbizana	No	202	Sipingo	No
134	Ngqusi/Inxaxo	No	157	Mngazana	No	180	Mvutshini	No	203	Mgeni	No
135	Cebe	partial	158	Mngazi	No	181	Bilahlolo	No	204	Mhlanga	No
136	Zalu	No	159	Gxwaleni	No	182	Kongweni	No	205	Mdloti	No
137	Ngqwara	No	160	Bulolo	No	183	Mhlangeni	No	206	Mhlali	No
138	Qora	No	161	Mtumbane	No	184	Zotsha	No	207	Mvoti	No
139	Jujura	No	162	Mzimvubu	No	185	Mzimkulu	No	208	Mdlotane	No
140	Ngadla	No	163	Ntlupeni	partial	186	Mtentweni	No	209	Zinkwasi	No
141	Shixini	No	164	Mntafufu	partial	187	Mhlangamkulu	No	210	Tugela	No
142	Mbashe	Yes	165	Msikaba	Yes	188	Damba	No	211	Matigulu/Nyoni	No
143	Ku-Mpenzu	No	166	Butsha	partial	189	Intshambili	No	212	Siyai	No
144	Ku-Bhula	No	167	Mgwegwe	partial	190	Mhlabatshane	No	213	Mlalazi	No
145	Kwa-Suku	No	168	Mgwetyana	partial	191	Fafa	No	214	Mfolozi/Msunduzi	No
146	Ntlonyane	No	169	Mtentu	Yes	192	Sezela	No	215	St Lucia	Partial
147	Nkanya	No	170	Mzamba	No	193	Mkumbane	No	216	Mgobezeleni	Partial
148	Sundwana	No	171	Mtentwana	No	194	Mzimayi	No	217	Kosi	Partial
149	Xora	No	172	Mtamvuna	No	195	Mpambanyoni	No			
150	Nenga	No	173	Sandlundlu	No	196	Mahlongwa	No			
151	Mapuzi	No	174	Tongazi	No	197	Mkomazi	No			
152	Mtata	No	175	Kandandlovu	No	198	Lovu	No			
153	Thsani	No	176	Mpenjati	No	199	L.Manzimtoti	No			
154	Mdumbi	No	177	Umhlangankulu	No	200	Manzimtoti	No			
155	Mpande	No	178	Kaba	No	201	Mbokodweni	No			

## REFERENCES

- Attwood, C. G., J. M. Harris, and A. J. Williams. 1997a. International experience of marine protected areas and their relevance to South Africa. *South African Journal of Marine Science* **18**:311 - 332.
- Attwood, C. G., B. Q. Mann, J. Beaumont, and J. M. Harris. 1997b. Review of the state of marine protected areas in South Africa. *South African Journal of Marine Science* **18**:341 - 367.
- Auster, P. J., R. J. Malatesta, R. W. Langton, L. Watting, P. C. Valentine, C. L. S. Donaldson, E. W. Langton, A. N. Shepard, and W. G. Babb. 1996. The impacts of mobile fishing gear on seafloor habitats in the gulf of Maine (Northwest Atlantic): Implications for conservation of fish populations. *Reviews in Fisheries Science* **4**:185 - 202.
- Bascompte, J., C. J. Melián, and E. Sala. 2005. Interaction strength combinations and the overfishing of a marine food web. *Proceedings of the National Academy of Sciences of the United States of America* **102**:5443-5447.
- Bax, N., A. Williamson, M. Agüero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. *Marine Policy* **27**:313-323.
- Beckley, L. E., S. T. Fennessy, and B. I. Everett. 2008. Few fish but many fishers: a case study of shore-based recreational angling in a major South African estuarine port. *African Journal of Marine Science* **30**:11 - 24.
- Behrenfeld, M. J., R. T. O'Malley, D. A. Siegel, C. R. McClain, J. L. Sarmiento, G. C. Feldman, A. J. Milligan, P. G. Falkowski, R. M. Letelier, and E. S. Boss. 2006. Climate-driven trends in contemporary ocean productivity. *Nature* **444**:752-755.
- Bennet, B. A., and C. G. Attwood. 1993. In defense of the De Hoop Marine Reserve. Oceanographic research Institute special publication.
- Branch, G. M., C. L. Griffiths, M. L. Branch, and L. E. Beckley 2002. *Two Oceans: A guide to the marine life of Southern Africa*. David Phillip Publishers, Cape Town.
- Brouwer, S. L., B. Q. Mann, S. J. Lamberth, W. H. H. Sauer, and C. Erasmus. 1997. A survey of the South African shore-angling fishery. *South African Journal of Marine Science* **18**:165 - 177.
- Castilla, J. C., and E. Nealler. 1978. Marine environmental impact due to mining activities of El Salvador copper mine, Chile. *Marine Pollution Bulletin* **9**:67-70.

