The potential impacts of South Africa's demersal hake trawl fishery on benthic habitats:

Historical perspectives, spatial analyses, current review and potential management actions

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Executive summary

The Marine Stewardship Council sets certification conditions to provide for agreed further improvement in certified fisheries and provide a basis for subsequent audit. South Africa's hake trawl fishery includes a certification condition that calls for a review of the state of knowledge of the impacts of this fishery on the seabed and the implementation of appropriate research and management measures. This report aims to address key aspects of this condition by improving and reviewing current knowledge of the potential impacts of this fishery on benthic habitats within a historical context, systematically identifying potential habitats of concern and supporting the development of potential research priorities and mitigation measures.

There is a considerable body of international literature that reports on the impacts of demersal trawling. These impacts vary according to the habitat type, complexity and resilience, the fishing operation (including vessel power, gear and fishing strategies) and the spatial scale, frequency and intensity of trawling including the history of fishing activity.

The history of South Africa's trawl fishery from the late 1880's until present is reviewed with a focus on information pertinent to understanding the potential impacts of hake trawling on seabed habitats. This includes the development of the fishery, increasing fishing capacity and the arrival of foreign fleets, changes in target species over time, advances in fishing gear and processing technology, the expansion of the fishing grounds and the implementation of management measures.

A description of the relevant fishing gear is provided, distinguishing between an inshore and offshore fleet, South African versus foreign trawlers and the current versus historical fleets. Different companies, vessels and skippers deploy a wide range of ground gear configurations that are likely to vary in terms of benthic impacts. Currently, the use of bobbin and rockhopper gear is confined to a portion of the offshore fleet and tickler chains are used by a few vessels targeting species other than hake in some inshore and offshore soft grounds.

The implementation of different management measures in the South African hake fishery, focusing on those pertinent to the management of the potential impacts of trawling on the seabed is also examined. These include the introduction of closed bays between 1928 and 1986, the exclusion of the offshore fleet inshore of the 110 m depth contour in 1978 (or within 20 nautical miles of the coast in 2002) on the south coast and limitations on the maximum size of rollers and bobbins, first introduced in 1991. These limits were based on the maximum size in use at that time and aimed to prevent the introduction of heavier gear and therefore limit further benthic impacts.

Historical maps and reports were used to provide an overview of the expansion of fishing activity over time and to support the assessment of the initial timing, duration and intensity of impact in different habitat types. Prior to 1920, trawling was confined to inshore grounds close to Cape Town, Mossel Bay and Port Elizabeth. Between 1920 and 1935, the fishery began to develop into two defined sectors, an inshore fleet working on inshore muds and sandy habitat along the south coast and an offshore fleet focused on deeper grounds (150-450 m) on the west coast and off Port Elizabeth (250-450 m). Between 1920 and 1960, fishing took place on discrete grounds with little difference in historical inshore grounds mapped in 1949 and those reflected in the mapped trawl footprint that reflects grounds fished over approximately the last 40 years. However, there was an increase in the inshore grounds in the 1960's and 1970's associated with increasing numbers of small private boats and especially large foreign vessels

trawling with bobbin and rockhopper gear. Access to the inshore grounds by foreign vessels was terminated by 1993 and by this time most inshore trawling was focused on the traditional soft grounds within the recent trawl footprint.

Offshore, fishing has expanded substantially since 1949 and many of the discrete offshore grounds that were previously separated from each other by untrawlable rough ground in the early days of this fishery have since been subjected to trawling. The expansion of offshore fishing grounds is difficult to track temporally but consistent trawling in deeper water (> 500m) is reported to have occurred mostly in the early 2000's with opening of new grounds between 2000 and 2008. Local companies brought in international experience that was a key element in the expansion of fishing into deeper ground and in some cases, rougher or more risky areas that were previously not trawled. The offshore grounds now extend in a near continuous band along the west coast and along much of the shelf edge on the south coast. In 2007, the fishery developed a map of their footprint along with a commitment that no further expansion in terms of fishing grounds would take place. A few trawls have taken place outside of this demarcated footprint on the southern tip of the African continental shelf during 2008 and 2009.

An overview of the major trawl grounds (current and historical), including details of their associated benthic habitats, was compiled and the duration and likely intensity of potential trawling impacts was assessed. South Africa recently classified and mapped 136 marine and coastal habitat types as a component of the National Biodiversity Assessment 2011. The development of this systematic habitat classification and map allowed for a comprehensive evaluation of the interaction of the South African hake trawl fishery with all habitat types. A total of 27 habitat types (20% of South Africa's 136 marine and coastal habitat types) occur within the recent footprint of the South African hake trawl fishery. The percentage of each habitat type that is included in the recent trawl footprint and the current trawling intensity was estimated using spatial analysis. The duration of trawling in each habitat type was assessed using the overview of fishing grounds and the historical perspectives compiled in the first sections of this report. Potential habitats of concern were identified by considering the 1) vulnerability and resilience of each habitat type to otter trawling 2) total habitat extent within South Africa's EEZ, 3) the proportion of each habitat type's total extent that occurs within the trawl footprint and 4) relative trawling effort across each habitat type within the footprint.

A total of 17 habitat types triggered concern based on one criteria and nine habitat types triggered potential concern on multiple criteria, but only 1 habitat type, Southern Benguela Canyon, triggered concern based on all 4 criteria. The nine habitat types that were highlighted by this analysis are recommended priorities for management action:

- Southern Benguela Canyon
- Southern Benguela Muddy Shelf Edge
- Southern Benguela Hard Shelf Edge
- Agulhas Canyon
- Southern Benguela Gravel Shelf Edge
- Agulhas Gravel Outer Shelf
- Southern Benguela Gravel Outer Shelf
- Southern Benguela Submarine Bank
- Southern Benguela Sandy Shelf Edge

The current state of knowledge of known or potential impacts of the South African hake trawl fishery was reviewed, summarising the results of the single in-situ trawl impact study that has been undertaken in South Africa and the considerable body of spatial analyses. Critical knowledge gaps, research priorities and potential management actions were then determined. Main gaps in knowledge include the impact of trawling on muds, gravels and hard grounds and the recovery potential in all habitat types. Better information on the distribution and nature of hard grounds and cold water corals is needed. Proposed mitigation measures comprise the implementation of management measures such as a review and strengthening of permit conditions to restrict benthic impacts, offshore spatial management measures including experimental closures, seabed protection zones and offshore MPAs and the collection of new information to support further assessment and the implementation of good practice. Further research is recommended to (1) improve the understanding of potential benthic impacts in hard grounds and muds (2) to assess recovery in the dominant habitat type in which trawling occurs and (3) to support the identification and protection of healthy examples of sensitive habitats.

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Section 1. Introduction

The South African hake trawl fishery holds Marine Stewardship Council (MSC) certification. As part of the certification process, conditions are raised. Conditions provide for agreed further improvement in MSC certified fisheries and provide a basis for subsequent audit. They are intended to improve performance against the MSC principles throughout the duration of the certification period. The South African hake fishery was first certified in 2004. During that certification period, concerns about the potential impacts of trawling on the seabed and its associated fauna and flora were noted and a specific condition (Condition 4) was raised to address these concerns triggering a substantial body of work in this field (see Wilkinson and Japp 2005a for details). The condition was "closed out" by the end of the certification period in 2009. The South African hake trawl fishery was recertified in 2010 and a new condition (Box 1) was raised to address outstanding concerns regarding the impacts of hake trawling on South African benthic habitats and communities. MSC Condition 2 Benthic habitat (see below) encourages this fishery to review the state of knowledge of the potential impacts on seabed habitats, identify critical gaps and support the implementation of appropriate research and management measures.

Box 1. MSC Condition 2. Benthic habitat

"**Action required**: Significant progress has been achieved in determining and managing impacts of the fishery on benthic habitat. The current MSC re-assessment process has, however, identified remaining gaps in knowledge, particularly in relation to the longer-term significance of impacts (e.g. the ability of habitats to recover from disturbance) within existing and any future trawl areas.
Timescale: Within 1 year of certification, remaining gaps in knowledge of benthic impacts should be reviewed and appropriate actions implemented (through further research and/or management) to address these, with specific annual milestones for delivery. Within 4 years of certification, any appropriate research should be completed. Appropriate management actions should be developed and implemented in line with the precautionary approach and ecosystem approach to fishery management. Appropriate management should be in place within 5 years of certification."

1.1 Objectives

This report aims to address key aspects of MSC Condition 2 by reviewing current knowledge, identifying potential habitats of current concern and proposing potential research priorities and mitigation measures. Specific objectives included;

1. Review the state of knowledge of the interaction of the South Africa hake trawl fishery with benthic habitats and communities and identify the critical gaps in understanding of the impacts of hake-directed trawling on seabed habitats in South Africa.
2. Assess which benthic habitat types are trawled by the South African hake trawl fishery and estimate the percentage of each habitat type that has been affected.
3. Provide a historical perspective on the impacts of hake-directed trawling on benthic habitat types in South Africa by estimating the duration and intensity of impact for each of the major trawl grounds and their associated habitats.
4. Identify habitats of concern and support the development of potential management and mitigation measures to address concerns.

South Africa has only recently developed the first national habitat map for its marine territory (Sink *et al.* 2012.). The development of such a systematic and consistent classification of the seabed environment is a key prerequisite to evaluate the extent and significance of disturbance in different habitat types (National Research Council 2002) and it was this development that facilitated a revised and comprehensive assessment of trawling on seabed habitats in South Africa. This report complements a parallel initiative that includes an experimental evaluation of the effect of trawl closures that will help to provide information about recovery potential in typical trawl habitat (Atkinson *et al.* 2012).

1.2 International perspectives

There is a growing body of international literature that reports on the impact or potential impacts of demersal trawling on benthic habitats and communities. This includes several reviews and meta-analyses (Auster and Langton 1999, Collie *et al.* 2000a, National Research Council 2002, Kaiser *et al.* 2002, 2006). Several authors report on the variable impact of demersal trawling in relation to the spatial scale, frequency and intensity of fishing (Kaiser *et al.* 2002).The impacts of trawling on benthic habitats and communities depend on three key factors:

- the habitat type, including habitat complexity, levels of natural disturbance and patchiness of habitats, all of which affect the inherent vulnerability of different habitat types
- the fishing operation including the vessel power, trawl gear and configuration and fishing strategies employed
- the spatial scale, frequency and intensity of trawling, including the history of fishing activities

(Kaiser and Spencer 1996, Kaiser *et al.* 1998, Kaiser *et al.* 2000, Collie *et al.* 2000a, Kaiser *et al.* 2002, Hiddink *et al.* 2006, Kaiser *et al.* 2006).

Habitats characterised by slow growing, fragile biota that form physical structure for many other species are generally considered more vulnerable to demersal trawling than other habitats (Collie 1998, Kaiser *et al.* 2000, Kaiser *et al.* 2006, Austin *et al.* 2007). Such complex habitats with slow growing species can be considered as Vulnerable Marine Ecosystems (VMEs) (see FAO 2009) and include habitats such as hard grounds, rocky shelf edges, submarine canyons, some seamounts, reefs, carbonate mounds and knolls. These habitats often support cold water corals, octocorals, sponges and other biota that constitute complex, three dimensional habitat (Rogers 1999, Koslow *et al.* 2000, Roberts *et al.* 2000, Freese 2003, Wheeler *et al.* 2005, Reed *et al.* 2006, Stone 2006, Rogers *et al.* 2008, FAO 2009, Miller *et al.* 2009). Many of these species are slow growing and recovery in these habitat types is usually very slow, if at all (Rogers 1999, Fosså *et al.* 2002, Reed 2002, Roberts and Gage 2003, Wheeler *et al.* 2005, Stone 2006, Reed *et al.* 2007, Heifetz *et al.* 2009).

Habitats that experience less frequent or lower levels of natural disturbance also recover more slowly than those with high levels of natural disturbance as habitats with less disturbance are characterised by species that are generally longer lived and slower to recolonise (Jennings and Kaiser 1998, Kaiser and Spencer 1996, Collie *et al.* 2002, Thrush and Dayton 2002, Hiddink *et al.* 2006). Examples of more stable or sheltered habitats include muddy habitats and sandy sediments in very deep water (Jennings and Kaiser 1998). Habitats that experience frequent natural disturbance such as sandy mobile megaripple habitats have been reported to recover in weeks to months (Kaiser and Spencer 1996, Kaiser *et al.* 2000, Collie *et al.* 2002). The substantial variability within different benthic habitats and communities also adds complexity to studies aimed at understanding the impacts of trawling. Habitat variability and natural disturbance can mask the impact of trawling (Jennings and Kaiser 1998, Auster and Langton 1999, Kaiser *et al.* 2003).

The type of trawl operation including vessel power, net size and configurations, footgear (e.g. use of rockhopper gear or bobbins, see Box 2), rope design and weight, weight of trawl doors (otter boards) and fishing strategy plays a key role in determining the impact of trawling on the seabed and associated benthic communities. Key elements that affect the impact of trawling include the mass of gear, towing speed and the degree of contact with the seafloor (Thrush and Dayton 2002). The skill and objective of the skipper also influences the impact as some skippers alter their gear to target certain species (Jennings and Kaiser 1998). Otter trawling with rockhopper gear has a more measurable impact on the seabed than gear without bobbins or rollers on the footropes (Prena *et. al.* 1999, Mc Connaughey et al 2000, Pitcher *et al.* 2000, Collie *et al.* 2002, Kaiser *et al.* 2002). This type of gear is often deployed in structurally complex habitats such as hard ground areas which support more diverse and sensitive species than less complex and vulnerable habitat types (Kaiser *et al.* 2000). Although many studies have investigated the effects of trawling on specific habitats, very little research has focused on how the impact of trawling on a given habitat varies with differing types and sizes of ground gear (Rowling 2008). Tickler chains also result in greater disturbance to benthic habitats and communities (Jennings and Kaiser 1998) but these are almost always deployed in soft grounds.

Documented impacts of trawling on the seabed and benthic communities include

- destruction or damage to structurally complex habitats
- reduction of habitat heterogeneity and homogenisation of subtly textured habitats
- reduction in bioturbation
- death and damage to infauna and epifauna
- reduction in benthic species diversity
- re-suspension of sediments
- attraction of scavengers
- declines in larger, slow growing species
- increases in smaller, faster growing taxa

(Jennings and Kaiser 1998, Auster and Langton 1999, Collie *et al.* 2000a,b, Jennings *et al.* 2001, Kaiser *et al.* 2002, Widdicombe *et al.* 2004, Kaiser *et al.* 2006, Hiddink *et al.* 2008).

The significance of these impacts is debated but such impacts are likely to affect predator-prey relationships, competitive interactions, productivity and other ecological processes. Trawling impacts have been associated with potential loss of prey for some species, increased predation risk (Walters and Juanes 1993, Tupper and Boutilier 1995, Auster *et al.* 1997, Collie *et al.* 2000b, Kaiser *et al.* 2002, Thrush and Dayton 2002, Kaiser *et al.* 2006) and changes in bioturbation with associated effects on nutrient cycling, oxygenation and sediment redistribution (Widdicombe *et al.* 2004). Some studies have investigated the effect of trawling on productivity. Jennings *et al.* (2001) reported a decrease in productivity, linked to decreased benthic biomass, in response to increased beam trawling effort. Cessation of mobile fishing in gravel habitats increased benthic production on George's Bank (Hermsen *et al.* 2003). Hiddink *et al.* (2006) also reported a modelled decline in total productivity of benthic invertebrate communities associated with trawling.

The variable impacts of trawling call for local research and an *in-situ* experimental approach. This report increases the knowledge base of potential benthic impacts through further desk-top research and spatial analyses, summarises the knowledge of potential benthic impacts in South Africa, and then identifies potential habitats of concern and remaining critical knowledge gaps.

Box 2 Explanations of bobbins, rollers and rockhopper gear as used in this report.

Otter trawling is the main trawling method used in the South African hake fishery (see Wilkinson and Japp 2005c for details. This method of trawling makes use of trawl doors (also known as otter boards) that are dragged along the seafloor ahead of the net, maintaining the horizontal net opening. A headline, bearing floats and a weighted footrope (that may include rope, steel wire, chains, rubber discs, spacers, bobbins or weights) maintain the vertical net opening. The "belly", "wings" and the "cod-end" (the part of the net that retains the catch) may contact the substrate. There is a wide range of ground gear configurations used with different companies, vessels and skippers using different combinations that have varied over time, in different grounds and with different fishing strategies relating to market demands. The following definitions explain the different types of footrope protection as referred to in this report, as applicable to the South African hake trawl fishery.

Bobbins

In the context of trawling, bobbins refer to the spherical weights that are added to the footrope to protect the footrope, raise it off the ground and allow the net to roll along the seabed. In South Africa, round wooden bobbins were used in the 1950's with hollow banded steel and solid rubber bobbins used from the 1960s. Solid rubber bobbins may be heavier than steel bobbins which are usually hollow although some skippers make holes in steel bobbins to increase the weight of their ground gear by allowing water to fill the hollow bobbins.

Rubber discs

Rubber discs (also referred to as rollers or cookies) refer to the circular rubber disks, wheels, rollers or plates of varying sizes (usually 75 to 600 mm in diameter) that are used along the footrope. An entire footrope can be "wrapped" with small rubber disks but larger disks (rockhopper gear) are usually spaced at regular intervals along the footrope with riubber spacers or disks in between the larger disks or rollers.

Rockhopper gear

Rockhopper gear refers to moulded rubber disks larger than 250 mm in diameter. Wilkinson and Japp (2005a) report that rockhopper gear in South Africa is not designed to roll over the seabed but rather to raise the belly of the net slightly off rocky grounds. Rockhopper gear seems to have developed in late 1970's. Early research (Main and Sangster 1979 in Rowling 2008) clearly showed that a fish trawl of 26 m headline length with ground gear consisting of 6 m of 350 mm diameter rubber wheels in the centre, and two 4.5 m wing sections of 90 mm diameter rubber discs, had the ability to traverse hard ground with boulders up to 2 m in height, and to physically displace boulders up to 1 m diameter when towed by a 22 m trawler with a 200 hp main engine. The development of so-called 'rockhopper' trawls, and resulting concerns about the ability of this gear to significantly modify hard habitats, has focused increasing attention on the potential impacts of hard ground gear (Rowling 2008).

Local skippers report that the main function of both bobbin and rockhopper gear is gear protection in rough ground. Many local skippers report that rockhopper gear is usually preferable to bobbin gear because it is less risky (less chance of snagging) and less dangerous on deck. There is also a perception that rockhoppers may cause less potential damage to the seabed than bobbins. Rockhopper gear is being increasingly used over bobbin gear, particularly in deep water.

Plate 1. Photographs showing examples of ground gear used currently or historically in the South African Hake Trawl fishery. Photograph (a) and (b) depict an inshore ground rig with small (less than 250 mm) rubber discs and small (100 mm) rubber spacers. Large heavy steel bobbins and large rubber rockhopper disks are shown in photograph (c) which was taken aboard a foreign vessel fishing on the inshore grounds of the Agulhas Bank in the 1980's. Current offshore ground rigs with rockhopper disks (d) and solid rubber bobbins (E) are also shown. Larger steel bobbins (610 mm maximum diameter) which are used on some vessels in offshore grounds are also depicted (F). These steel bobbins are no longer frequently deployed in this fishery but are within the size restrictions of current permit conditions. Some photos courtesy of Rob Whitehead.

Section 2. Historical perspectives

2.1 Methods and sources

Information relevant to the history of trawling in South Africa is documented in historical reports (reports of Gilchrist and Van Bonde 1887-1945, Marchand 1933), books (Lees 1969, Irvin and Johnson 1964, Payne and Lutjeharms 1986, Payne 1989, Payne and Badenhorst 1989, Payne and Punt 1989, Payne and Punt 1995), theses (Payne 1986, Fairweather 2002), journal publications (Payne 1989, Japp *et al.* 1994, Brown 1997, Booth and Punt 1998, Fairweather *et al.* 2006). These texts were reviewed to provide an overview of the history of South Africa's trawl fishery with a focus on factors pertinent to the potential benthic impacts of this fishery. The minutes and reports of management meetings and scientific working group meetings would also add to this perspective, but such comprehensive review is beyond the scope of this report.

2.2 The Development of the South African hake trawl fishery

An overview of the history of key developments in South Africa's demersal trawl fishery is summarised in Table 1. Relevant historical aspects for understanding the potential impacts of hake trawling on seabed habitats include

- the development of the trawl industry and the growth in fishing capacity and effort
- shifts in target species and market demands
- the modernisation of the fleets, fishing,storage and processing operations and advances in fishing gear
- the arrival of foreign fleets
- the expansion of the fishing grounds and
- the implementation of management measures.

1878–1910

The first trawl attempt was apparently made by a steam powered tugboat in Algoa Bay in 1878 followed by attempts by a Norwegian trawler in Table Bay, False Bay and Mossel Bay in 1892 (I&J 1964, Payne and Badenhorst 1989). The government's purpose-built research vessel, the 176 ton steam trawler *Pieter Faure* pioneered the development of the inshore fishing grounds from 1887. In 1898, the first conflict between local line fishers and trawlers was reported (Gilchrist 1899) with local fishers accusing the government and other steam trawlers of depleting local stocks, removing immature fish and damaging fish spawn on the seabed. In 1899, the side steam trawler *Undine* successfully targeted sole in the inshore grounds of the Agulhas Bank (Payne and Badenhorst 1989). Several small (210 ton) side steam trawlers were imported in 1904 (*Star of Peace*, *Star of the South*, *Star of the Isles* and *Star of the East* I&J 1964) but were limited by a lack of infrastructure and the very limited local market. In 1905, these early trawlers were successfully fishing but it was only with the start of rail transport of fish to Johannesburg, the mining capital of South Africa, in 1906 that a larger market was secured (I&J 1964). Three trawlers were lost due to storms in 1907 leading, in 1910, to the merging of two companies to form what would later become Irvine and Johnson (I&J), the organisation that dominated the capital intensive trawling industry for the next 40 years (I&J 1964). This company had four ships, a smoker and cold stores at this time (Roy Bross, SADSTIA, pers. comm).

1910-1920

Between 1910 and 1920, there were a small number of side trawlers based in Cape Town, Mossel Bay and Port Elizabeth with approximately 12 active vessels by 1920. These trawlers were relatively small steam powered vessels (*Gertrude Wadner* was the largest at 28 m) operating on soft grounds in bays and close to the coast. They mostly targeted sole and linefish such as panga, silverfish, seventy four and kob. A component of this linefish catch was and still is termed as "redfish" and refers to several sparid species with red colouring including panga, silverfish (also known as carpenter), red stumpnose, red steenbras, dageraad, santer and roman. Hake or stockfish was also caught and gradually became the mainstay of this fishery, increasing in importance from 1920 onwards.

1921-1935

The pioneering of fishing grounds by the government fisheries department played a key role in the developing hake fishery. In 1921, the government marine biologist, John Gilchrist (1922) discovered what can be considered as the first offshore trawl ground. He described "the existence of a large deep-sea area near Cape Town, hitherto untouched. The area is well adapted for trawling, and the valuable stockfish and kingklip fish were found in good quantities" Gilchrist (1922) noted that commercial trawlers were quick to realise the potential of this resource and were exploiting these deepsea grounds with vessels such as the *Una*, obtaining good catches of hake (7 tons in two hours) in approximately 250 m of water in 1921. It appears that these trawlers were most commonly fishing in the 200-350 m depth range although Gilchrist (1922) noted that these commercial trawlers could trawl in water depths of up to 540 m at this time.

1935-1960

In 1935, there were three further developments that were significant in terms of the development of separate inshore and offshore trawl sectors in South Africa's hake trawl fishery (noting that these two sectors were only formally separated by managers in 1978). Van Bonde described 1935 as "a year of unprecedented and heavy capital outlay in the deep-sea fisheries, which undoubtedly serves as proof of the essential soundness of the industry at the present time and confidence in its future potentialities and stability". Although small (<28 m) trawlers were fishing the bays and inshore areas at this time, the development of the offshore sector was initiated by the introduction of larger vessels that ventured offshore. I&J acquired two 250 ton side trawlers (*Aristea* and *Crassula*) for deepsea work in 1935, both equipped with echosounders, direction finding equipment and wireless telegraph (Van Bonde 1936). In 1937, two larger (300 tons, 45 m), "modern" vessels (*Anemone* and *Morea*) were imported with with two additional similarly "impressive" vessels (*Protea* and *Petunia*) joining the fleet in 1938 (Director of Fisheries 1939). The second important development in 1935 was the discovery of the the offshore grounds off Port Elizabeth (see the Chalkline grounds below). These grounds not only had significant hake catches but large quantities of kingklip were found and this was reflected in commercial catches very soon after their discovery (Director of Fisheries 1939). The new larger steam trawlers fished both the inshore and offshore grounds and some of the Cape Town based vessels started to venture towards the south coast at this time. The third development in 1935 was the introduction of the first vessel with on-board freezer facilities although it was only in the 1960's that the modern factory freezer ships entered the scene.

During the Second World War (1939-1945), several trawl vessels were seconded to the war effort but a portion of the fleet continued to make good catches, mostly on the offshore grounds along the west coast (Scott 1949). In 1947, even bigger vessels (515 tons) were acquired by

I&J and by 1948 there were 40 trawlers (Scott 1949). The offshore vessels were imported British built vessels ranging from 250 to 515 tons and 36-50 m in length and were fitted with triple expansion steam engines. In 1949, Scott reported that the trawlers operating on the inshore grounds were mostly 23 m, locally made, wooden motor trawlers designed for fishing on the Agulhas Bank. The origin of the modern inshore fleet, the first “Cape Class” vessels (such as *Jack* and *Sheila*) were acquired in approximately 1960 and these small (22 m) diesel vessels gradually replaced the old small steam vessels based at the south east coast ports by about 1978. In the 1960’s and 1970’s these local vessels fished the Agulhas Bank, mostly operating from Mossel Bay and Port Elizabeth but Cape Town formed the base of the larger ships that worked the west coast and further offshore. In South Africa, the availability and low price of coal delayed the use of large diesel-engined ships in the trawling industry with most large vessels, built up until 1959, powered by reciprocating steam engines (I&J 1964). The first large (360 ton, 42 m) diesel trawler was only introduced in 1960 with four additional similar vessels (two imported and two locally built) added by 1963.

Table 1: A historical overview of the South African demersal trawl fishery.

Year	Historical developments or state	References
1896	First trawling by steam tugs in Algoa Bay.	Gilchrist 1896
1897	The government steam trawler *Pieter Faure* initiated work with a focus on delineating viable and safe trawl grounds.	Gilchrist 1897
1898	Report of the select committee appointed to enquire into grievance of trawl impacts (3 mile limit recommended, the origin of False bay closure).	Gilchrist 1889
1899	First sole trawling by the *Undine* in inshore grounds of the Agulhas Bank.	Payne and Badenhorst 1989
1904	Several small steam driven side trawlers imported to South Africa	I&J 1964
1920	Start of the gradual expansion of commercial trawl fleet with increasing demand for quality fish. First offshore grounds exploited. The average annual hake catch in this period (until 1917 - 1922) was approximately 1000 tons.	Gilchrist 1922 Payne 1989
1921	Development of the west grounds and the start of hake-focused trawl activity.	Gilchrist 1922
1928	False Bay closed to trawling.	Van Bonde 1928
1932	Total annul hake catch rose from 2800 tons in 1931 to 14 300 in 1932.	Leslie 1998
1935	Western part of Algoa Bay closed to trawling.	Van Bonde 1936
1935	Expansion of west coast fleet into deeper waters along the western edge of the Agulhas Bank (Browns Bank).	Japp *et al.* 1994
1937 - 1940	Hake catch in South African waters reached 20 000 tons for the first time in 1937. A total of 26 commercial trawlers were operating at the start of World War II.	Payne and Punt 1995
1941 – 1945	In 1941, the hake catch reached 30 000 tons. Two thirds of fleet fished during World War II (1939-1945) and. In 1945 the hake catch dropped to 29 200 tons. Little expansion occurred during this period with catches below 40 000 tons	Leslie 1998
1946 - 1960	A period of exponential growth in fishing effort and catch with the annual hake catch exceeding 100 000 tons in 1954. In 1948, 40 local trawlers were operating in South Africa.	Payne and Punt 1995, Leslie 1998
Early 1960’s	Arrival of large, foreign vessels and the introduction of heavy, industrial fishing gear with steel and rubber bobbins on hard grounds on the Agulhas Bank. This period was characterized by further growth in effort and total catches. The annual catch doubled between 1954 and 1965, reaching 200 000 tons in that year.	Payne 1989, Payne and Punt 1995, Booth and Payne 1998, Leslie 1998, Sims 2007

Year	Historical developments or state	References
1969	Initiation of petroleum activities on the Agulhas bank with gradual development of infrastructure impacting on historical trawl grounds.	Sims 2007
1971	First meeting of the International Commission for the Southeast Atlantic Fisheries (ICSEAF).	Payne 1989
1972	Peak South African hake catch of almost 300 000 tons.	Payne 1989
1975	ICSEAF introduced minimum mesh size (110 mm) and later a member country quota allocation was introduced. The total hake catch declined to approximately 163 000 tons	ICSEAF 1979, Payne 1989
1977	Declaration of the 200 nautical mile Exclusive Economic Zone (EEZ). Exclusion of the majority of the foreign effort and reduction in panga directed fishing by foreign fleets on hard grounds. In 1977 the total hake catch declined to approximately 140 000 tons.	Payne 1989, Booth and Payne 1998
1978	Introduction of a national Total allowable Catch (TAC) for hake and sole which was individualised (as quotas) within 3 years.	Anon 1980
1978	Offshore fleet excluded from water shallower than 110m (largely to protect sole fishery).	Japp *et al.* 1994
1979	First permits for horse mackerel using mid water gear issued.	Japp *et al.* 1994
Early 1980's	Conservative catch limits implemented and gradual increases in hake catches.	Payne and Punt 1995
1983	First experimental demersal longline permits issued.	Atkinson 2010
1980's	Several additional trawl closures implemented.	Attwood *et al.* 1997
1990	Quota board established issuing quotas on an annual basis.	PFS
1991	Restrictions on footrope protection implemented (size and weight limits for bobbins and other devices)	Permit conditions (PFS)
1991	Minimum mesh size on the south coast was relaxed to 75 mm to accommodate mixed-species fishers. This also allowed offshore vessels to use 75 mm mesh size until 2001.	Payne and Punt 1995
1991	Operational Management Procedure (OMP) implemented.	Rademeyer *et al.* 2008.
1998	The Marine Living Resources Act (Act 18 of 1998) was promulgated promoting equitable access to resources, resource sustainability and socio-economic stability.	
1995 - 2006	Several OMP revisions to account for updated data sets, changes in fishing selectivity (introduction of longline etc) and improved understanding of hake stock dynamics.	D. Durholz , DAFF pers. comm..
1999	Interim rights process underway.	PFS
2001	Permit conditions restricted all offshore vessels to 110 mm mesh size	RWL
2002	Medium term rights issued introducing some stability and facilitating longer term planning and the basis for raising capital	RWL
2004	MSC certification of South African hake trawl fishery	
2005	Seasonal closure to protect spawning aggregations of kingklip (Kingklip box) implemented.	Permit conditions
2006	Long term rights issued.	
2007	Revised OMP implemented based on the use of species-disaggregated resource assessments. Large reductions in TAC to account for apparent depleted *M. paradoxus* resource following several years of poor recruitment in early 2000s.	Rademeyer *et al.* 2008.
2007	Permit conditions for inshore fishery specified separate mesh sizes for hake versus sole directed fishing. A 90 mm mesh size restriction for hake directed fishing was introduced. For sole directed fishing, the 75 mm mesh size continued to apply. The 110 mm mesh size restriction continued to apply to the offshore fleet on both coasts.	Permit conditions
2008	An effort limitation model was developed and implemented to restrict	RWL

Year	Historical developments or state	References
	seadays where vessel power and size are not aligned with quotas.	
2008	Industry mapped the trawl footprint and implemented a ring fencing initiative with a commitment to freeze the trawl footprint.	Wilkinson and Japp 2008
2010	MSC Re-certification of South African hake trawl fishery. Revised OMP implemented, based on species, sex and coast disaggregated assessments. Incorporation of more stringent target and limit reference points in response to MSC re-certification.	DAFF 2010

1961-1978

The 1960’s and 1970’s were a period of higher impact on both the resources and most likely the seabed as substantial changes in fishing gear, effort, catch and processing took place (Tables 1 and 2). Advances in food technology, mechanized fish filleting and freezing technology, along with the introduction of large factory ships revolutionized the trawl industry at this time. The industrialisation and modernisation of trawling was accompanied by the arrival of the foreign fleets in 1962 (Table 2). This represented the most significant change in South Africa’s trawling history. Foreign vessels at this time included those countries of the Five Nations Accord (Russia, Bulgaria, Rumania, East Germany and Poland) who fished along both the south and west coast, Japan (and possibly Taiwan) fishing on the south coast and in the latter years of this period, Spain, focusing on the west coast. In most cases foreign vessels constituted large factory trawlers and these fleets constituted an unprecedented increase in fishing effort and pressure on resources and the seabed environment (Table 1). Much of this foreign interest was driven by declining catch rates by groundfish fleets in the northern hemisphere. A further development in the local fleet at this time was the introduction of private boats and new entrants into a sector that had been dominated by a single large company. Converted purse seine vessels and additional purpose-built stern trawlers joined the fleet. These vessels also expanded the trawling grounds during this period with private boats developing new trawl lanes and clearing previously unfished areas of loose rocks. The number of trawlers increased from approximately 20 in 1959 to about 100 vessels in 1977. Smaller vessels based along the south coast rose from 3 active trawlers in 1959 to 10 in 1960, 26 in 1962, 39 in 1969 and 49 in 1977. This excludes the additional foreign vessels (at least 20 with reports of up to 50 vessels) operating between 1962 and 1978.

Key changes in the trawl fishery at this time included the introduction of diesel engines, large stern trawlers in the mid and late 60’s and other advances in fishing technology. The small old steam trawlers were phased out during the 1960’s as they were replaced by larger steam trawlers (Table 2). Only side trawlers were used in the fishery until 1963 when the first experimental stern trawler, *Keurbooms,* was employed to try new fishing methods (I&J 1964). Side trawlers were reported to be able to fish down to 900 m in 1964 (I&J 1964) although the majority of fishing at this time was most likely shallower than 500 m. Side trawlers are more limited than stern trawlers in poor weather and fishing operations are more risky that from stern trawlers, with few of these vessels currently remaining in the existing fleets. The introduction of stern trawlers allowed greater flexibility in where fishers could operate, particularly in rough weather and reduced the time of fishing operations. The development of synthetic materials also introduced trawl gear changes in the 1960’s. Until then, locally made manilla twine nets were used and these were replaced with longer lasting, stronger synthetic (nylon) netting in the 1960’s. Increased technological changes such as the introduction of more sophisticated echo-sounders, radar and navigational beacons (DECCA) also led to the discovery of new fishing grounds and allowed fishers to return to the same grounds with greater accuracy and confidence. These advances increased the catchability of fish, improved fishing efficiency and influenced the economics of the fishery.

It is important to clearly distinguish the size and scale of fishing operations conducted by the South African and foreign fleets (Table 2). In the 1960's, the "I&J Cape Class" inshore trawlers (and the converted purse seiners) were relatively small (average size 22m) with 350 to 400 horse power diesel engines. The foreign vessels that arrived in the early 1960's were much larger and more efficient than the local fleet, especially the local inshore trawlers, much of whose grounds they shared. These factory vessels were fitted with 3000-4000 horsepower diesel engines and were therefore an order of magnitude more powerful than the inshore vessels that were fishing in this area. The only restriction on foreign vessels between 1960 and 1978, was that they could not fish inshore of the 12 nautical mile territorial limit. In the 1970's the Five Nations Accord authorized a global fleet of up to 100 large factory vessels (M. Lipinski DAFF, pers. comm.) of which 20-30 worked on the Agulhas Bank at any given time. Local skippers recall ten large foreign vessels working abreast on traditional inshore grounds during this period. (Sims 2007).

Many of the foreign vessels fished with heavier ground gear including large (61 cm) steel bobbins (see Box 2 and Plate 1). The heavy gear, powerful vessels and experienced skippers accessed areas that were previously unfished by local vessels. Many of these vessels had scientific personnel aboard and seemed to have the knowledge to follow the seasonal movement of panga, carpenter and other red fish from the central bank eastward along the coast to the Chalumna River, off the former Transkei coast (Sims 2007). During this period, panga-directed trawling by foreign fleets depended on the use of bobbin gear and later rockhopper gear (see Box 2 for definitions) (Brill 1989, Japp *et al.* 1994, Sims 2007). This is reported to have caused significant damage to hard ground habitats including reefs and corals (Badenhorst and Smale, 1991, Japp *et al.* 1994, Booth and Payne 1998). This type of fishing started in 1964 although effort was gradually reduced from 1977 and stopped by 1993 (Japp *et al.* 1994). Catch rates declined as these areas gradually became "mined out". Newman (1977) reported that catch rates of Panga by Japanese trawlers fell by 81% between 1964-1975.

The first meeting of the International Commission for the Southeast Atlantic Fisheries (ICSEAF) was held in 1971. This commission divided the South East Atlantic into fishing areas for reporting of catch statistics and to support international management of this joint area. They adopted a minimium mesh size limit in 1975. As South Africa was not part of the world stage at this time, ICSEAF played an important role in starting to manage the activities and catches of the foreign fleets.

All things considered, the 1960's and 1970's period constituted a rapid and unprecedented growth in fishing effort and although total catches rocketed, catch rates of local trawlers declined dramatically (Payne 1989, Payne and Punt 1995, Booth and Payne 1998). From the early 1960's until the proclamation of the Exclusive Economic Zone (EEZ) in November 1977, demersal trawling was largely uncontrolled in the area extending up to the 12 mile limit of the territorial sea of South Africa.

Table 2: Vessel specifics over time reflecting differences between historical and current fleets, local versus foreign vessels and inshore versus offshore sectors.