- CBD. 2002. Conserving plant diversity. In: Report of the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity, The Hague, 7-19 April 2002. Agenda item 17.3. UNEP.
- CBD. 2008. Marine and coastal biodiversity. In: Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its ninth meeting, 19 to 30 May 2008. Agenda item 4.9. UNEP.
- Clarke, J. R., and C. D. Buxton. 1989. A survey of the recreational rock-angling fishery at Port Elizabeth, on the south-east coast of South Africa. *South African Journal of Marine Science* **8**:183 - 194.
- Clarke, K. R., and R. N. Gorley 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth, UK.
- Clarke, K. R., and R. M. Warwick 2001. Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E, Plymouth, UK.
- Coates, S., A. Waugh, A. Anwar, and M. Robson. 2007. Efficacy of a multi-metric fish index as an analysis tool for the transitional fish component of the Water Framework Directive. *Marine Pollution Bulletin* **55**:225-240.
- Coetzee, P. S., and D. Baird. 1981. Catch composition and catch per unit effort of anglers' catches off St Croix Island, Algoa Bay. *South African journal of wildlife research* **11**:14.
- Coetzee, P. S., D. Baird, and C. Tregoning. 1989. Catch statistics and trends in the shore angling fishery of the east coast, South Africa, for the period 1959-1982. *South African Journal of Marine Science* **8**:155 - 171.
- Collie, J. S., S. J. Hall, M. J. Kaiser, and I. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* **69**:785-798.
- Correa, J., J. Castilla, M. Ramírez, M. Varas, N. Lagos, S. Vergara, A. Moenne, D. Román, and M. Brown. 1999. Copper, copper mine tailings and their effect on marine algae in Northern Chile. *Journal of Applied Phycology* **11**:57-67.
- Crain, C. M., B. S. Halpern, M. W. Beck, and C. V. Kappel. 2009. Understanding and managing human threats to the coastal marine environment. *Annals of the New York Academy of Sciences* **1162**:39-62.
- Dee Boersma, P., and J. K. Parrish. 1999. Limiting abuse: marine protected areas, a limited solution. *Ecological Economics* **31**:287-304.