Period & sector (example vessel names)	**Vessel length m**	**Gross Registered Tonnage**	**Engines**	**Reference**
Pre 1935: Steam trawlers (*Gertrude Wadner*)	22- 28	96	Steam side trawlers	PS
1935-1960: Motor trawlers (*Gleanaway*)	22 (average)	80	160 hp	Bross 2012
1935-1960: Steam trawlers (*Crassula*, *Anemone*)	36 – 50	250-515	Steam side trawlers	Scott 1949
1960's-1970's: Local inshore fleet (Cape Class, *Jack, Sheila*)	22	65	300 – 450 bhp	PS
1960's-1970's Steam trawlers	40	360 - 535	1960 first diesel (George Irvin)	I&J 1964
1960s-1978 Five nations factory fleet	80-100	Approximately 3000	3000-4000 bhp	Bross 2012
1964-1993 Japanese vessels	73	1858	2880 ps diesel	Brill 1989
1978 – 1989 Inshore	22	70	350 bhp	Bross 2012
1971 – 1975 Wetfish (*Aberdeen*, *Hibiscus*)	40	200-589 GRT	350-1500 bhp	Anonymous 1976
1971 – 1975 Freezer (stern) (e.g. *Prima*, *Protea*)	40 - 70	150 – 1600	385 – 2000 bhp	Anonymous 1976
1990 – present inshore fleet	14-30	50-200	Limited to 1000 hp	Wilkinson and Japp 2005c
1990 – present offshore fleet (wetfish)	23- 61 (average 45)	96-1100	1799- 2991 (maximum corrected 3619 hp)	Wilkinson and Japp 2005c, Bross 2012
1990 – present offshore fleet (factory)	30- 90 m	500-2500	1000- 4500 (maximum corrected 3619 hp)	Wilkinson and Japp 2005c, Bross 2012

1978-present

The year 1978 marks the start of the controlled access era in the trawl fishery and this period saw the introduction of increasing numbers of management measures (Table 1). Firstly, the implementation of the EEZ was a very important development that significantly reduced fishing effort by foreign vessels within the EEZ. However, between 1978 and 1993, foreign vessels continued to operate in South African waters under bilateral agreements and joint ventures (Japp *et al.* 1994). Foreign vessels fishing at this time included Japan, Taiwan, Israel, Spain and Portugal (in mid 1998) (South African Fishing Industry Handbook 1989) with fishing controlled by permits and species allocations or quotas. There was considerable concern amongst local companies about foreign allocations and the impact of these arrangements on local resources and fishing efficiency (Fishing Industry Handbook 1989). A key management intervention in this period was the separation of the inshore and offshore fleets east of the 20 degrees east line of latitude. This excluded the offshore fleet with its larger vessels from the area inshore at the 110 m isobath. However, this restriction did not apply to foreign vessels, leading to conflict in the area known as the “foreign triangle (see overview of grounds below).

Although the biggest changes in the inshore sector took place in the 1960’s and 1970’s, significant changes in trawl gear and fishing strategies in the offshore sector took place in the 1980’s, 1990’s and particularly in the early 2000s. Key changes included the introduction of bigger vessels suitable for fishing at depth (500m and deeper), new international expertise in deep water fishing and associated changes in gear. Although rockhopper gear (see Box 2) was developed as early as 1980 (Ingólfsson and Jørgensen 2006) it was only in the 2000’s that this was used more frequently in South Africa’s offshore fishing grounds. Internationally the development of rockhopper gear was a key element that allowed trawlers to fish on rougher seabed and in deeper water and led to the start of global concerns around trawling impacts on hard grounds (Rowling 2008). Prior to this innovation, the costs associated with the higher frequency of gear loss or damage prevented most fishers from fishing in hard ground areas, limiting the scope and potentially the magnitude of seafloor impacts (National Research Council 2002).

The timing of the introduction of rockhopper gear in South Africa is difficult to pinpoint but skippers suggest that such innovation allowed fishers to trawl in previously inaccessible areas (such as low profile reef and hard grounds, the edges of submarine canyons and the slopes of submarine banks). An early form of rockhopper type gear comprising a series of complete car tyres along the footrope was used in 1982 by Japanese vessels on the south coast (RWL) but modern rockhopper gear (Box 2) seems to have been used from the late 1990’s but with consistent effort in deeper water and a an expansion into deep water grounds in the early 2000’s. Brill (1989) reported on the use of rockhopper gear by foreign vessels fishing on the inshore grounds of the Agulhas Bank at this time. Although trawlers fished with wooden and then steel bobbins in offshore grounds in the period between 1950’s and 1990, it is reported that rockhopper gear was first employed in the offshore grounds only in the late 1990’s or even 2000’s.

A further and related key development of particular importance to potential benthic impacts was the expansion of offshore fishing into even deeper water. Although Gilchrist (1922) noted that trawlers could fish in 500 m of water in 1921, frequent trawling in deep water, beyond the 500 m contour, seems to have started only in the 1990’s or 2000’s in response to market forces. Some more adventurous offshore operators were experimenting in deeper grounds such as the “orange roughy areas” off the Orange River (900 -1300 m *Iris*), Browns Bank (800 m and deeper) and in the Chalkline ground (400-500 m) in the 1980’s. However, regular hake trawling below 500 m is reported to only start after 2000. Smith (2009) reported a progressive increase of hake trawl fishing effort in deeper water per decade from the 1980s through the 1990s to

2007 in a recent analysis of depth related effort and catch. The total effort spent in water depths greater than 500 m is 0.76%, 4.96% and 12.62% for the 1980s, 1990s and 2000s respectively (Smith 2009). Similarly, the total reported hake caught in water depths greater than 500 m is 1.24%, 6.05%, 11.9%, 17%, and 22% of the total catch for the time intervals 1983-1989; 1990-1994; 1995-1999; 2000-2004 and 2005-2007 respectively (Smith 1990). This progressive incursion into deep water is linked to the demand for prime quality hake, particularly large *Merluccius paradoxus*. Cleaner hake catches (with less bycatch which can reduce fish quality) were found in deeper water and the larger fishing companies brought in international expertise to help establish new grounds in deep water. This is further discussed in the overview of hake fishing grounds below.

The South African trawl fishery has consistently used otter trawl gear from the outset of this fishery although beam trawls were experimented with in the 1970's and 1980's. Lusitania tried fishing with three beam trawlers in 1976 and 1977 but these were phased out after negative reactions by other operators. Then two beam trawlers (imported from Holland) were experimented with in 1989 off Mossel Bay to target sole but these were found unsuitable due to rocky obstacles and the risks involved (Peter Sims, DAFF, pers.comm.). The first twin trawlers joined South Africa in 2004, with 4 vessels that sometimes fish with twin trawls in the current offshore fleet. Note that these vessels do not always fish using twin trawls.

2.3 Current South African fleet and gear

South Africa's inshore and offshore trawlers use otter trawl gear with doors ranging between 180 and 3600 kg according to vessel size and power. A range of doors are employed but all are designed for possible passage over rocky ground while maintaining the net opening (Wilkinson and Japp 2005a). Inshore vessels are usually 14-30 (or 36 m in length, 50 to 200 tons and are limited to less than 1000 horse power. Both stern and side trawlers are included in the inshore fleet. Tows are usually between 1 to 5 hours (average 2.7 hours) and a typical catch is approximately 1 ton. In 2005, there were 35 vessels in the inshore fleet decreasing to 18 vessels in 2011.

The offshore vessels include the wet-fish fleet (approximately 40 vessels) and the deep-sea freezer fleet (about 25 vessels). Wet-fish vessels range between 23-61 m (average 45 m), 96 to 1100 tons and up to 3175 horse power. The average weight of the wet-fish trawler door is 1400 kg. The freezer fleet vessels range between 30-90 m in length, 300–2900 tons and 1000 to 4500 horse power. Trawl doors range between 659 kg to 3600 kg per door. Offshore wetfish vessels usually tow for an average 2.6 hours and land an average of 3 tons per tow. Freezer vessels usually tow for an average of 3.1 hours, landing an average of 4 tons.

Wilkinson and Japp (2005b) report that the intention in demersal hake trawling is to have the ground gear in close contact with the seafloor surface and to skim over it rather than to dig into the ground although trawl doors often penetrate up to 150 mm into the seafloor on soft grounds. Footrope protection such as the use of wire in the footrope, bound ropes along the footrope, the addition of rubber disks or rollers (large rollers are considered rock hoper gear (Box 2) or rubber or steel bobbins at regular intervals along the footrope is required, particularly for fishing in hard or irregular ground. There are many perceptions on the role of such modifications to ground gear including the protection of the gear, raising the footrope slightly off the seabed and adding weight to the footrope to reduce the escape of fish. Most skippers assert that the main aim is to protect the fishing gear and more (although not necessarily heavier) protection is needed in hard and rough or irregular grounds than on softer or smooth grounds with less obstacles. Additional footrope protection can comprise the addition of steel or rubber bobbins or increasingly large rubber discs at regular intervals along the footrope. Hard ground fishing also requires greater power and control from the fishing vessel (speed and trawl length). Tickler chains are employed by some vessels when targeting monk and sole in the soft offshore and inshore grounds respectively.

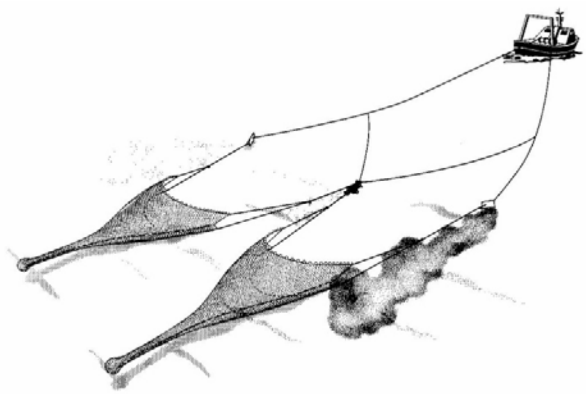
In 1995, Payne and Punt reported that bobbins and other hard ground equipment were rarely used in South Africa's demersal hake fishery although historically, both foreign and local trawlers are reported to have used wooden, steel and rubber bobbins and rockhopper gear on hard grounds along the inshore areas of the South Coast. Wilkinson and Japp (2005b) report that bobbins and rockhopper discs are no longer used in the inshore trawl sector but that some inshore vessels may carry such gear for trawling in areas where grounds might be harder and the risk of fouling gear increased. Currently, industry representatives, the suppliers of trawl gear in South Africa and DAFF staff indicate that some inshore trawlers use rubber discs or rollers (less than 375 mm) (see Box 2) to protect the footrope whereas others use thicker intertwined ropes with no further protection on the footrope.

In the South African offshore fleet, rubber disks of varying sizes are deployed along the footrope of all trawlers and rockhopper gear is reported to be necessary in hard ground areas or areas that are adjacent to hard or irregular grounds. As discussed in the both the historical overview above (1980's to present) and further in the overview of grounds below, the introduction of skippers and fishing gear consultants with international experience led to changes in fishing gear and strategies in the last 30 years, driven largely by changing international markets. In the

1980's a Spanish influence led to the use of heavier bobbin gear on the offshore grounds of the west coast with heavier absorbent nylon netting and heavier footropes with steel bobbins (sometimes perforated to increase weight) to fish harder on the ground. This allowed fishing in previously inaccessible areas and reduced damage to gear. Experimental fishing prospecting for orange roughy in the late 1990's and early 2000's drew from New Zealand and Canadian expertise and involved the use of rockhopper gear. This took place mostly in the high seas. In the 2000's a Scandanavian influence altered hake fishing strategies with a tendency towards lighter gear (with lighter polyethelene netting and rockhopper footropes) on some grounds to reduce drag and fuel costs, improve fishing efficiency and reduce the risk of snagging.

Rockhopper discs currently in use in the South African offshore fleet range up to 610 mm (24 inches) in diameter (maximum of 55 kg per disc) on the largest offshore vessels and are sometimes made from tractor tyres (Wilkinson and Japp 2005). Wilkinson and Japp (2005b) also report that steel bobbins (up to 150 kg per bobbin) are sometimes used by the offshore fleet and additional weights are sometimes integrated into the footrope (Wilkinson and Japp 2005b). The mass of the footrope of the larger freezer vessels may reach 3 tons (on land). Note that the weight of gear in water is approximately 25% of the weight on land. In the current South African offshore fleet, an estimated 25% of vessels use steel bobbins attached to the footrope with most trawlers using 300 mm (12 inch) bobbins while the use of 530-610 mm (21 or 24 inch) bobbins is confined to a few very large offshore vessels. A further estimated 25% of the offshore fleet use rubber rockhopper disks placed along the footrope with the remainder of the fleet using smaller nylon or rubber rollers. Local skippers report that gear is adjusted according to the grounds being fished, the species being targeted and other individual preferences.

Since 1991, permit conditions have imposed maximum size restrictions on individual bobbins, nylon rollers, rubber disks and other devices in the South African hake trawl fisheries (See Box 3 in Section 4 Management Measures). There are no limits on the number of weights, bobbins or rollers or the total mass of the footrope. Permit conditions were slightly revised to accommodate the clump weight used by twin trawlers when this type of trawling was introduced in 2004. Twin trawling is a modern variation and expansion of the single demersal otter trawl that it generally used to target shrimp, other crustacea and groundfish such as monk. The gear is rigged in a similar way to a single demersal trawl in that doors (otter boards) are used to provide spread on the outer wings of both nets (see Drawing 1) but a central wire from the boat to a large weight (referred to as the clump and weighing up to four tons on land) is located on short brides between the two nets. The weight is often fitted with rollers or wheels or composed of a large heavy roller to prevent unnecessary digging into the seabed and to help reduce drag.



Drawing 1. A twin trawler showing the two otter trawl nets separated by a clump weight. (Drawing courtesy of http://www.crimond.com/twintrawl.htm).

Section 3. South African hake fishing grounds

The increasing fishing effort, advances in fishing gear and technology and changes in fishing strategy drove the increasing spatial extent of the fishery to include greater depth and more rugged terrain. This section of the report provides an overview of the fishing grounds, both current and historical in preparation for an assessment of the timing, duration and intensity of the likely impacts of trawling in South Africa (see Section 5). Figure 1 provides an overview of all grounds referred to in this report.

3.1 Methods and Sources

Wilkinson and Japp (2008) delineated the trawl footprint for the inshore and offshore fleet based on South African vessel tracks as documented by Maxsea (or conversions from DECCA) (Figure 2). A one nautical mile resolution grid was used to capture the footprint. Offshore grounds include data from 2007 as far back to mid 1970s but most tracks were recorded after 1990. Inshore grounds were based on tracks recorded between 2007 and 1980. Observer data were also used to supplement track data (see Wilkinson and Japp 2008 for details). This map therefore reflects the majority of trawled area in the last approximately 40 years but does not include all trawled areas over the entire history of the fishery.

Trawling effort was mapped by Fairweather (2002 and Fairweather *et al.* 2006) and by Wilkinson and Japp (2005a). Two maps of trawling effort, reflected at different spatial resolutions (Figure 3 and 4) are included in this report. These maps are based on hours of trawling per 20 nautical mile square grid block (2000-2008 data) and at a finer resolution using trawl start positions and a one nautical mile grid (2004-2008).

An overview of South Africa's hake trawl grounds was constructed by reviewing published maps (Scott 1949, Punt and Japp 1998, Fairweather *et al.* 2006), the recently mapped trawl footprint (Figure 2) and through discussions with scientists, management and industry representatives. Maps of the historical grounds published by Scott (1949) were digitised (Figures 1, 6, 8, 9 and 10) to allow overview in GIS with habitat maps, the trawl footprint and other spatial GIS layers.

3.2 The footprint of the South African hake trawl fishery

Figure 2 shows the recent footprint of the South African demersal hake trawl fishery as mapped by Wilkinson and Japp (2008). As the trawl footprint does not include data prior to 1980 for the inshore sector and 1970 for the offshore sector, there are some grounds that were trawled in the past but are no longer trawled that are not reflected in this footprint. This includes inshore grounds that were fished by foreign trawlers and local inshore vessels prior to 1980 and some of the grounds that were explored by adventurous skippers.

As mentioned earlier in this report (Section 2), the South African hake trawl fishery includes two sectors which fish mostly on different grounds (Figure 2). Offshore vessels operate along the west and south coast between the Namibian border and Port Alfred, fishing along almost the entire shelf break between Hondeklipbaai and the southern tip of the Agulhas Bank. Hard grounds interrupt trawling in this area at the tip of the Agulhas bank and trawling is patchier along the eastern edge of the Agulhas shelf edge. Offshore vessels fish mostly in depths ranging between 110 and 1000 m (Fairweather *et al.* 2006). Along the south coast, offshore vessels may not operate in water shallower than 110 m or within 20 nm of the coast, whichever is the greater distance from the coast (Figure 2). On the west coast, the trawl exclusion zone extends 5 nautical miles from the shore. A key area of overlap between the offshore and inshore sectors is “the Blues” off Mossel Bay (see overview of grounds below). There are no permanently closed offshore areas although a time/area closure is in place (since 2005) off Port Elizabeth to protect spawning kingklip during the period 1 September to 30 November.

Inshore trawlers fish along the south coast between Cape Agulhas and the Kei River. The offshore extent of inshore trawlers is limited by vessel power and gear limitations rather than any regulation. Along the south coast, trawling is focused on a set of relatively distinct grounds with untrawlable hard grounds and high profile reefs that tend to separate the inshore grounds (Wilkinson and Japp 2005a) (Figures 1, 2). Trawling is prohibited within several trawl closures implemented between 1928 and 1986 and within the De Hoop and Tsitsikamma Marine Protected Areas. Some trawl fishing does take place in the extractive use zone of the Table Mountain National Park MPA. See Section 4 Management measures for further details of trawl closures.

Trawling effort is not evenly distributed across the trawl grounds with higher effort along the west coast shelf break (especially between Saldahna and Cape Hangklip) and in the inshore grounds between Struis Baai and Mossel Bay (Figures 3 and 4). Wilkinson and Japp (2005b) provide a very comprehensive overview of spatial patterns in fishing effort which is not repeated here.

3.3 Overview of grounds

Scott (1949) provided a first description of all the trawl grounds drawing from several sources including the 1887-1948 reports of the government marine biologists, John Gilchrist and Cecil Van Bonde. Several main grounds were recognised (see Figure 1 and Figures 5 - 10) and an overview of these grounds is provided, following Scott’s terminology, from west to east, to support the estimate of the timing, duration and extent of impacts in different habitat types and supplement current estimates of fishing intensity in different grounds.

3.3.1 North Grounds (St Helena - Port Nolloth)

Scott (1949) did not map the north grounds but did describe a small ground in shallow water (25 m - 80 m) offshore of Port Nolloth and trawling in the 100 – 540 m depth range between the Orange River and St Helena bay. The shallow Port Nolloth grounds were considered an important area for “supersoles” *Austroglossus pectoralis* (Scott 1949) and were trawled as early as 1921 (Gilchrist 1922) but have not been trawled in at least the last 40 years following the disappearance of that species in this area (Colin to provide reference).

The main North ground is an offshore ground extending from St Helena Bay in the south to the border with Namibia in the north (Figure 1). This ground is characterised largely by sandy and muddy sand with isolated patches of hard ground. These grounds appear to have been first trawled in the 1930’s or 1940’s. Gilchrist surveyed these northern offshore grounds in 1921 and 1925, sampling in very deep water (approximately 1000 m) in the latter survey. Scott reported in 1949 that these grounds were only trawled occasionally, especially in winter when yields declined on the west grounds (Scott 1949). This area seems to have been fished more regularly since the 1950’s in the 150-400 m depth range. Fishing extended regularly below 500 m depth only in the mid to late 1990’s. The expansion of the offshore grounds into deeper water is related to changing markets, particularly the development of the prime quality hake market (fresh, high quality hake for export). Offshore trawling now extends along most of the shelf break in this area although hard grounds interrupt trawling in the far north (Figure 1). Trawling around the slopes of the submarine feature Childs Bank (the “karbonkle”) off Hondeklip Bay is evident in the trawl footprint, although initiation of trawling activity in this area is difficult to pinpoint. It was unlikely to have occurred prior to the 1980's. Skippers and deckhands report fragments of corals sometimes caught in isolated locations in this area and that there are several patches of hard ground, requiring additional footrope protection (e.g bobbins and rockhopper gear, see Box 2). Tickler chains are used on occasion in this area where monk is an important bycatch species (Sink *et al.* 2011). Fishing intensity in the north has declined since the mid 90's (Russell Hall, Sea Harvest pers.comm.) and was unlikely to ever have been comparable to the more intensively fished west grounds closer to Cape Town (Figures 3 and 4). Spanish vessels permitted to fish in Namibia may have engaged in illegal trawling south of the border which may have contributed to higher effort in this area in the late 1980's.

3.3.2 West ground

The primary offshore fishing ground on the west coast was originally termed the West ground (Figures 1, 5 and 6) and is a sandy and muddy offshore ground that was first fished in the 1920's and continues to be a very important area for the offshore trawl fleet (Figures 3, 4). Scott (1949) reported the West grounds as the most productive trawl grounds and noted that the highest intensity of trawling took place at the shelf break (average depth 330 m) in the area between Table Bay and Dassen Island. Roux (1949) showed that most of the hake catch came from the area shown as the heart of the west ground (Figure 6). He reported that rocks inshore of 140 m contour did not permit trawling inshore and that hard grounds to the west (where the Cape Valley submarine canyon breaches the shelf off Cape Point) prevented trawling in this area. North of Saldanha Bay, in the vicinity of the Cape Canyon, rocky ground and strong currents made trawling impossible in this area at that time. The west coast grounds were generally considered to be relatively clear with few rocky areas or trawl obstacles. Currently, skippers report that this generally continues to be the case with noted exceptions being around the two submarine canyons, isolated patches of rocky ground and the "karbonkle" described above (North grounds).

Discussions with industry representatives, skippers and deckhands report that fragments of corals were sometimes caught around the canyons and in hard ground areas and that these areas required greater footrope protection (such as bobbins or rockhoppers, See Box 2) in the years that these areas were first fished. Maxsea plots showing trawl tracks around the two submarine features are shown in Figure 7. Trawling on rough ground near the Cape Canyon (off Saldahna) started in the late 1990's and was regularly fished after 2000. The progression into deeper water is associated with changing markets and the associated international gear expertise that was brought into South Africa's fishery. The appointment of Icelandic and Norwegian trawl skippers in the 2000's with substantial deep water experience into the local offshore sector played a key role in the offshore expansion of fishing activity. Rough ground in areas such as "the Blades" off Cape Point (an area of irregular hard ground near Cape valley) were more frequently and confidently trawled at this time with less damage or loss to gear than previous attempts in earlier times. At present, the Cape Valley (Figure 1), the southern canyon off Cape Point, has a high trawling effort in the South African context (Figures 3 and 4) and this area has been fairly intensively fished for the last approximately 25 years. Commercial grid block 469 is reported to have one of the highest commercial effort values across the commercial grid with more than 5000 hours of trawling per annum reported for this 20 minute grid over an 8 year period (Figure 3).

3.3.3 Table Bay, False Bay and Cape Hangklip

A small sandy inshore ground in Table Bay was fished from the late 1890's until 1949. The False Bay and Cape Hangklip grounds are also shown on Figure 6. The grounds of False Bay and Cape Hangklip are mostly sandy with some rocky ground adjacent to the Cape Hangklip ground. The False Bay ground was closed in 1928 and the Cape Hangklip grounds do not seem to have been trawled in the last 30 or 40 years (Figure 2). Scott (1949) reported that "the relatively low productivity of the False Bay grounds, together with the presence of ammunition in large quantities dumped on these grounds by naval authorities, suffices to ensure immunity from trawling"!

3.3.4 Browns Bank

Browns Bank is an offshore ground that extends along the outer shelf and shelf edge from Cape Point to the southern tip of the African continental shelf (Figure 1). Fishing expanded into the area south of the west ground along the western edge of the Agulhas Bank since approximately 1935 (Japp *et. al.* 1994). This area is a very important and productive area that has sustained more than 50% of the offshore trawling effort since 1994 (Japp *et al.* 1994) (see Figures 3 and 4). Although part of this ground has been fished since at least 1960, consistent fishing in water deeper than 500 m is also reported to have started only in the 1990's with the development of the prime quality hake market and arrival of international expertise in deeper water fishing (Barrie Rose and Russel Hall, pers. comm.). Also, fishing has slowly been extending further east in this area with reports of recent breaking of ground at the southern tip of the African continental shelf. This is the only area where a few commercial trawls have been reported outside of the trawl footprint since it was mapped (See Appendix 1).

3.3.5 Rocky grounds and submarine canyons that previously separated the North ground, West ground and Browns Bank

In the past, rocky ground and the submarine canyons separated the North, West and Browns Bank grounds but at some stage these grounds expanded and fishing gear and technology allowed trawlers to overcome the previously reported difficulties of trawling in these rougher and harder grounds. Figure 2 shows the total extent of the recent trawl footprint along almost the entire west coast shelf edge of South Africa. There are a few very small areas characterised by rocky features (excluded from the actual footprint) within the broader footprint area that remain untrawled. This expansion is also associated with evolving gear and expertise in trawling in rougher and deeper ground over the past 20 years.

3.3.6 Half way house (off Cape Agulhas)

This relatively small offshore ground (Figure 1) was not mapped by Scott (1949) and was unlikely to have been trawled prior to 1955. Named according to its convenient location between Cape Town and the south coast fishing grounds, this ground was fished en route to and from Cape Town. The ground is muddy with some patches of hard ground in the north. It is reflected in the footprint (Figure 2) and seems to have been fished at moderate to low intensities between 1960 and the 1990's with less intensity in recent times. Currently, it is seldom fished with only one reported trawl track in this muddy ground between 2002 and 2007. No further information was found about this area which was also not included in any historical research surveys between 1897 and 1948, perhaps explaining the late development of this ground.

3.3.7 South Coast Inshore Grounds (Cape Agulhas to Cape St Francis)

Gilchrist (1986-1925), Van Bonde (1928, 1933, 1936, Director of Fisheries 1939) and Scott (1949) all remarked on the habitat complexity of the inshore grounds on the Agulhas Bank. The grounds in this area were described as several discrete relatively small grounds (Figures 2, 8 and 9) that are limited by rocky ground and outcrops of coral. Sole, hake and many linefish species (including kob, redfish and white stumpnose) were caught in these grounds.

The Cape Infanta grounds (also referred to as the Struis Bay grounds include the Martha point, Cape Barracouta and Kaffirkuils grounds. The Martha Point ground was described as an isolated mud patch in the 65-90 m depth range and was considered as a sole ground where the abundance of sole fluctuates with migrations. Offshore of the Martha Point ground is another mud patch that does not seem to have been trawled in the last ten years although it is reflected in the trawl footprint. The "Strawberry patch" east of the Martha point ground was named by the predominance of unattached redbait (*Pyura* sp.) in this area (Scott 1949) and much of this shallow area is no longer trawled due to trawl exclusions.

The Struis Bay ground (Figure 8) is considered prime sole habitat, a muddy area that slopes between 45-90 m and joins onto the adjacent Middle Ground. This broader area is also known as the Cape Infanta Ground, the northern part of which is muddy. The southern section off Cape Barracouta was reported to range between 54-72 m and this area is sand dominated with few soles reported. These Cape Barracouta Grounds connect to the Kaffirkuils Ground via an area known as "The Channel", the northern area is reported to be composed of a thick layer of mud (similar to northern part of Cape Infanta) but in the south, a thin layer of mud lies over a layer of sandstone in the 54 – 67 m depth range. Grounds composed of a thick layer of deep mud were fished the gear more heavily on the bottom (by letting out more trawl warp) to "dig out the soles", but where a thin layer of mud occurred over sandstone outcrops, shorter warps were used (shorter lengths of wire). The mud grounds off Cape Infanta were fished from the early 1900's and continue to be fairly intensively fished (Figures 3 and 4) with sole as the main target species.

Between Bull Point, Vlees Baai and Mossel Bay, the Cape St. Blaize Grounds (Figure 8) join up extending to Gericke Point. Scott (1949) reported that the seaward limit of these grounds was uncertain but that the main sole habitat is found shallower than 80 m. These grounds have expanded very little since Scott mapped them in 1949, although they have extended into slightly deeper water. The defined grounds around the Kaffirkuils ground area have expanded despite reports that trawling is very difficult in this area because of rocky obstacles (Director of Fisheries 1939). Closed bays have reduced the area trawled for some of the inshore habitat types but an expansion of trawl activities in this area, most likely in the 1960's and 1970's, led to trawling on harder ground that was previously considered untrawlable (Scott 1949).

The grounds between Knysna and Cape St Francis (Figure 9) include Knysna Ground, Plettenberg Bay Ground, Storms River Ground, Robhoek Point Ground and the Cape St Francis grounds. In 1949 Scott reported that these small isolated areas are trawlable habitat between rocky patches and that these areas are not consistently exploited. These grounds also expanded into slightly deeper water and into rougher ground (Figure 2) and this probably occurred in the 1970's and 1980's. Some patches off Cape St Francis are however not included in the trawl footprint and therefore have not been trawled in the last 30 years.

3.3.8 The Foreign triangle

This is not a distinct fishing ground *per se* but refers to a region that overlaps with other more distinct grounds (such as the blues) and is included here for the sake of completeness (Figure 1 and 8). After the proclamation of the EEZ, the local offshore trawl fleet were excluded from fishing inshore of the 110 m isobath whereas the foreign vessels were excluded from fishing closer than 20 nautical miles from the coast (see Historical perspectives). There is an area between Cape Agulhas and Knysna where the 110m isobath extends further than 20 nautical miles from the coast. This area became known as the “foreign triangle” because the foreign vessels were permitted to fish there whereas the local offshore fleet were excluded.

The area includes sandy shelf and hard grounds with stylasterine corals, black corals and gorgonians. Large foreign trawlers, using heavy bobbin gear, were allowed to fish in this area over an approximately 30 year period. The reef-associated panga was a key target of foreign (Japan and Taiwan) trawlers in this area between 1964 and 1993 (Hatanaka *et al.* 1983, Uozumi *et al.* 1984, Uozumi *et al* 1985). The main commercial grids that were targeted within this broader area include Grids 553, 538, 539 and 540 (Figure 3), an area just inside of the Blues. Hard ground and inner shelf gravel habitats within this area would probably have been impacted by bobbin trawling on these grounds during this period. As reflected in the trawl footprint, a small proportion of these grids are currently fished with moderate fishing intensities.

3.3.9 The Blues

The blues is an important ground off Mossel Bay ranging between 110 and 130 m in depth (Figure 1). This area is reported to be characterised by sand and shale interspersed with occasional rocky outcrops. It is distinguished by the frequent presence of an oceanographic feature known as the cold water ridge (Beckley 1983; Swart and Largier 1987) which is reported to influence fish community composition in this area (Attwood *et al.* 2011). This distinct ground was unlikely to have been fished prior to 1960 but since then is fished by both sectors, although offshore vessels cannot fish the inner blues (inshore of 110 m depth contour). The Blues is a shallow water hake ground with limited sole catches made in this area. The Blues has been relatively heavily fished for approximately 50 years (Figure 3). Since the late 1960’s trawl grounds have decreased slightly in extent in this area due to expanding petroleum activities.

3.3.10 Southeast Coast Inshore Grounds (Cape St Francis to Stoney Point)

Trawling in this area (Figure 10 and 11) started in 1897 with sole fishing in Algoa Bay and extending up to Bowkers Bay Ground by 1920 (Scott 1949). This area has complex geology with muds, sand, gravel, reefs, coral outcrops and rough ground along this stretch (Van Bonde 1933, Sink *et al.* 2012). Trawling has not extended east of Port Alfred for at least the last 40 years and permit conditions prohibit trawling east of 27 degrees. Grounds between Stalwart Point (just north of Port Alfred) and Stoney Point in the former Transkei (Figure 10) were occasionally trawled in earlier days by local and foreign fleets (Scott 1949, Japp *et al.* 1994). Scott (1949) reported low catches and high risk of net damage in this area. The *Africana* lost a trawl net off the Transkei during the only known experimental research trawl in this area (RWL). The two sandy grounds off Stalwart point are also excluded from the trawl footprint reflecting an absence of trawling east of Port Alfred in the last 40 years. The Chalumna River grounds were reported to “occur but are never exploited” (Scott 1949) suggesting that these grounds were not fished very much in the 1930’s and 1940’s (but note that the trawler *Nerine* did catch a coelacanth there in 1938). The Chalumna River Grounds (Figure 10) occur on gravel patches and anecdotal reports suggest that these were key grounds for targeting redfish in the 1960’s and 1970’s.

Scott (1949) reported that trawling was concentrated in the Jeffreys Bay Ground and the Roman Rock Ground in Algoa Bay in the 1930’s and 1940’s. He remarked that the St Croix Island Ground was usually only trawled in poor weather. A large portion of Algoa Bay (see Figure 2) was closed in 1935 to protect young soles, kabeljou and geelbek (Scott 1949). The northern and shallower sections of the muddy Cape Padrone ground were reported to be very productive and a key area for boats based in Port Elizabeth and East London (Scott 1949).

Trawling mostly likely expanded in this area in the 1960's and 1970's with fishing taking place closer to harder ground and in more risky areas than in earlier times. The introduction of DECCA, associated improved abilities to relocate grounds, the use of echosounders and bobbin and later rockhopper gear facilitated this expansion. Many of the private boats that were introduced in the 1970's invested in the establishment of new trawl lanes within or adjacent to the historical inshore grounds. Large quanitities of rock were trawled up and moved into areas adjacent to trawling grounds or in deeper water in the process of clearing and establishing new trawl areas. Large foreign vessels, particularly those vessels using bobbin and later rockhopper gear, fished between Cape St Francis and the Chalumna River near East London (particularly Grids 622 625, 629, 633) between 1964 and the early 1990's. The trawled area in these grounds has since diminished in the last 30 years due to the introduction of trawl closures, declining catch rates in the 1970's and 1980's and other factors relating to fishing strategies.

Currently highest effort in this area is in the Cape Padrone and Bird Island grounds (Figures 3 and 4) and some of the grounds within the footprint in this area have been fished for a 100 years. The Bird Island MPA, proclaimed in 2004 (Sink *et al.* 2012), prohibits trawling close to the island and there is a current initiative to plan towards the proclamation of a larger zoned MPA in this area. This proposed MPA, the Addo MPA is still under development but may afford further protectionSoft ground areas have been exposed to trawling much longer (100 years in many cases) than areas close to or on rocky areas in these grounds which were most likely only impacted in the 1970's with less impact in recent times.

3.3.11 The Chalkline Grounds

Van Bonde (1936) first reported on the Chalkline grounds (Figures 1, 9 and10) after surveys there in 1935. The increasing importance of Port Elizabeth and the decline of East London as a trawling port was attributed to the discovery of these important offshore grounds (Scott 1949).This area includes sandy, gravel and hard ground habitats along the outer shelf and shelf edge. The shelf edge is incised by several submarine canyons in this area with early reports of the complex geology and topography in these grounds (Van Bonde 1936, Sink *et al.* 2011). Scott (1949) reported that "The sea-floor deposits over these grounds are composed of rather coarse sand and broken shell, together with varying amounts of finely broken coral. Distributed over the untrawlable sections, in addition to these deposits, are numerous hillocks of clayey sandstone, partly or wholly covered with coral". Early trawling in this area was most likely confined to soft grounds with harder and riskier grounds only exploited later and particularly after the introduction of heavier ground gear. The submarine canyons east of Port Elizabeth were not trawled in 1949 but are included in the recent trawl footprint (Figure 2). Larger stern trawlers did start to fish these grounds in the late 1960's. Anecdotal evidence suggests that trawlers started fishing rougher ground in this area more regularly in the 1970's or 1980's but prior to this such trawling was ery occassional. Demersal longliners targeted such hard ground areas from 1983 (Dave Japp, Capfish, pers. comm.). As with many other offshore grounds, progressive fishing below 500 m started as late as 2000 but skippers suggest that the Chalkline grounds do not extend much below 600 m.

Table 3: Overview of main trawl grounds (west to east) indicating dominant habitat types (as classified by Sink et al. 2012), the approximate start of trawling, key trends and approximate current trawl intensity (Figures 3 and 4). See text for appropriate references.

Ground	Dominant habitat types	Approximate start of trawling & any key trends
Port Nolloth	Namaqua Muddy Inner Shelf, Southern Benguela Outer Shelf Sands and Muds, 25-80 m	1921. Trawling stopped by the 1960's
North	Namaqua Muddy inner Shelf, Namaqua Sandy Inner Shelf, Southern Benguela Sandy Outer Shelf, South Atlantic Upper Bathyal	1930's, increasing in extent and depth since 1960
West	Southern Benguela Sandy Outer Shelf and Shelf Edge, South Atlantic Upper Bathyal	1920 with increasing intensity and depth
Table Bay	Southwestern Cape Sandy Inner Shelf	1890's (tugs). Trawling stopped in 1949
False Bay & Buffels Bay	Agulhas Sandy Inshore, Agulhas Sandy Inner Shelf	Late 1890's until 1928 when bay closed
Cape Hangklip inshore	Agulhas Sandy Inner Shelf	Early 1900's, grounds reduced by closure of False Bay but some trawling in 1949. Not trawled in the past 30 years.
Cape Hangklip offshore	Southern Benguela Sandy Outer Shelf and Muddy Outer Shelf	Uncertain, probably 1930's
Browns bank	(Southern Benguela Sandy Outer Shelf and Shelf Edge, Hard Shelf Edge, South Atlantic Upper Bathyal)	1930's but 1980's -2000's for the deeper & rougher ground
Half way house	Agulhas Muddy Outer Shelf, Agulhas Sandy Outer Shelf, Southern Benguela Muddy Outer Shelf	Approximately 1960 with declining effort since 1980's
Cape Infanta grounds	Agulhas Muddy Inner Shelf, Agulhas Sandy Inner Shelf and limited trawling in Agulhas Hard Inner Shelf (after 1963)	1915 with high variability across ground
Mossel Bay grounds (including Bull point to Cape St Blaize)	Agulhas Muddy Inner Shelf, Agulhas Sandy Inner Shelf, limited trawling in Agulhas Hard Inner Shelf (after 1963)	1900
Knysna – Jeffreys Bay Ground	Agulhas Muddy Inner Shelf, Agulhas Sandy Inner Shelf, Agulhas Sandy Outer Shelf, Agulhas Mixed Sediment Outer Shelf, Agulhas Hard Outer Shelf, Agulhas Hard Inner Shelf	1915 but hard grounds most likely only trawled after 1963
Foreign triangle	Agulhas Sandy Inner Shelf, Agulhas gravel inner shelf, Agulhas Hard Inner Shelf	1930s but hard grounds trawled with bobbin gear from 1963-1993 and rockhoppers from 1989 – 1993. Mostly no longer trawled by 1980
The Blues	Agulhas Sandy Inner and Outer Shelf	1960
South east coast inshore grounds	Agulhas Sandy Inner Shelf, Agulhas gravel inner shelf, Agulhas Hard Inner Shelf	1900
Chalk line (original)	Agulhas Gravel Outer Shelf, Agulhas Sandy Shelf Edge	1935 with expansion into deeper water and into irregular habitat since 1990
Chalkline (deeper, rougher ground)	Agulhas Hard Outer Shelf, Agulhas Hard Shelf Edge, Agulhas Canyon Southwest Indian Upper Bathyal	Approximately 1970-1980 & further offshore in the 1990's/ 2000's.