- Dudley, N., editor. 2008. Guidelines for applying protected area management categories. IUCN, Gland, Switzerland.
- Edgar, G. J., J. Moverley, N. S. Barrett, D. Peters, and C. Reed. 1997. The conservation-related benefits of a systematic marine biological sampling programme: The Tasmanian reef bioregionalisation as a case study. *Biological Conservation* **79**:227-240.
- Emanuel, B. P., R. H. Bustamante, G. M. Branch, S. Eekhout, and F. J. Odendaal. 1992. A zoogeographic and functional approach to the selection of marine reserves on the west coast of South Africa. *South African Journal of Marine Science* **12**:341 - 354.
- FAO. 2005. Review of the state of world marine fishery resources. Pages i-iv, 1-235. FAO Fisheries Technical Paper.
- FAO. 2008. Fisheries and Aquaculture topics. The State of World Fisheries and Aquaculture (SOFIA). Topics Fact Sheets. Text by Jean- Francois Pulvenis. In: FAO Fisheries and Aquaculture Department [online]. Updated 2 April 2008. [<http://www.fao.org/fishery/sofia/en>] Accessed 17 January 2011.
- Fennessy, S. T., A. M. McDonald, B. Q. Mann, and B. I. Everett. 2003. An assessment of the recreational and commercial skiboat fishery in the Transkei. *African Journal of Marine Science* **25**:61 - 78.
- Götz, A., S. E. Kerwath, C. G. Attwood, and W. H. H. Sauer. 2009. Effects of fishing on a temperate reef community in South Africa I: Ichthyofauna. *African Journal of Marine Science* **31**:241-252.
- Griffis, R. B., and K. W. Kimball. 1996. Ecosystem approaches to coastal and ocean stewardship. *Ecological Applications* **6**:708-712.
- Griffiths, C. L., T. B. Robinson, L. Lange, and A. Mead. 2010. Marine Biodiversity in South Africa: An Evaluation of Current States of Knowledge. *PLoS ONE* **5**:e12008.
- Harriott, V. J., D. Davis, and A. B. Simon. 1997. Recreational diving and its impact in marine protected areas in eastern Australia. *Ambio* **26**:173-179.
- Harrison, T. D. 2002. Preliminary assessment of the biogeography of fishes in South African estuaries. *Marine Freshwater Research* **53**:479-490.
- Harrison, T. D. 2003. Biogeography and community structure of fishes in South African estuaries. PhD thesis. Rhodes University, Grahamstown.

- Harrison, T. D., J. A. G. Cooper, and A. E. L. Ramm. 2000. State of South African estuaries: geomorphology, ichthyofauna, water quality and aesthetics. State of the Environment Series Report No. 2. Department of Environmental Affairs and Tourism, South Africa.
- Hockey, P. A. R., and G. M. Branch. 1997. Criteria, objectives and methodology for evaluating marine protected areas in South Africa. *South African Journal of Marine Science* **18**:369 - 383.
- Hutchings, K., B. M. Clark, L. J. Atkinson, and C. G. Attwood. 2008. Evidence of recovery of the linefishery in the Berg River Estuary, Western Cape, South Africa, subsequent to closure of commercial gillnetting. *African Journal of Marine Science* **30**:507 - 517.
- Hutchings, L., L. E. Beckley, M. H. Griffiths, M. J. Roberts, S. Sundby, and C. van der Lingen. 2002. Spawning on the edge: spawning grounds and nursery areas around the southern African coastline. *Marine and Freshwater Research* **53**:307-318.
- Isaac, W. E. 1937. South African coastal waters in relation to ocean currents. *Geographical Review* **27**:651-664.
- IUCN. 1994. Guidelines for Protected Area Management Categories. IUCN, Gland, Switzerland and Cambridge, UK.
- IUCN. 2003. WPC Recommendation V.23 Protecting Marine Biodiversity and Ecosystem Processes through Marine Protected Areas beyond National Jurisdiction. In: Proceedings of the Vth IUCN World Parks Congress, Durban, South Africa, 8 to 17 September 2003, pp 194-196. [<http://cmsdata.iucn.org/downloads/recommendationen.pdf>] Accessed 3 February 2011.
- Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**:629-637.
- Jennings, S., J. K. Pinnegar, N. V. Polunin, and K. J. Warr. 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. *Marine Ecology Progress Series* **213**:127-142