Section 4. Management measures to protect the benthic environment

An overview of key developments in South Africa's hake trawl fishery, including broader management measures, is detailed in the historical overview provided in this report (Table 1). Currently implemented key management measures that provide protection to benthic habitats in South Africa include various trawl exclusion zones, Marine Protected Areas (Figure 2) and permit conditions that restrict the size and mass of bobbins and rollers (see Box 2 and 3).

4.1 Trawl exclusion zones and MPAs

The first trawl closure was implemented in False Bay in 1928, followed by a closure in part of Algoa Bay in 1935 (Scott 1949). Further closures were introduced in the 1976 (Mossel Bay), 1983 (Cape Infanta), 1985 (de Hoop), 1986 (Plettenberg Bay and Jeffery's Bay) (Attwood *et al.* 1997). Most of these closures were introduced to address the concerns of other inshore fisheries sectors, particularly commercial and recreational linefishers. Although these closures were not implemented with the aim of protecting habitats, it is likely that they do afford some protection to several inshore and inner shelf habitat types. As Attwood *et al.* (1997) noted, the effectiveness of these closures in terms of habitat protection has never been examined.

The habitat types included in trawl closures and MPAs were assessed in the spatial analyses included in Section 5. Eight of the 27 habitats included in the recent trawl footprint (Wilkinson and Japp 2008) are included in MPAs or trawl closures and most of these are inshore or inner shelf habitats (less than 100 m in depth). The National Biodiversity Assessment 2011 (Driver *et al.* in press) reports that offshore habitat types are the most poorly protected ecosystems in all of South Africa, considering terrestrial, fresh water, estuarine and marine habitats. (See Management recommendations).

4.2 Exclusion of the offshore fleet from inshore grounds

The introduction of the permit restriction that prevents the offshore fleet from fishing shallower than the 110 m depth contour east of Cape Agulhas was introduced in 1978 (Table 1), after the establishment of the EEZ. This exclusion zone consitituted an area of approximately 10 000 square nautical miles extending between the 20 and 27 degrees of latitude. This measure most likely limited impacts in some seabed habitats although this may have been compromised to some extent by large foreign vessels fishing within the foreign triangle (see historical overview and overview of grounds) between 1978 and 1993.

Since 1991, permit conditions for the South African hake trawl fishery have set limits on the size of individual rollers, bobbins and other footrope protection devices in order to minimise the potential impacts of fishing on the seabed (Box 3). The limits on bobbins and rollers are reported to be based on the maximum size in use at that time (RWL and Rob Whitehead, African Maritime Services pers. comm.) and aimed to prevent the introduction of heavier gear and limit further potential benthic impacts, particularly in rough and hard grounds. Permit conditions for foreign trawlers trawling under bilateral agreements did not seem to include such restrictions (at least in 1991). The actual size and mass limits, 375 mm (inshore) and 650 mm (offshore) or 200 kgs (both sectors) have remained the same from 1991 until 2011.

4.3 Trawl gear restrictions

South Africa first introduced restrictions on footrope protection in the trawl fishery in 1991 (Table 1, Box 3). These restrictions were based on the maximum size of bobbins and rollers in use at that time and aimed to prevent the introduction of heavier gear.

Box 3. Relevant permit conditions for the South African inshore and offshore trawl fisheries

Inshore trawl (2007-2010)
"The Permit Holder shall utilise only bottom trawl. No bobbins, nylon rollers or other devices whatsoever, with a diameter in excess of 375 mm or a weight in excess of 200kgs may be deployed with, or as part of, the trawl gear, except for floats and the single pair of trawl doors."

Offshore trawl (2007-2010)
"The Permit Holder shall utilise only bottom trawl gear with a minimum codend mesh size (measured knot-to-knot and stretched to a maximum tension of 5 kgs) of 110 mm. No bobbins, nylon rollers or other devices whatsoever, with a diameter in excess of 750 mm or a weight in excess of 200kgs may be deployed with, or as part of, the trawl gear, except for floats and the single pair of trawl doors and the device separating trawls in the case of twin trawling."

Other countries, states and fisheries have also imposed restrictions on the maximum size of trawl rollers or bobbins such as 100 mm (New South Wales Ocean Trawl fishery, Rowling 2008), 150 mm (Conneticut), 200 mm (California and most rockfish fisheries in Oregon), 300 mm (Massachusetts and Gulf of Mexico) and 460 mm (scub and black seabass fisheries in Maryland, New York, Rhode Island and New Jersey).

The effectiveness of such restrictions are seldom evaluated as there is limited information to support such review. This is exemplified by the review of regulations pertaining to the use of ground gear in the New South Wales Ocean Trawl Fishery in 2007 (Rowling 2008) that was undertaken with a view to allowing an increase in the permitted size of rollers to a maximum of 150 mm diameter. Rowling (2008) concluded that "there is little information available which would allow an assessment of the effects on the marine environment of an increase in the maximum size of bobbin gear from 100 to 150 mm diameter" and that "it is likely that differences in the design and construction of the ground gear on different demersal trawls" might have a more significant influence on demersal biota than the maximum diameter of the rollers employed. Hannah (2003) noted that such gear restrictions may need to be complemented by catch restrictions for species favouring rocky habitats in managing the spatial distribution of trawl effort in potentially vulnerable areas.

Section 5. Spatial analyses to assess the interaction of the South African hake trawl fishery with all habitat types.

5.1 Methods and data sources

South Africa only recently developed a first systematic marine and coastal habitat classification and map (Sink *et al.* 2012). The footprint of the South African hake trawl fishery was similarly only recently determined and mapped (Wilkinson and Japp 2008, Figure 2). Building on the comprehensive spatial analyses undertaken by Wilkinson and Japp (2005a), new analyses were undertaken using these two new maps. Key differences between the previous work (Wilkinson and Japp 2005a) and the new analyses include the more comprehensive habitat classification that accounted not only for substrate but also differences likely due to biogeography and depth within each substrate type. Wilkinson and Japp (2005c) also did not include hard grounds or features such as canyons, submarine banks and the shelf edge in their analyses. Finer resolution data based on trawl tracks (Wilkinson and Japp 2008) and updated fishing effort data was also included in the undated analyses included in this report.

The interaction of the hake trawl fishery footprint with all marine habitat types as classified and mapped by Sink *et al.* (in prep.) was evaluated through spatial analysis. The area and relative proportion of each habitat type within the trawl footprint and the total percentage of the total extent of each habitat type within the trawl footprint was calculated using Arcview Spatial Analyst. Detailed spatial analyses were not conducted using the older historical mpas and digitised spatial data because of the lower levels of accuracy in historical maps but cases where trawling that is not reflected in the current footprint may have increased impacts on habitat types were noted. Habitat types that were impacted in the past but are not included in the recent trawl footprint were also reported. The percentage of each habitat type within existing spatial management measures (trawl exclusion zones, MPAs and spatio-temporal closures) was also examined to complement the protection level analyses for habitat types undertaken in the 2011 National Biodiversity assessment (Sink *et al.* 2012). To support an assessment of the potential intensity of trawling impact in different habitat types, the trawl effort across the area of each habitat type within the footprint was calculated using the number of reported commercial trawl start positions (2004 – 2008). Interviews with DAFF staff, previous and current industry staff, current or retired skippers, experienced trawler crew and observers were also undertaken to broaden the understanding of interactions between trawling and benthic habitats.

5.2 Results

A total of 27 of the 136 (20 %) marine and coastal benthic habitat types in South Africa (Sink *et al.* 2011) are included in the current trawl footprint (Table 4, Figures 2, 12, 13 and 14). The dominant habitat type within the trawl footprint is the Southern Benguela Sandy Outer Shelf (14 661 km^2 or 21% of the footprint) followed by the Southern Benguela Sandy Shelf Edge (9 727 km^2 or 14% of the footprint) (Figures 12 and 13). In the deepsea region (i.e. beyond the shelf edge), the dominant habitat type within the footprint is the South Atlantic Upper Bathyal (12% of the footprint). Hard ground habitats are also included within the trawl footprint with 5% and 3% of the footprint consisting of Southern Benguela Hard Shelf Edge and Hard Outer Shelf respectively (Figure 2). It must be noted that the extent of the hard ground habitats may be overestimated in the habitat map (see Sink *et al.* 2012 for further details) due to limitations in habitat mapping. In the Agulhas Ecoregion (Figures 12 and 14), the habitat types with the greatest area within the footprint are the Agulhas Sandy Inner (8 568 km^2 or 12%) and Outer (8 244 km^2 or 12%) Shelf. The Agulhas Muddy Inner Shelf constitutes 3% of the total trawling footprint. On the shelf edge, Agulhas Sandy Shelf Edge is the dominant habitat type within the footprint (3%). In the deepsea (Southwest Indian Ecoregion), the expansive Southwest Indian Upper Bathyal constitutes only 3% of the trawl footprint.

Table 4: Habitat types that occur within the trawl footprint for the South African hake directed demersal trawl fishery (Wilkinson and Japp 2008). Habitat types used the classification and map from the 2011 National Biodiversity assessment (Sink et al. 2011).

	Habitat Name	Total habitat extent (km^2)	Percentage of footprint per habitat type	Percentage of total extent of habitat type within footprint	Number of trawl starts per km^2 of habitat type within trawl footprint (average 2004 - 2008)
1	Agulhas Canyon	1119.7	0.84	52.75	0.75
2	Agulhas Gravel Outer Shelf	1481.1	0.96	45.46	1.82
3	Agulhas Gravel Shelf Edge	1788.1	0.13	5.21	0.01
4	Agulhas Hard Inner Shelf	4279.1	0.82	13.45	0.61
5	Agulhas Hard Outer Shelf	11537.3	1.45	8.82	0.75
6	Agulhas Hard Shelf Edge	4162.9	0.98	16.49	0.31
7	Agulhas Mixed Sediment Inner Shelf	627.5	0.16	18.02	0.66
8	Agulhas Mixed Sediment Outer Shelf	1308.2	0.15	8.17	0.25
9	Agulhas Muddy Inner Shelf	2684.5	3.22	84.08	0.76
10	Agulhas Muddy Outer Shelf	1772.1	0.98	38.66	0.26
11	Agulhas Muddy Shelf Edge	170.7	0.05	19.01	0.03
12	Agulhas Sandy Inshore	1708.8	0.02	0.65	0.36
13	Agulhas Sandy Outer Shelf	32869.3	11.75	25.08	0.85
14	Agulhas Sandy Shelf Edge	4067.5	2.93	50.52	0.49
15	South Atlantic Upper Bathyal	37312.6	11.67	21.94	0.64
16	Southern Benguela Canyon	785.9	1.07	95.49	1.19
17	Southern Benguela Carbonate Mound	1449.2	0.76	36.60	0.27
18	Southern Benguela Gravel Outer Shelf	433.4	0.26	41.76	2.13
19	Southern Benguela Gravel Shelf Edge	29.9	0.04	100.00	0.90
20	Southern Benguela Hard Outer Shelf	10612.9	4.41	29.15	0.78
21	Southern Benguela Hard Shelf Edge	4532.0	5.02	77.74	1.55
22	Southern Benguela Muddy Outer Shelf	6054.3	1.15	13.30	0.03
23	Southern Benguela Muddy Shelf Edge	567.3	0.81	100.00	1.48
24	Southern Benguela Sandy Outer Shelf	56231.7	20.90	26.07	0.47
25	Southern Benguela Sandy Shelf Edge	13237.7	13.86	73.48	1.13
26	Southwest Indian Upper Bathyal	84840.8	3.27	2.71	0.22
27	Southwestern Cape Sandy Inner Shelf	1652.1	0.03	1.21	0.19

Table 5: Estimated start, duration, intensity and extent of the interaction of trawling with the classified habitat types that occur within the trawl footprint (Wilkinson and Japp 2008). In the last two columns, + indicates heavier trawling in the past or additional areas of habitat type that were likely to have been trawled prior to the period of trawling activity reflected in the recent trawl footprint (i.e before 1980 for inshore and 1970 for offshore).

	Habitat Name	Start of trawling (approx.)	Duration (approx. years)	Intensity (Average number of trawl starts per km^2 per year for the period 2004 - 2008)	Percentage of total extent of habitat type within recent footprint
1	Agulhas Canyon	1970s	40	0.75	52.75
2	Agulhas Gravel Outer Shelf	1935	75	1.82	45.46
3	Agulhas Gravel Shelf Edge	1980s	30	0.01	5.21
4	Agulhas Hard Inner Shelf	1960s	50	0.61	13.45+
5	Agulhas Hard Outer Shelf	1960s	50	0.75	8.82+
6	Agulhas Hard Shelf Edge	1960s	50	0.31	16.49
7	Agulhas Mixed Sediment Inner Shelf	1920s	90	0.66	18.02+
8	Agulhas Mixed Sediment Outer Shelf	1930s	80	0.25	8.17
9	Agulhas Muddy Inner Shelf	1900s	110	0.76	84.08+
10	Agulhas Muddy Outer Shelf	1930s	80	0.26	38.66+
11	Agulhas Muddy Shelf Edge	1930s	80	0.03	19.01
12	Agulhas Sandy Inshore	1900s	110	0.36	0.65+
13	Agulhas Sandy Outer Shelf	1930s	80	0.85	25.08+
14	Agulhas Sandy Shelf Edge	1990s	30	0.49	50.52
15	South Atlantic Upper Bathyal	1990s	30	0.64	21.94
16	Southern Benguela Canyon	1970s	40	1.19	95.49
17	Southern Benguela Carbonate Mound	1990s	30	0.27	36.60
18	Southern Benguela Gravel Outer Shelf	1990s	30	2.13	41.76
19	Southern Benguela Gravel Shelf Edge	1990’s	30	0.90	100.00
20	Southern Benguela Hard Outer Shelf	1990’s	30	0.78	29.15
21	Southern Benguela Hard Shelf Edge	1990’s	30	1.55	77.74
22	Southern Benguela Muddy Outer Shelf	1950’s	60	0.03	13.30
23	Southern Benguela Muddy Shelf Edge	1930’s	80	1.48	100.00
24	Southern Benguela Sandy Outer Shelf	1920’s	90	0.47	26.07
25	Southern Benguela Sandy Shelf Edge	1930’s	80	1.13	73.48
26	Southwest Indian Upper Bathyal	1990’s	30	0.22	2.71
27	Southwestern Cape Sandy Inner Shelf	1900’s	110	0.19	1.21+

Section 6. Potential habitats of concern

6.1 Methods and approach

Potential habitats of concern were identified by considering the following four factors for each of the 27 habitat types occurring within the South African hake trawl fishery footprint (Table 4).

1. expected inherent habitat vulnerability and recovery potential
2. total habitat extent within South Africa's EEZ
3. the proportion of the total extent of each habitat type within the trawl footprint
4. trawling intensity across habitat types within the footprint

Habitat threat status and current habitat protection levels were also considered for all habitat types that occur within the trawl footprint, to further support the identification of priorities and potential management measures.

6.2 Consideration of habitat vulnerability and recovery potential

As only one study has examined trawling impacts in South Africa, there is no local information to compare the impact of trawling in different habitat types. Atkinson *et al.* (2011a) compared heavily and lightly trawled areas in the Southern Benguela Shelf Edge with a focus on sandy substrates on the Benguela shelf edge, although some samples had greater mud content at some sites (Atkinson 2010, Atkinson *et al.* 2011a). South Africa has very limited information about most of the offshore habitat types subjected to trawling and the limited knowledge of species composition, limits the interpretation of potential trawling impacts.

The FAO guidelines for the management of deep-sea fisheries in the high seas (FAO 2009) provide guidance in identifying and protecting vulnerable marine ecosystems and Rogers *et al.* (2008) provide further scientific background. Vulnerable marine ecosystems (VMEs) include "habitat types that are physically or functionally fragile, easily disturbed and very slow to recover, or may never recover" (FAO 2009). Examples of potentially vulnerable species, habitats and communities and the features that may support them, are listed in Box 4. It is recommended that vulnerability is considered in relation to specific threats and in this case, ecosystem or habitat vulnerability is considered in the context of the South African demersal hake trawl fishery and the gear deployed, as previously described.

Sink and Samaai (2009) undertook a first attempt in applying the FAO guidelines to identify potential VMEs in South Africa and noted that South Africa has at least three species of fragile reef building corals (Plate 2), slow growing stylasterine hydrocorals (Plate 3), many species of black coral and octocoral and sponge dominated communities (Plate 3) (Sink and Samaai 2009). Seep communities are also very likely to be present although this has not been investigated in South Africa. Methane seeps are widespread on productive margins (Levin 2005) and occur off Nigeria, Angola and the Congo (Olu *et al.* 2010), but have yet to be explored on most of the West and East southern Africa margins. In terms of topographic features that may support VMEs, South Africa's shelf edge (particularly the steep rocky areas), numerous submarine canyons, seamounts, the large submarine bank on the west coast (Childs Bank), deep reefs and other hard ground habitats may also support fragile, structurally complex species that in turn provide habitat for other species.

Box 4. Key information from the FAO (2009) guidelines (Annex 1)

EXAMPLES OF POTENTIALLY VULNERABLE SPECIES GROUPS, COMMUNITIES AND HABITATS, AS WELL AS FEATURES THAT POTENTIALLY SUPPORT THEM

Examples of species groups, communities and habitat forming species that are documented or considered sensitive and potentially vulnerable to DSFs in the high-seas, and which may contribute to forming VMEs:
i. certain coldwater corals and hydroids, e.g. reef builders and coral forest including: stony corals (Scleractinia), alcyonaceans and gorgonians (Octocorallia), black corals (Antipatharia) and hydrocorals (Stylasteridae);
ii. some types of sponge dominated communities;
iii. communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (e.g. hydroids and bryozoans) form an important structural component of habitat; and
iv. seep and vent communities comprised of invertebrate and microbial species found nowhere else (i.e. endemic).

Examples of topographical, hydrophysical or geological features, including fragile geological structures, that potentially support the species groups or communities, referred to above:
i. submerged edges and slopes (e.g. corals and sponges);
ii. summits and flanks of seamounts, guyots, banks, knolls, and hills (e.g. corals, sponges, xenophyphores);
iii. canyons and trenches (e.g. burrowed clay outcrops, corals);
iv. hydrothermal vents (e.g. microbial communities and endemic invertebrates); and
v. cold seeps (e.g. mud volcanoes for microbes, hard substrates for sessile invertebrates).

Guidance on Significant adverse impacts

Significant adverse impacts are those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.