- Kelleher, G. 1999. Guidelines for marine protected areas. IUCN, Gland, Switzerland and Cambridge, UK.
- Kelleher, G., and R. Kenchington 1992. Guidelines for establishing marine protected areas. A Marine Conservation and Development Report. IUCN, Gland, Switzerland.
- Kelleher, G., and C. Recchia. 1998. Editorial: Lessons from marine protected areas around the world. *Parks* **8**:1-4.
- Kura, Y., C. Revenga, E. Hoshino, and G. Mock. 2004. Fishing for answers: making sense of the global fish crisis. World Resources Institute, Washington, DC.
- Laffoley, D., K. Gjerde, and L. Wood. 2008. Progress with marine protected areas since Durban, and future directions. *Parks* **17**:13-22.
- Lapointe, N. W. R., L. D. Corkum, and N. E. Mandrak. 2006. A comparison of methods for sampling fish diversity in shallow offshore waters of large rivers. *North American Journal of Fisheries Management* **26**:503-513.
- Law, R. 2000. Fishing, selection, and phenotypic evolution. *ICES Journal of Marine Science: Journal du Conseil* **57**:659-668.
- Lombard, A. T., T. Strauss, J. Harris, K. Sink, C. Attwood, and L. Hutchings. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 4: Marine Component. South African National Biodiversity Institute, Pretoria.
- Lubchenco, J., S. R. Palumbi, S. D. Gaines, and S. Andelman. 2003. Plugging a hole in the ocean: the emerging science of marine reserves. *Ecological Applications* **13**:3-7.
- Mann, B. Q., L. Celliers, S. T. Fennessy, S. Bailey, and A. D. Wood. 2006. Towards the declaration of a large marine protected area: a subtidal ichthyofaunal survey of the Pondoland coast in the Eastern Cape, South Africa. *African Journal of Marine Science* **28**:535 - 551.
- Mann, B. Q., N. C. James, and L. E. Beckley. 2002. An assessment of the recreational fishery in the St Lucia estuarine system, KwaZulu-Natal, South Africa. *South African Journal of Marine Science* **24**:263-279.
- Mann, B. Q., A. M. McDonald, W. H. H. Sauer, and T. Hecht. 2003. Evaluation of participation in and management of the Transkei shore linefishery. *African Journal of Marine Science* **25**:79 - 97.

- Maree, R. C., A. K. Whitfield, and A. J. Booth. 2000. Effect of water temperature on the biogeography of South African estuarine fishes associated with the subtropical/warm temperate subtraction zone. *South African Journal of Science* **96**.
- McQuaid, C. D., and G. M. Branch. 1984. Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: An analysis of faunal and floral biomass. *Marine ecology. Progress series* **19**:145.
- Molnar, J. L., R. L. Gamboa, C. Revenga, and M. D. Spalding. 2008. Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment* **6**:485-492.
- Palumbi, S. R. 2001. The ecology of marine protected areas. Pages 509–530 in M. Bertness, S. D. Gaines, and M. E. Hoy, editors. *Marine ecology: the new synthesis*. Sinauer, Sunderland, Massachusetts, USA.
- Pauly, D., V. Christensen, S. Guenette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. *Nature* **418**:689-695.
- Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. *American Fisheries Society Special Publication* **25**:i-xvii, 1-371.
- Pradervand, P., and D. Baird. 2002. Assessment of the recreational linefishery in selected Eastern Cape estuaries: trends in catches and effort. *South African Journal of Marine Science* **24**:87 - 101.
- Pradervand, P., L. E. Beckley, B. Q. Mann, and P. V. Radebe. 2003. Assessment of the linefishery in two urban estuarine systems in Kwazulu-natal, South Africa. *African Journal of Marine Science* **25**:111 - 130.
- Pradervand, P., and R. Hiseman. 2006. An analysis of the recreational shore fishery in the Goukamma Marine Protected Area. *African Zoology* **41**:275-289.
- Prochazka, K. 1994. Habitat partitioning in shallow-water cryptic ichthyofaunal communities in the Western and Southwestern Cape, South Africa. PhD thesis. Department of Zoology. University of Cape Town, Cape Town.
- Rosenberg, A. A. 2003. Managing to the margins: the overexploitation of fisheries. *Frontiers in Ecology and the Environment* **1**:102-106.