When determining the scale and significance of an impact, the following six factors should be considered:
i. the intensity or severity of the impact at the specific site being affected;
ii. the spatial extent of the impact relative to the availability of the habitat type affected;
iii. the sensitivity/vulnerability of the ecosystem to the impact;
iv. the ability of an ecosystem to recover from harm, and the rate of such recovery;
v. the extent to which ecosystem functions may be altered by the impact; and
vi. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life-history stages.

From FAO (2009). Annex F of the Report of the Technical Consultation on International Guidelines for the Management of Deepsea Fisheries in the High Seas. Rome, 4–8 February and 25-29 August 2008.

Cold water coral reefs have never been mapped in South Africa, although there is evidence of these features occurring on the outer shelf and shelf edge (Sink and Samaai 2009). Isolated records of framework reef building corals have been reported in depths ranging between 86 and 930 m but the extent of the communities and habitats supporting these corals is unknown.

Aside from the canyons on South Africa's north east coast (Sink *et al.* 2006, Samaai *et al.* 2010), deep rocky habitats in South Africa have very seldom been sampled (Gibbons *et al.*1999) although recently uncovered historical data reflects sampling from deep submarine banks and canyons 80-120 years ago (Gilchrist 1922). This historical sampling indicated cold water corals, hydrocorals (such as *Stylaster* sp.) and octocorals associated with habitats such as Childs Bank the Cape canyon off Saldanha and deep hard ground on the west and south coasts (Gilchrist 1922, Van Bonde 1928).

Of the 27 habitat types included in the trawl footprint, those that are considered vulnerable to trawling and likely to support VMEs are shown in Table 6. Of these 12 habitat types, 8 include rocky areas that may provide habitat for vulnerable, slow growing species. The remaining 4 habitats are gravel habitat types in different depth zones and ecoregions. Of the rocky and hard ground habitats, only the Southern Benguela Hard Shelf Edge and the Southern Benguela Hard Outer Shelf constitute a significant portion of the trawl footprint (5% and 4% respectively). The other habitat types constitute less than 1% of the footprint although several are of very limited spatial extent and in many cases a substantial proportion (up to 100%) of the total habitat extent is within the footprint (Table 4).

Based on the catch of reef associated species in the demersal trawl fishery, it is tempting to infer that fishing may have occurred in hard ground areas during the various stages of this fishery. Targeting of panga by foreign fleets on the Agulhas Bank and concerns about associated damage to reefs, corals and hard grounds are mentioned in the historical perspectives section of this report. Nepgen (1977) showed the preference of carpenter for reef areas and this was further confirmed by Smale and Badenhorst (1991). Atwood *et al. (*2011) report an average annual catch of 107 tons for carpenter with higher CPUE over areas with reef and hard ground habitat. Japp *et al.* (1994) also report that rock and coral constitute the preferred habitat of kingklip, and noted that trawlers do exploit kingklip even at the risk of losing their gear, particularly in the chalkline grounds. Catches of red steenbras *Petrus rupestris*, caught frequently on the central Agulhas Bank in bottom trawls (Japp *et al.* 1994) have also raised concerns, as this species is strongly reef associated. Wreckfish *Polyprion americanus* are also associated with deep reef areas and are sometimes caught by commercial trawlers (Japp *et al.*1994). Although such catches do suggest fishing on hard ground areas, this remains speculative. Japp *et al.* (1994) however reported that although the damage caused by foreign vessels using heavy bobbin gear in the so-called "foreign triangle" is difficult to assess, '' destruction of much reef and coral is certain''. Although fishing by foreign vessels was still permitted in 1993, bobbins exceeding 375 mm in diameter were apparently not permitted in the inshore fishery at this time (Japp *et al.* 1994). (Note: the only foreign permit available from this time, that for 1991, does not include any restrictions on the use of bobbins or rollers).

The international literature reflects the different types of impacts, different intensities of impact and different rates of recovery in different habitat types (see international review in this report). Greater impacts and slower recovery is generally expected in biogenic habitats and habitats that support structurally complex, fragile and long lived species (Prenna *et al.* 1999, Pitcher *et al.* 2000, Kaiser *et al.* 2000, Wheeler *et al.* 2005, Reed 2006, Rogers *et al.* 2008, FAO 2009). Based on this knowledge, reefs, submarine banks, submarine canyons and hard grounds are considered more sensitive to trawling than unconsolidated habitat types (such as sandy and mud habitats) in South Africa.

Table 6: Habitat types (within current trawl footprint) that may support VMEs and are therefore considered potentially vulnerable to South Africa's demersal hake trawl fishery. Habitat types are ordered by expected level of vulnerability and level of certainty. Other potentially vulnerable habitat types that do not occur within the footprint, or that are trawled less than 5% of their total extent are not considered.

Habitat type (% within trawl footprint)	Expected level of vulnerability	VME indicator species	Level of certainty	Key references
1. Southern Benguela Canyon (96%)	High (structurally complex habitat type supporting cold water corals and dense invertebrate communities)	Cold water corals, 200 large sponges collected in 1 otter trawl, gorgonians and black corals	High: evidence from Cape Valley footage, dredge samples and otter trawls (Station 54 -1920)	Gilchrist 1921, Sink and Samaai 2009
2. Agulhas canyon (53%)	High (structurally complex habitat type with framework building cold water corals reported)	Cold water corals	Medium-low: no known samples, anecdotal reports of corals associated with canyons off Port Elizabeth, international literature	Van Bonde 1932
3. Southern Benguela Submarine Bank (37%)	High (structurally complex, cold water corals and dense invertebrate assemblages)	Cold water corals	High-medium: evidence from dredges, cold water coral fragments collected on several expeditions	Gilchrist 1925, Atkinson 2010
4. Southern Benguela Hard Shelf Edge (77%)	Medium-high (hard grounds likely to support structurally complex habitat) type, evidence from dredge and otter trawl samples)	Cold water corals	Medium-low: evidence from dredge and otter trawls	Gilchrist 1925, Zibrowius and Gili 1990
5. Agulhas Hard Shelf Edge (17%)	Medium-high (hard grounds likely to support structurally complex habitat), evidence from video images and otter trawl samples)	Limited footage of this habitat type indicated stylasterine corals, gorgnians, cold water corals (uncertain if reef forming) and large sponges.	Medium-low: (evidence from footage of the shelf edge off East London)	Sink and Samaai 2009
6. Southern Benguela Hard Outer Shelf (29%)	Medium-high - Footage south of Childs Bank and in the Bhubesi gas development area off Hondeklip baai suggests that corals and other habitat forming species colonise rocky ledges and reef	Gorgonians, small thickets of cold water corals, large sponges.	Medium – some evidence from ROV and submersible surveys.	Sink and Samaai 2009
7. Agulhas Hard Outer Shelf (8%)	Medium-high - some observed areas with structural complexity but some areas with low complexity (varies with profile & damage from trawling may have occurred in the past)	Smale and Badenhorst (1991) report that the collection of sponges and soft corals as well as net damage at most stations where silverfish *Argyrozona argyrozona* were caught.	Low – this habitat is poorly understood. Only one ROV survey undertaken on this habitat type.	Smale and Badenhorst 1991, Sink *et al.* 2010 (PetroSA)
8. Agulhas Hard Inner Shelf (13%)	Medium-high - some observed areas with structural complexity but some areas with low complexity (varies with profile and damage from	Reef building cold water corals *Solensmila variabilis* and *Goniochorella dumosa* reported in association with this habitat type off	Moderate – some evidence from ROV surveys	Smale and Badenhorst 1991, Sink *et al.* 2010.

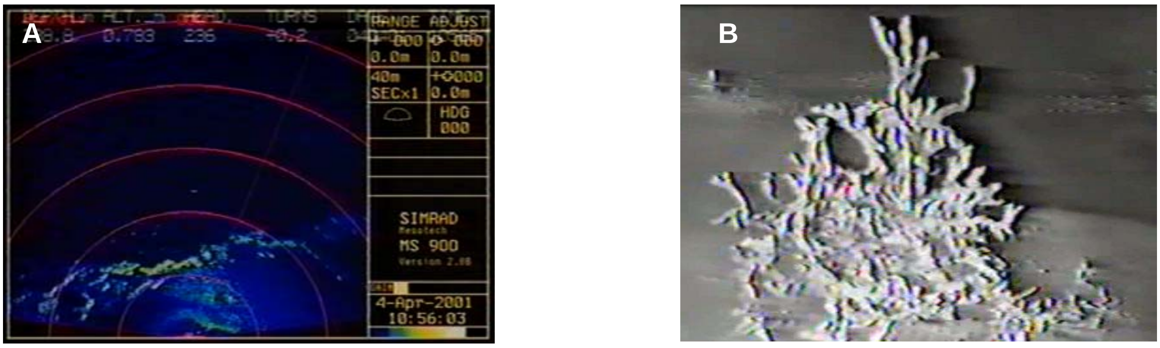
Habitat type (% within trawl footprint)	Expected level of vulnerability	VME indicator species	Level of certainty	Key references
	trawling in the may have occurred in the past)	the Chalumnae River. Stylasterine corals, gorgonians and black corals reported from this habitat type.		
9. Southern Benguela Gravel Shelf Edge (100%)	Medium-high	No samples or images available	Low (inferred from international literature)	Hermsen et. al. 2003, Collie *et al.* 2009
10. Agulhas gravel outer shelf (46%)	Medium-high	No samples or images available	Low (inferred from international literature)	Hermsen et. al. 2003, Collie *et al.* 2009
11. Southern Benguela Gravel outer shelf (42%)	Medium-high	No samples or images available	Low (inferred from international literature)	Hermsen et. al. 2003, Collie *et al.* 2009
12. Agulhas gravel shelf edge (5%)	Medium-high	No samples or images available but one record of coral *Solensmila variabilis f*ound within this habitat type.	Low (inferred from international literature)	Hermsen et. al. 2003, Collie *et al.* 2009, Sink and Samaai 2009

Some impacts on canyons, hard ground and gravel habitats have most likely occurred in South Africa although it seems that there is still opportunity to secure examples of most of these habitat types under protection from trawling, outside of the footprint. Both of the two examples of Southern Benguela canyons are however within the footprint and any management action for this habitat type would impact on current trawling areas. In the Agulhas ecoregion, some canyons do not seem to have been exposed to trawling and vulnerable areas can still be protected outside of the footprint. The submarine bank off Hondeklipbaai, Childs Bank, has only an estimated 33% of its extent trawled with trawl tracks indicating that most trawling currently occurs around the sides of the bank. There is scope to formally protect this potential vulnerable marine ecosystem with very little, if any, adverse impact on the fishery.

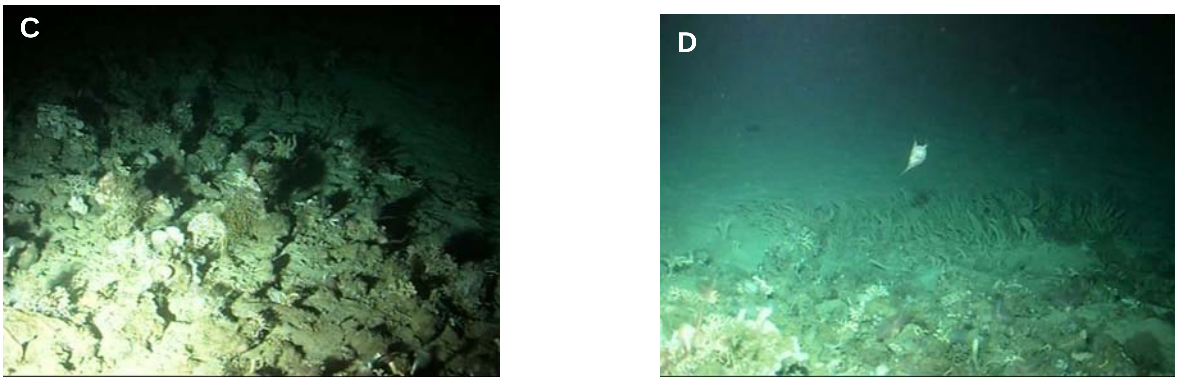
Gravels are also particularly susceptible to trawling with greater impact and slower recovery than most other unconsolidated habitat types (Hermsen *et al.* 2003, Collie *et al.* 2009). There is no information about the species composition and potential ecological role of gravel habitats in South Africa. The fact that all of the Southern Benguela Gravel Shelf Edge occurs within the footprint is concerning, although international literature suggests that gravel habitats can recover even though this recovery is slow.

Muds may be more sensitive to trawling than sands (Sanchez *et al.* 2000, Kaiser *et al.* 2006) however the impact of trawling in muddy habitat types in South Africa has never been examined. There is no published information about the invertebrate communities that reside in muddy habitats and therefore no inference about potential impacts can be made. Examination of historical reports indicates that some sampling of muddy habitat types took place in the early part of last century. Dedicated analyses of historical data and interrogation of museum records could be used to develop an understanding of the biodiversity in muddy habitats in South Africa. The entire Southern Benguela Muddy Shelf Edge lies within the trawl footprint and 84% of the Agulhas Muddy Inner shelf occurs within the trawl footprint.

Plate 2. South African specimens of reef building cold water corals photographed from the invertebrate collection in the South African Museum (A-D) or from collections made between 86 and 907 m in the southern Cape (E, F). A & B *Solensmilia variabilis*. Specimen A was sampled from 904 m on the eastern edge of the Agulhas Bank. A research trawl sample with extensive framework reef building coral is shown in (F). This photo was taken during a demersal research survey from an approximate depth of 907 m (Photo courtesy of Dave Japp).

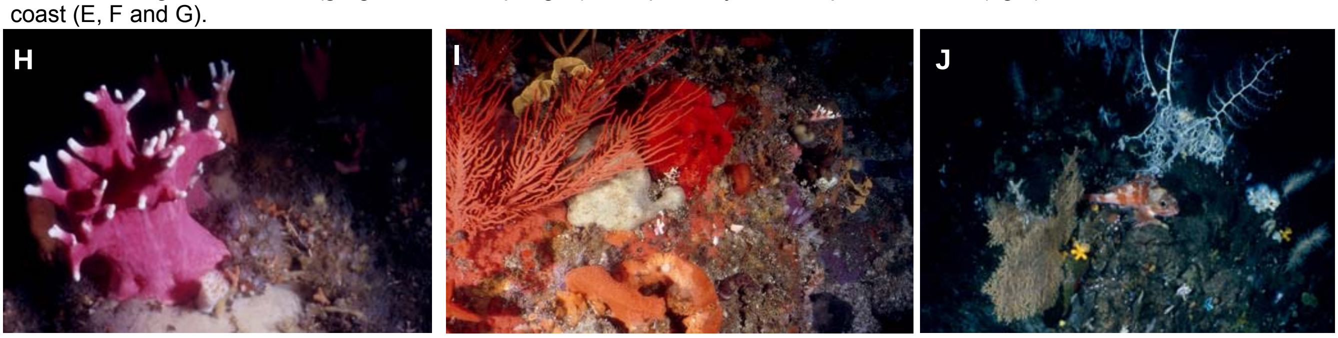


A sonar image (A) of the cold water coral reef recorded during oil and gas explorations on the west coast, (B) an ROV image of a *Lophelia* or *Solenosmilia* coral colony within this reef complex at a depth of 246 m.



Potentially vulnerable epifauna on rocky ground south east of Child's Bank, Jago Dive 587 (C & D).

Habitat forming invertebrates (gorgonians and sponges) in Cape Canyon off Cape Columbine (right) on the west coast (E, F and G).



Stylaster nobilis (H), the milleporid noble coral from South Africa. Colonies of this size are reported to be over 100 years old (Branch *et al.* 2010). Gorgonian groves from the deep reef Middelbank in the Tsitsikamma National Park (I), the shelf edge off East London (J).

Plate 3. Examples of species that characterize potential Vulnerable Marine Ecosystems as captured by Remotely Operated Vehicle or submersible in the South African offshore environment (50-400 m). Images taken from Sink and Samaai (2009). Credits: Jago team, De Beers, Robin Stobbs and DAFF.

6.3 Consideration of total habitat extent

Most (67%) of the habitat types within the trawl footprint exceed 1 500 km^2 in extent (Table 4). Nine habitat types have a total spatial extent of less than this and these habitat types are considered particularly vulnerable to trawling because of their very limited spatial extent. They include gravel, mud, hard ground and canyon habitats (Table 4). The habitat of smallest estimated extent (30 km^2) is the Southern Benguela Gravel Shelf Edge (Figure 12). A single patch of this habitat type occurs at the southern tip of the African continental shelf edge (not easily visible in Figure 12) and the entire estimated habitat extent occurs within the footprint. Similarly the adjacent Southern Benguela Gravel Outer Shelf also occurs in a single patch and is also very limited in extent (433 km^2). The Agulhas Muddy Shelf Edge (171 km^2) only occurs in two places (off Mossel Bay and Cape St Francis) most of which are outside of the footprint (Figure 13). The Southern Benguela Muddy Shelf Edge comprises two patches off Saldahna comprising an estimated 567 km^2. The two Southern Benguela Canyons off Saldahna and Cape point comprise less than 800 km$^{2.}$ Other habitat types of limited extent include Agulhas Mixed Sediment Inner Shelf, Agulhas Canyon, Agulhas Gravel Outer Shelf and Southern Benguela Submarine Bank (Childs Bank).

The remaining 18 habitat types have an estimated extent greater than 1 500 km^2. The habitat type of greatest total extent is the Southwest Indian Upper Bathyal (over 84 000 km^2), followed by the Southern Benguela Sandy Outer Shelf (more than 56 000 km^2) which is also the dominant habitat type within South Africa's hake trawl footprint.

6.4 Consideration of the proportion of the total extent of each habitat type within the trawl footprint

Of the 27 habitat types exposed to trawling, more than 50% of the estimated total habitat extent occurs within the trawl footprint for only 8 habitat types (Table 4). All of the Southern Benguela Gravel Shelf Edge and all of the Southern Benguela Muddy Shelf Edge occur within the trawl footprint. Both of these habitat types have very limited spatial extent. Submarine canyons are not well delineated in the Southern Benguela and Agulhas ecoregions (Sink *et al.* 2012.) but, using existing data, 96% of the Southern Benguela Canyon habitat type is within the trawl footprint. It is recognised that trawling does not occur within the canyon but tends to focus on the edges of the canyon (Figure 7) and a finer resolution analysis would be appropriate in this regard. An estimated 84% of the Agulhas Muddy Inner Shelf (2 685 km^2 in total extent) occurs within the trawl footprint, although historical records suggest that more of this habitat type was trawled in the past (see historical perspectives in this report). This habitat type overlaps with the east coast sole grounds.

The Southern Benguela Hard Shelf Edge comprises approximately 4 532 km^2, of which 78% is within the trawl footprint. Approximately 74% of the Southern Benguela Sandy Shelf Edge occurs within the footprint indicating the preference of trawlers to fish this expansive habitat type. An estimated 53% of the Agulhas Canyon habitat is within the trawl footprint, recognising that canyons are not well delineated but that the existing habitat map includes the potentially vulnerable canyon head and margin (Sink *et al.* 2006, Sink *et al.* 2012.). Of the 9 individual canyons of this type included in the habitat map, 3 are outside of the trawl footprint and 6 occur within the footprint. Approximately half of the extent of the Agulhas Sandy Shelf Edge lies within the trawl footprint.

Less than 50% of the estimated total habitat extent of the remaining 21 habitat types are included in the footprint. Note that, of the dominant habitat types within the footprint (Figure 11), an estimated 26% and 74% of the Southern Benguela Sandy Outer Shelf and Southern

Benguela Sandy Shelf Edge is within the footprint. A total of 33% and 25% of the expansive Agulhas Sandy Inner (8 568 km^2) and Outer Shelf habitat types (8 244 km^2) respectively occur within the footprint. Of the dominant hard ground habitats within the trawl footprint, 77% and 29% of the Southern Benguela Hard Shelf Edge and Hard Outer Shelf occur in the trawling footprint respectively. The habitat types constituting the least proportion of the footprint are the Agulhas Sandy Inshore (0.02% of the footprint) and the South western Cape Sandy Inner Shelf.

6.5 Consideration of trawling intensity on habitat types within the trawl footprint

To consider the intensity of trawling on different habitat types, the average number of trawl start positions (2004-2008) per km^2 of each habitat type within the trawl footprint was calculated (Table 4). Trawl intensity values ranged from 0.01 to 2.13 trawl starts per km^2 per year over the four year period for which appropriate data was available. More than 1 trawl start position per km ^{2} of habitat type is considered relatively high and less than 0.5 is considered relatively low, with moderate intensities between 0.5 and 1. The habitat with the estimated greatest trawl effort was the Southern Benguela Gravel Outer Shelf, a habitat of very limited spatial extent, all of which occurs within the footprint. Other habitat types with relatively high trawl effort include the Agulhas Gravel Outer Shelf (1.82 trawl starts per km^2 per year), Southern Benguela Hard Shelf Edge (1.55 trawl starts per km^2 per year) and the Southern Benguela Muddy Shelf Edge (1.48 trawl starts per km^2 per year). Relatively high trawl effort was calculated in the Southern Benguela Canyon habitat type (1.19 trawl starts per km^2 per year) although moderate intensity was calculated for the Agulhas Canyon habitat type (0.75 trawl starts per km^2 per year) which has greater estimated extent than former habitat type.

Note that of the dominant habitat types within the footprint (Figure 11) the expansive Southern Benguela Sandy Outer Shelf experiences a relatively low (0.47 trawl starts per km^2 per year) trawl intensity although the trawl effort on the Southern Benguela Sandy Shelf Edge can be considered relatively high (1.13 trawl starts per km^2 per year). The Agulhas Sandy Inner and Outer Shelf habitat types and the Agulhas Muddy Inner Shelf experience moderate trawl intensities. Of the dominant hard ground habitats within the trawl footprint, the Southern Benguela Hard Shelf Edge has the highest trawl effort, followed by the Southern Benguela Hard Outer Shelf. The habitat types with the lowest trawl intensity include Agulhas Gravel Shelf Edge (0.01 trawl starts per km^2 per year), Agulhas Muddy Shelf Edge (0.03 trawl starts per km^2 per year) and Southern Benguela Muddy Outer Shelf (0.03 trawl starts per km^2 per year).

6.5.1 Habitats of greatest potential impact and concern

Habitats of greatest expected impact and concern were identified by consideration of all the criteria discussed above (Table 7). Those that are 1) inherently vulnerable to trawling (with low recovery potential), 2) of very limited spatial extent, 3) where trawling may impact the majority of the habitat type and 4) particularly where there is high trawl effort across the habitat type, are of greatest concern. Only one habitat type triggered concern based on all four criteria (Southern Benguela Canyon, Table 7). Three habitat types triggered concern based on three criteria and five habitat types met two of the criteria indicating potential concern. These nine habitat types were identified as the priorities for management action (Figures 14 and 15).
They are:

- Southern Benguela Canyon
- Southern Benguela Muddy Shelf Edge
- Southern Benguela Hard Shelf Edge
- Agulhas Canyon

- Southern Benguela Gravel Shelf Edge
- Agulhas Gravel Outer Shelf
- Southern Benguela Gravel Outer Shelf
- Southern Benguela Submarine Bank
- Southern Benguela Sandy Shelf Edge

Table 7: Habitat types in approximate order of decreasing expected impact and concern as indicated by number of criteria indicating concern, then percentage of total habitat extent within the footprint and then by decreasing vulnerability. Highlighted cells indicate concern under each of 4 criteria; habitat vulnerability, habitat extent, proportion of total habitat type extent within the footprint and traw lintensity. Potential habitat vulnerability (Vu) as based on international literature is reflected in the first column, ranging from 4 reflecting greatest vulnerability and 1 indicating more resilient habitat types with greater recovery potential. In the second column, total habitat extent of less than 1500 km^2 constitutes concern under the habitat extent criteria and concern in the third column is triggered by the inclusion of more than 50% of the total habitat extent within the footprint. In the fourth column, trawl intensities exceeding 4.5 trawls per Km^2 were considered potentially concerning. The priority habitat types for management action are indicated with an asterix. Threat status and protection levels are also reported, drawing from the 2011 National Biodiversity Assessment (Sink et al. 2012.). The last 2 columns indicate the percentage of each habitat types in MPAs and trawl exclusion zones (TEZ).

Habitat Name	Vu	Total habitat extent (km^2)	% of habitat type within footprint	Intensity (Number of trawls.km^2 per year)	No. of criteria	Threat Status	Protection Level	% of total footprint	% in MPA	% in TEZ
*Southern Benguela Canyon	4	785.9	95.5	1.19	4	CR	Not protected	1.07	0	0
*Southern Benguela Muddy Shelf Edge	2	567.3	100.0	1.48	3	CR	Not protected	0.81	0	0
*Southern Benguela Hard Shelf Edge	4	4532.0	77.7	1.55	3	CR	Not protected	5.02	0	0
*Agulhas Canyon	4	1119.7	52.7	0.75	3	CR	Not protected	0.84	0	0
*Southern Benguela Gravel Shelf Edge	3	29.9	100.0	0.90	2	CR	Not protected	0.04	0	0
*Agulhas Gravel Outer Shelf	3	1481.1	45.5	1.82	2	VU	Hardly protected	0.96	0	0
*Southern Benguela Gravel Outer Shelf	3	433.4	41.8	2.13	2	CR	Not protected	0.26	0	0
*Southern Benguela Submarine Bank	4	1449.2	36.6	0.27	2	LT	Not protected	0.76	0	0
Southern Benguela Sandy Shelf Edge	1	13237.7	73.5	1.13	2	VU	Not protected	13.86	0	0
Agulhas Muddy Inner Shelf	2	2684.5	84.1	0.76	1	CR	Not protected	3.22	0	4.4
Agulhas Sandy Shelf Edge	1	4067.5	50.5	0.49	1	VU	Not protected	2.93	0	0
Southern Benguela Hard Outer Shelf	4	10612.9	29.2	0.78	1	VU	Hardly protected	4.41	0.45	0
Agulhas Hard Shelf Edge	4	4162.9	16.5	0.31	1	VU	Not protected	0.98	0	0
Agulhas Hard Inner Shelf	4	4279.1	13.4	0.61	1	EN	Poorly protected	0.82	2.80	21.6
Agulhas Hard Outer Shelf	4	11537.3	8.8	0.75	1	VU	Not protected	1.45	0	0
Agulhas Muddy	2	170.7	19.0	0.03	1	VU	Not	0.05	0	0

Habitat Name	Vu	Total habitat extent (km^2)	% of habitat type within footprint	Intensity (Number of trawls.km^2 per year)	No. of criteria	Threat Status	Protection Level	% of total footprint	% in MPA	% in TEZ
Shelf Edge							protected			
Agulhas Mixed Sediment Inner Shelf	2	627.5	18.0	0.66	1	LT	Not protected	0.16	0	0
Agulhas Muddy Outer Shelf	2	1772.1	38.7	0.26	0	VU	Not protected	0.98	0	0
Agulhas Sandy Inner Shelf	1	26175.2	32.7	0.63	0	VU	Poorly protected	12.21	1.73	8.6
Southern Benguela Sandy Outer Shelf	1	56231.7	26.1	0.47	0	LT	Hardly protected	20.90	0.03	0
Agulhas Sandy Outer Shelf	1	32869.3	25.1	0.85	0	LT	Not protected	11.75	0	0
South Atlantic Upper Bathyal	2	37312.6	21.9	0.64	0	LT	Not protected	11.67	0	0
Southern Benguela Muddy Outer Shelf	2	6054.3	13.3	0.03	0	LT	Not protected	1.15	0	0
Agulhas Mixed Sediment Outer Shelf	2	1308.2	8.2	0.25	0	CR	Not protected	0.15	0	0
Agulhas Gravel Shelf Edge	3	1788.1	5.2	0.01	0	LT	Not protected	0.13	0	0
Southwest Indian Upper Bathyal	2	84840.8	2.7	0.22	0	LT	Hardly protected	3.27	0.21	0
Southwestern Cape Sandy Inner Shelf	1	1652.1	1.2	0.19	0	LT	Moderately protected	0.03	17.3	29.5

The 2011 National Biodiversity Assessment reported ecosystem threat status for marine habitats for the first time (Driver *et al.* in press., see Box 5) although Driver *et al.* 2005 first reported on ecosystem threat status for terrestrial, estuarine and fresh water habitats in the National Spatial Biodiversity Assessment 2004. In 2004, ecosystem threat status was reported at the level of broad biozones in the marine environment because of the lack of a National habitat map and pressure data at a sufficiently fine scale. Ecosystem threat status is determined relative to a series of thresholds relating to the proportion of each habitat type in good condition and a standard approach is used across environments. In the marine environment, 27 different pressures on marine biodiversity, including all types of fishing, petroleum and diamond mining, shipping and pollution, are used to infer ecosystem condition. Of the 27 habitat types within the trawl footprint, 18 (66%) are considered threatened with 9 least threatened habitat types, 9 vulnerable habitat types, 1 endangered habitat type and 8 critically endangered habitat types (Table 7). Demersal trawling is one of the 27 pressures on marine biodiversity that were considered in the assessment of habitat threat status. In some cases trawling contributes to the threatened status of the habitat, particularly for habitats of very limited extent and for rocky or hard habitat types. However, other pressures also contribute to the ecosystem threat status of many habitat types including other fisheries and petroleum activities. The work conducted as part of this report is specific to the trawling sector and represents a more comprehensive examination of the interaction between trawling and habitats than the broader National Biodiversity Assessment.

Five of the nine priority habitat types were also assessed as being critically endangered (Sink *et al.* 2012.). These habitat types are considered to have very little remaining areas in pristine or natural condition and the remaining healthy remnants of habitat should receive conservation action (Box 5). Any management measures that afford some protection to these habitat types would constitute such conservation action.

Habitat types that receive some protection from trawling in MPAs or other trawl exclusion areas could mitigate potential benthic impact concerns. The National Biodiversity Assessment 2011 (Driver *et al.* in press.) also reported on the habitat protection levels (see Box 5) and noted that offshore habitats are the least protected ecosystems of all South Africa's terrestrial, fresh water, estuarine and marine.

Of the 27 habitat types within the trawl footprint, 20 (74%) are not represented in South Africa's MPA network (Sink *et al.* 2012). Only one habitat type within the footprint is moderately protected (Southwestern Cape Sandy Inner Shelf) and an additional 29% of this habitat type is protected from trawling in the trawl exclusion zones within certain bays along the south coast. Two habitat types, Agulhas Sandy Inner Shelf and Agulhas Hard Inner Shelf, are poorly protected (<3% of these habitat types in MPAs) but these both receive additional protection from trawling in closed bays. Four habitat types are hardly protected (with 0.5 to 0.03% of the habitat type in MPAs and no additional protection in exclusion zones). Of the 20 habitat types that are not represented in any MPAs, only one additional habitat type receives some protection through the closed bays along the south coast. Approximately 4% of the Agulhas Muddy Inner Shelf is protected within trawl exclusion zones along the south coast. In total, 19 of the 27 habitat types within the trawl footprint have no protection in MPAs or trawl exclusion zones (Sink *et al.* 2012.).

The closed bays along the south coast also exclude trawling from some habitat types that are not within the footprint. For example, approximately 50% of the Agulhas Sandy Inshore is protected from trawling by the fact that it occurs within bays. Although trawlers do not currently interact with these habitat types, they did in the past and current protection from trawling in these inshore areas represents a worthwhile management measure to protect diverse and potentially vulnerable inshore habitat types and reduce conflict with other sectors in the inshore environment. The trawl exclusion zone along the west coast does not include any of the habitat types that occur in the trawl footprint, protecting mostly inshore and inner shelf habitat types. This highlights the need for offshore protection along South Africa's west coast.

The Kingklip box, a time-area closure to protect spawning aggregations of the valuable and lucrative knigklip resource includes several habitat types; Agulhas Sandy Shelf Edge, Agulhus canyon, Agulhas Hard Shelf Edge, Agulhas Sandy Outer Shelf, Agulhas Hard Outer Shelf, South West Indian Upper Bathyal. The temporary nature of this closure does not afford protection to these habitat types.

Box 5. Ecosystem threat status and protection levels as per the National Biodiversity Assessment 2011

The primary purpose of the National Biodiversity Assessment (NBA) (Driver *et al.* in press.) is to provide a regular high-level summary of the state of South Africa's biodiversity, with a strong focus on spatial assessment. The NBA reports on two headline indicators, namely ecosystem threat status and ecosystem protection level for terrestrial, fresh water, estuarine and marine habitats. Ecosystem threat status tells us how threatened our ecosystems or habitats are (considering *all* pressures) and ecosystem protection level tells how well- or under-protected our ecosystems are. These headline indicators provide not a way of comparing results meaningfully across the different terrestrial and aquatic environments and a standardised framework that links with policy and legislation in South Africa, facilitating the interface between science and policy. Working in an integrated and aligned way across aquatic and terrestrial environments is challenging, as disciplines in these environments have historically developed separately, with separate sets of terminology, methods and approaches. The required compatible approach has constrained the assessment methods and termininology however, the benefits are numerous, including enabling comparisons and innovations across environments.

Ecosystem threat status relates to the proportion of each habitat type in good condition with the following explanations for ecosystem threat categories drawn from Driver *et al.* (in press):

<u>Critically endangered ecosystems</u> are ecosystem or habitat types that have very little of their original extent (measured as area, length or volume) left in natural or near-natural condition. Most of the ecosystem type has been severely or moderately modified from its natural state. These ecosystem types are likely to have lost much of their natural structure and functioning, and species associated with the ecosystem may have been lost. We are in danger of losing the last remaining natural examples of these ecosystem types. Any further loss of natural habitat or deterioration in condition of the remaining healthy examples of these ecosystem types must be avoided, and the remaining healthy examples should be the focus of urgent conservation action.

<u>Endangered ecosystems</u> are ecosystem or habitat types that are close to becoming critically endangered. Any further loss of natural habitat or deterioration of condition in these ecosystem types should be avoided, and the remaining healthy examples should be the focus of conservation action.

<u>Vulnerable ecosystems</u> are ecosystem or habitat types that still have the majority of their original extent (measured as area, length or volume) left in natural or near-natural condition, but have experienced some loss of habitat or deterioration in condition. These ecosystem types are likely to have lost some of their structure and functioning, and will be further compromised if they continue to lose natural habitat or deteriorate in condition. Maps of biodiversity priority areas should guide planning, resource management and decision-making in these ecosystems types.

<u>Least threatened ecosystems</u> are ecosystem or habitat types that have experienced little or no loss of natural habitat or deterioration in condition. Maps of biodiversity priority areas should guide planning, resource management and decision-making in these ecosystems types.

The marine component of the National Biodiversity Assessment determined level of protection for each habitat type by evaluating the percentage protected against the 20% biodiversity target (Sink *et al.* 2012). Habitats were classified as "Zero protection" if there was no formal protection; as "Hardly protected" if under 5% of target was met in protected areas; as "Poorly protected" if from 5% to just under 50% of biodiversity target is met in protected areas; as "Moderately protected" if from 50% to just under 100% of the biodiversity target is met in protected areas; and as "Well protected" if the biodiversity target is fully met and 15% of that target is met in no-take zones. Note that a standard 20% biodiveesity target was used for all marine habitats.

Section 7. Review of state of knowledge of potential benthic impacts.

7.1 Methods and Sources

Previous reviews and reports, published literature and theses were reviewed to summarise the current state of knowledge of the potential impacts of the hake trawl fishery on benthic habitats and communities. Key sources included a previous report evaluating the extent and intensity of hake-directed trawling on different sediment types (Wilkinson and Japp 2005), work undertaken to support Offshore Marine Protected Area planning (Sink and Samaai 2009, Sink *et al.* 2011) and the research outputs from South Africa's only trawl impact study (Atkinson 2010, Atkinson *et al.* 2011a,b). The new work undertaken as a component of this report is also considered.

7.2 Impacts of trawling in South Africa

Fairweather (2002) undertook the first spatial analysis of demersal trawling in South Africa and related trawl effort and catch rates between 1994 and 1999 to substrate type along the west coast (Fairweather *et al.* 2006). Wilkinson and Japp (2005a) updated and refined spatial estimates of trawling effort and undertook a detailed desktop analysis of potential trawling impacts on different unconsolidated substrate types for the inshore and offshore sectors. They provide a comprehensive account of the fishery and gear used (see also Wilkinson and Japp 2005b), mapped fishing effort and investigated the spatial extent of hake-directed trawling (2002-2004) in relation to different unconsolidated substrate types. Further information about hake-directed trawling operations and gear is provided by Wilkinson and Japp (2005b). Wilkinson and Japp (2008) further refined spatial analyses of fishing effort at a finer scale to determine the footprint of hake directed trawling between 1970 and 2007.

Wilkinson and Japp (2005c) reported that trawling covers approximately 5% of South Africa's EEZ and is focused on sandy substrates on the shelf and shelf edge. Although 'sand' was the sediment type reported to overlap most with the trawl grounds, trawling intensity was less over sandy substrates than on muddy substrates. Mud and gravel habitats are of limited extent and were reported to experience higher trawling intensities than sandy habitats. Habitat impacts were considered to be higher in gravel habitats and in areas where there is frequent trawling. These authors did not consider the effect of biogeography, depth or large scale topography (such as shelf versus shelf edge and slope) in their analysis as there was no systematic habitat classification including such factors available at that time. The new spatial analyses in this report use the recently completed National marine and coastal habitat classification and map and were therefore able to undertake a more comprehensive analysis of the interaction of the South African hake trawl fishery with all habitat types. The new analyses also consider potential vulnerable marine ecosystems. These new developments make a significant contribution in terms of addressing key knowledge gaps that were noted during the last MSC certification period. The following 3 main points from MSC surveillance reports are pertinent:

- "All potential impacts of gear use on habitat need to be adequately identified" (2.1.3.1)
- "Further information is needed to confirm there are no significant impacts on habitat structure" (2.1.5.3)
- "Further determination of some elements is required to confirm whether there are no significant impacts on benthic communities" (2.1.5.4)

The present study has now examined the interaction of this fishery with all habitat types using the best available information. It will remain a significant challenge to confirm whether significant adverse impacts have occurred with the current data resolution, quality and considering the challenges of using very limited historical data to try and understand pristine conditions. By considering historical perspectives and the expansion of fishing grounds over the 120 year duration of this fishery, the potential impacts in different habitat types have been examined as best as possible with currently available data and resources. The work conducted through the present study has enabled a systematic evaluation of potential habitats of concern, resulting in the identification of priority habitats for potential management action.