- Rosenzweig, M. L. 1992. Species Diversity Gradients: We Know More and Less Than We Thought. *Journal of Mammalogy* **73**:715-730.
- Shoup, D. E., R. E. Carlson, R. T. Heath, and M. W. Kershner. 2003. Comparison of the Species Composition, Catch Rate, and Length Distribution of the Catch from Trap Nets with Three Different Mesh and Throat Size Combinations. *North American Journal of Fisheries Management* **23**:462-469.
- Smith, M. M., and P. C. Heemstra 1986. *Smiths' sea fishes*. Macmillian, Johannesburg.
- Spalding, M. D., L. Fish, and L. J. Wood. 2008. Toward representative protection of the world's coasts and oceans—progress, gaps, and opportunities. *Conservation Letters* **1**:217-226.
- Spalding, M. D., H. E. Fox, G. R. Allen, N. Davidson, Z. A. Ferdana, M. Finlayson, B. S. Halpern, M. A. Jorge, A. Lombana, S. A. Lourie, D. K. Martin, E. McManus, J. Molnar, C. A. Recchia, and J. Robertson. 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience* **57**:573-584
- Sumaila, U. R., S. Guenette, J. Alder, and R. Chuenpagdee. 2000. Addressing ecosystem effects of fishing using marine protected areas. *ICES Journal of Marine Science: Journal du Conseil* **57**:752-760.
- Thrush, S. F., and P. K. Dayton. 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Annual Review of Ecology and Systematics* **33**:449-473.
- Tovar, A., C. Moreno, M. P. Manuel-Vez, and M. García-Vargas. 2000. Environmental implications of intensive marine aquaculture in earthen ponds. *Marine Pollution Bulletin* **40**:981-988.
- Tremain, D. M., and D. H. Adams. 1995. Seasonal Variations in Species Diversity, Abundance, and Composition of Fish Communities in the Northern Indian River Lagoon, Florida. *Bulletin of Marine Science* **57**:171-192.
- Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, A. K. Whitfield, T. H. Wooldridge, S. J. Lamberth, S. Taljaard, and L. Van Niekerk. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water S.A* **28**:191-206.
- Turpie, J. K., L. E. Beckley, and S. M. Katua. 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biological Conservation* **92**:59-72.

- UN. 2002. Protecting and managing the natural resource base of economic and social development. In: Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August to 4 September 2002, pp 25. [[http://www.un.org/jsummit/html/documents/summit\\_docs/131302\\_wssd\\_report\\_reissued.pdf](http://www.un.org/jsummit/html/documents/summit_docs/131302_wssd_report_reissued.pdf)] Accessed 5 February 2011.
- Wallace, J. H., H. M. Kok, C. D. Buxton, and B. Bennett. 1984. Inshore small-mesh trawling survey of the Cape south coast. Part 1. Introduction, methods, stations and catches. *South African Journal of Zoology* **19**:154-164.
- Watling, L., and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology* **12**:1180-1197.
- Whitfield, A. K. 1994. Fish species diversity in southern african estuarine systems- an evolutionary perspective. *Environmental Biology of Fishes* **40**:37-48.
- Whitfield, A. K. 1997. Fish conservation in South African estuaries. *Aquatic Conservation: Marine and Freshwater Ecosystems* **7**:1-11.
- Whitfield, A. K. 1999. Ichthyofaunal assemblages in estuaries: A South African case study. *Reviews in Fish Biology and Fisheries* **9**:151-186.
- Williams, A., J. A. Koslow, and P. R. Last. 2001. Diversity, density and community structure of the demersal fish fauna of the continental slope off western Australia (20 to 35 degrees S). *Marine Ecology-Progress Series* **212**:247-263.
- Williams, C. 1996. Combatting marine pollution from land-based activities: Australian initiatives. *Ocean & Coastal Management* **33**:87-112.
- Wood, L. J., L. Fish, J. Laughren, and D. Pauly. 2008. Assessing progress towards global marine protection targets: shortfalls in information and action. *Oryx* **42**:340-351.
- Wu, R. S. S. 1995. The environmental impact of marine fish culture: Towards a sustainable future. *Marine Pollution Bulletin* **31**:159-166.
- Wu, R. S. S., K. S. Lam, D. W. MacKay, T. C. Lau, and V. Yam. 1994. Impact of marine fish farming on water quality and bottom sediment: A case study in the sub-tropical environment. *Marine Environmental Research* **38**:115-145.
- Yemane, D., J. G. Field, and R. W. Leslie. 2010. Spatio-temporal patterns in the diversity of demersal fish communities off the south coast of South Africa. *Marine Biology (Berlin)* **157**:269-281.

Zakai, D., and N. E. Chadwick-Furman. 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. *Biological Conservation* **105**:179-187.

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