Only one study has conducted in-situ research to examine the impact of trawling in southern Africa, largely in one habitat type (Atkinson 2010). This first analysis of the potential impact of hake-directed trawling on benthic infauna and epifauna compared heavily and lightly trawled areas at four sites in the Southern Benguela Shelf Edge. Results suggest that intense trawling is at least partly responsible for significant differences in benthic infauna and epifauna occurring in heavily and lightly trawled sites. The abundance, biomass, diversity and community composition differed significantly at heavily versus lightly trawled sites, with epifauna (particularly larger, slower growing epifauna) showing a stronger response than infauna. Two urchin species appear to be vulnerable to heavy trawling, *Brissopsis lyifera capensis* and *Spatangus capensis*, yielding lower densities at heavily trawled sites. The burrowing anemone *Actinauge granulata*, (previously misidentified as *Actinauge richardii*) and the brittlestars *Ophiura* sp. were more abundant at lightly trawled sites than heavily trawled sites. The anemones are considered likely to survive trawling by burrowing and the brittlestars may rapidly colonise disturbed areas. Atkinson (2010) also used biological traits analysis to explore trawling impacts on benthic macrofauna. Although 17% of infaunal traits and 24% of epifaunal traits differed between trawl intensities, few traits were lost under intense trawling conditions, leading Atkinson (2010) to suggest that the overall ecological functioning was not likely to be compromised by trawling at the current levels in this habitat type. However, the lack of an appropriate untrawled reference site, limited this study and the functional role of benthic fauna may differ in untrawled areas and different habitat types. The limited loss of infaunal species diversity at heavily trawled sites led Atkinson (2010) to suggest that hake-directed trawling is unlikely to have a severe impact on infauna or their role in the sandy shelf edge habitat of the southern Benguela at the current operational intensities. Reduced epifaunal species diversity, abundance and biomass was linked to heavy trawling intensities, this being considered likely to impact on ecosystem functioning, specifically in terms of bioturbation and its associated functional role in such habitat types.

Although Atkinson's study focused on one habitat type, this is a dominant habitat type within the trawl footprint (Figure 11). In fact, more than 60% of the entire recent trawl footprint is comprised of such sandy shelf and shelf edge habitat types, indicating that South Africa's only in situ examination of trawling impacts was conducted on an appropriate habitat type. There remains uncertainty in terms of the significance of these impacts and the potential for recovery, this is best addressed through a local experimental approach, for which planning is currently at an advanced stage (Atkinson *et al.* 2012). The following gaps in knowledge raised in previous MSC surveillance reports are pertinent:

- Recovery potential and timescales (2.1.3.1 and 2.1.5.3)
- Further determination of some elements is required to confirm whether there are no significant impacts on benthic communities (2.1.5.4)

Section 8. Critical knowledge gaps and mitigation measures

8.1 Knowledge gaps and research priorities

South Africa has made further advances in understanding the potential impacts of trawling on benthic habitats and communities, building on previous work undertaken during the previous MSC certification period. This report has framed potential impacts within a historical context and the extent, intensity and duration of trawling impact has been considered for all habitat types that occur within the recent trawl footprint. There is improved insight on the potential impact of trawling in benthic communities of the Benguela Sandy Outer Shelf (Atkinson 2010, Atkinson *et al.* 2011a,b) but the significance of these impacts remains poorly understood. This is not a situation unique to neither South Africa nor this fishery. The key remaining gaps in knowledge therefore include: (1) the impacts of trawling in mud, gravel and hard ground habitats in South Africa and (2) the recovery potential and recovery timescales for all habitat types.

The limitations in South Africa's new marine habitat classification and map are pertinent to the present study. These include the need for improved knowledge of benthic communities occurring in different habitat types and better delineation of various marine benthic habitats, as acknowledged in the appropriate technical report from the National Biodiversity Assessment 2011 (Sink *et al.* 2012). This is particularly important for sensitive habitats.

In-situ research to understand the impact of trawling in mud, gravel and hard ground habitats should be encouraged. An improved understanding of the current distribution of muddy habitats, their benthic communities and ecology is a national research priority (Sink *et al.* 2012) and existing trawl closures do offer opportunities to assess the potential impact of trawling in such habitat types. Gravel habitats in South Africa seem to be very limited in extent (according to current knowledge) and this has led to high trawling effort in some areas and possibly high impacts in some of these habitat types. However, almost nothing is known about gravel habitats in South Africa and an appropriate starting point may be interrogation of existing data sets (such as historical research data, and geological data) to assess what information could be compiled to develop an improved understanding of these habitat types. The fact that none of these gravel habitat types constitute more than 0.1% of the trawl footprint indicates that these are not priority habitat types for understanding impacts. However, the inclusion of the entire extent of some of these habitat types within the trawl footprint and the relatively high intensity of trawling suggests that a precautionary approach should be applied. The implementation of some protection for a portion of such habitat types may be the best current mitigation measure for gravel habitats. This could also support a later assessment of potential recovery or impact.

Improved bathymetric data for key submarine features (canyons, submarine banks, reefs, cold water coral beds and other hard ground habitats) and finer scale investigation of trawl tracks using Maxsea plots could improve the understanding of the interaction of the offshore trawl sector with these habitat types. Also, further detailed information on existing rockhopper and bobbin gear currently used in this fishery would support an improved understanding of potential benthic impacts in such sensitive habitat types and a potential review of current permit conditions aimed at limiting seabed impacts. Details on the different size, mass (individual bobbin and rollers and total mass) and configuration of ground gear used by the offshore sector in different grounds is needed.

Field based research to understand impacts in hard ground habitats is more challenging with many impacts (particularly inshore) expected to have occurred in the 1960's and 1970's or in the 1990's and 2000's in the offshore environment. Such studies are limited by poor knowledge of the distribution and nature of such habitat types. New research to advance the mapping, description and understanding of these habitats has long been recognised as a research priority (Gibbons *et al.* 1999, Sink *et al.* 2006). South Africa's cold water coral reefs warrant further exploration with a focus on their distribution and extent. One of the cold water coral features observed by researchers appears to stand 30 m off the seabed at a depth of approximately 900 m (Dave Japp, Capfish, pers. comm.)

The recovery potential after trawling has not been assessed for any South African habitat types but new work is planned to address this gap in the most appropriate sandy habitat type. A proposed experimental closure and monitoring program (Atkinson *et al.* 2012) can address recovery potential in sandy shelf edge habitat on the west coast.

International studies have demonstrated the poor recovery potential of sensitive habitat types such as hard grounds and habitats that support structurally complex habitat-forming species. This will be very difficult to address in South Africa with current knowledge, research expertise, equipment and the very limited available resources. However, every opportunity to improve the mapping, description and understanding of potential trawl impacts in such vulnerable habitats should be seized and core government funding should be secured to improve the mapping of sensitive ecosystems to support improved environmental management across all sectors. An appropriate current focus should be on mapping and protecting existing healthy examples of potentially vulnerable habitat types. The potential impacts of trawling on productivity have also never been examined in South Africa, and internationally this remains a very challenging research field.

8.2 Management recommendations

8.2.1 Review or develop management objectives

The first recommendation from this report is the review of any existing management objectives for benthic habitats that are affected by this fishery. If such objectives are documented, these should be reviewed with due consideration for the information presented in this report. Alternatively, specific management objectives for benthic habitats should be developed.

Recommended management measures to limit further impacts on benthic habitats by the South African trawl fishery include spatial management measures such as MPAs and benthic protection areas, strengthened permit conditions and improved knowledge to support impact assessment and good environmental practice in this fishery and for other sectors. Catch limits to restrict targeting of bycatch species that are associated with vulnerable habitats are also advised. This is in line with international recommendations and global initiatives to address concerns about the impact of demersal trawling on seabed habitats (Hannah 2003, Rowling 2008, Brock *et al.* 2009, Miller *et al.* 2009).

8.2.2 Avoid trawling outside of the recent trawl footprint

Wilkinson and Japp (2008) delineated the recent trawling footprint for this fishery. If the commitment to restrict future trawl activities to within this footprint can be secured and effected in legislation, this would constitute an effective management measure to limit the impacts of this fishery on benthic habitats. However, some habitat types are completely within this footprint and other management measures would be needed to address concerns about impacts in such habitat types. It is important that any new measures do not displace fishing activities into more sensitive areas that have not been subjected to trawling (Sink *et al.* 2011) and therefore trawling should first be excluded from areas outside of the footprint, prior to the implementation of other management measures.

8.2.3 Protect representative habitat types and potential vulnerable marine ecosystems

As 19 of the 27 habitat types that occur in the recent trawl footprint are unprotected (Table 4), it is recommended that a portion of each habitat type is included in South Africa's MPA network. This aligns with South Africa's commitment for a representative protected area network (Government of South Africa 2010). In addition, other spatial management measures should be considered to limit benthic impacts, particularly in potential vulnerable marine ecosystems.

Table 8: Summary of recommended mitigation measures for the nine priority habitat types identified in this report. Focus areas refer to recently identified focus areas for offshore protection as identified by systematic biodiversity planning (Sink et al. 2011).

Habitat type	Potential mitigation measures
Southern Benguela Canyon	Protect representative canyon habitat off Saldahna (Cape Canyon focus area). This area has been less intensively fished and is less important to offshore industries than in the only other area off Cape point with this canyon habitat (Sink *et al.* 2011). Improve the delineation of canyon habitats, understanding of canyon biota and canyon ecology through research. Improve the understanding of fishery interaction with canyon biota.
Southern Benguela Muddy Shelf Edge	Protect a portion of representative habitat off Saldahna in the Cape Canyon focus area (Sink *et al.* 2011).
Southern Benguela Hard Shelf Edge	Protect untrawled examples of habitat type on Browns Bank (Browns Bank focus area, Sink *et al.* 2011).).
Agulhas Canyon	Protect representative canyon habitat outside of the trawl footprint and possibly offshore of Port Elizabeth (Sink *et al.* 2011). Investigate the option of extending the Amathole MPA offshore. Improve the delineation of canyon habitats, understanding of canyon biota and canyon ecology through research. Improve the understanding of fishery interaction with canyon biota.
Southern Benguela Gravel Shelf Edge	Undertake research to validate this habitat type and explore benthic communities. Protect a portion of representative habitat in the Browns Bank focus area (Sink *et al.* 2011).
Agulhas Gravel Outer Shelf	Undertake research to validate this habitat type and explore benthic communities. Protect a portion of representative habitat such as in Agulhas Bank or Port Elizabeth offshore focus area (Sink et al. 2011) or by expanding the Dwesa MPA where this habitat type receives some protection (<1% of the habitat type).
Southern Benguela Gravel Outer Shelf	Undertake research to validate this habitat type and explore benthic communities. Protect a portion of representative habitat in the Browns Bank focus area (Sink *et al.* 2011).
Southern Benguela Submarine Bank	Protect this potential vulnerable marine ecosystem through a benthic protection zone that includes Childs Bank. Ensure that the implementation of the experimental closure adjacent to Childs Bank does not shift effort into this potentially vulnerable area. Investigate benthic communities on the bank opportunistically during research trips conducting work at the adjacent experimental closure site.
Southern Benguela Sandy Shelf Edge	Assess recovery potential through an experimental closure within the Childs Bank focus area (Sink *et al.* 2011, Atkinson *et al.* 2012).

The current set of trawl exclusion areas fail to include most of the habitat types on which demersal trawling takes place. These areas do protect habitat types that used to be exposed to trawling and provide some protection for the Agulhas Muddy Inner Shelf, a key habitat type for sole directed fishing. The closed bays play an important role in limiting conflict between different trawl sectors (particularly the linefishery) and most likely protect juvenile fish and important nursery habitats for many species. Offshore habitat types are the least protected of all South African ecosystems (Driver *et al.* in press) and improved protection of offshore habitats is a national priority.

There are opportunities to implement management measures to start addressing concerns for the priority habitats identified in this report (Table 8). Sink *et al.* (2011) recently identified a set of focus areas for offshore protection and most of the priority habitat types occur within these identified focus areas (such as the Childs Bank, Cape Canyon, Browns Bank, Agulhas Bank and Southwest Indian Seamount focus areas).

8.2.4 Review size and mass limits for trawl gear in permit conditions

The current size and mass limits for bobbins and rollers, as included in the permit conditions for the South African hake trawl fishery, should be reviewed. This would be most appropriate with due consideration of the specific management objectives that underlie these restrictions. Elsewhere, fisheries that have used such restrictions to limit benthic impacts, have introduced smaller size restrictions than those used in the South African hake trawl fishery, particularly those applied to the offshore sector. The roller and bobbin limits for South Africa's inshore fishery could be strengthened to prevent the use of bobbin and rockhopper gear in the inshore fishery. As this sector is reported not to use this type of gear, this could be a simple and effective measure with little or no impact on existing operations. Offshore, the current limits are less restrictive than restrictions in other countries that aim to limit habitat damage in sensitive and vulnerable habitats.

Valdemarsen *et al.* (2007) suggest three methods to balance the conflicting objectives of maximizing trawl net protection, minimizing seabed contact and minimizing the under-trawl escape of target species. These are:

1. Reduce width and length of ground gear (They report that many trawl gears will maintain capture efficiency using shorter ground gears than is commonly used in most fisheries).
2. Reduce the physical pressure of the gear on the bottom. This is achieved by reducing gear weight (optimal gear weight is one that balances the lifting forces in such a way that the ground rope is touching but not digging into the seabed) and through the use of bottom contact sensors (these can help to reduce the risk of losing bottom contact when using light gear).
3. Reduce the number of bottom contact points along the ground gear – reduce the number of rollers or rock hopper disks.

Other such international gear developments could be considered for application in South Africa's hake trawl fishery. He and Foster (2000) replaced 31 bobbins (21 and 24 inch in diameter) with 9 bobbins, reducing the weight of the ground gear from 2984 to 1306 kg along with a 70% reduction in affected seabed area. This did not affect the catch of shrimp but it did increase the risk of gear damage, especially in rough seas and rough bottom. There are other studies and initiatives aimed at developing good practice in trawl fisheries. A thorough analysis of such work is recommended to support the review of existing practices (although more information on local ground gear is first needed) and align with international good practice. A current dedicated international research project entitled "Development of fishing gears with reduced effects on the environment" (DEGREE - See http://www.rivo.dlo.nl/degree) could provide additional guidance in this regard. Any such changes would need to be considered within the current management framework with due considerations for potential impacts on the economic efficiencies and costs. It is recommended that stakeholders, including skippers, are involved in such decisions.

8.2.5 Improve gear information and spatial data collection in this fishery

The final recommended management measures include improved data collection to support ongoing assessment of potential trawling impacts and the development of mitigation measures. As previously mentioned, better information on the ground gear configuration (including use of bobbin and rockhopper gear) currently in use in different grounds and habitat types is needed. Commercial trawlers should continue to collect spatial fishing data such as Maxsea tracks and these could be improved by standardising the fields of collection (including depth and date information) and developing and disseminating a clear protocol to collect such data. The systematic labelling and collection of Maxsea tracks following each trip for compilation into a dedicated spatial database, possibly managed by an independent third party should be considered. This could enable finer resolution spatial analyses for multiples purposes (research, assessment, compliance and the development of additional management measures). An appropriate start would be an investigation of international practice in this regard. The maintenance of the government observer program is critical to provide an independent verification of fishing position, catch data and could support the collection of improved habitat data as noted in the National Biodiversity assessment 2011 (Sink *et al.* 2012). Specific observer training on potential vulnerable marine ecosystems will be required if this latter objective is to be met.

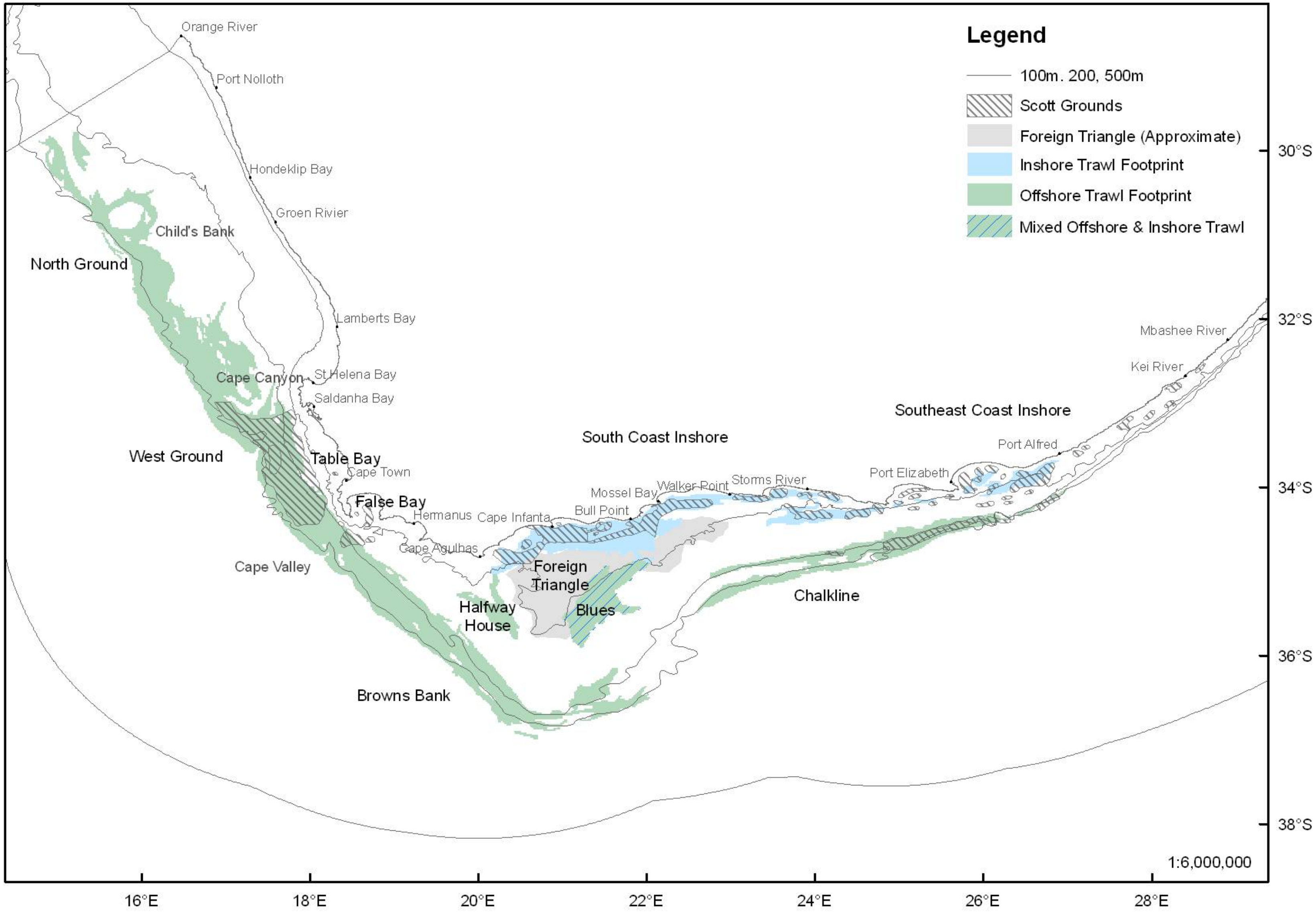


Figure 1. The location of all the trawl grounds referred to in this report.

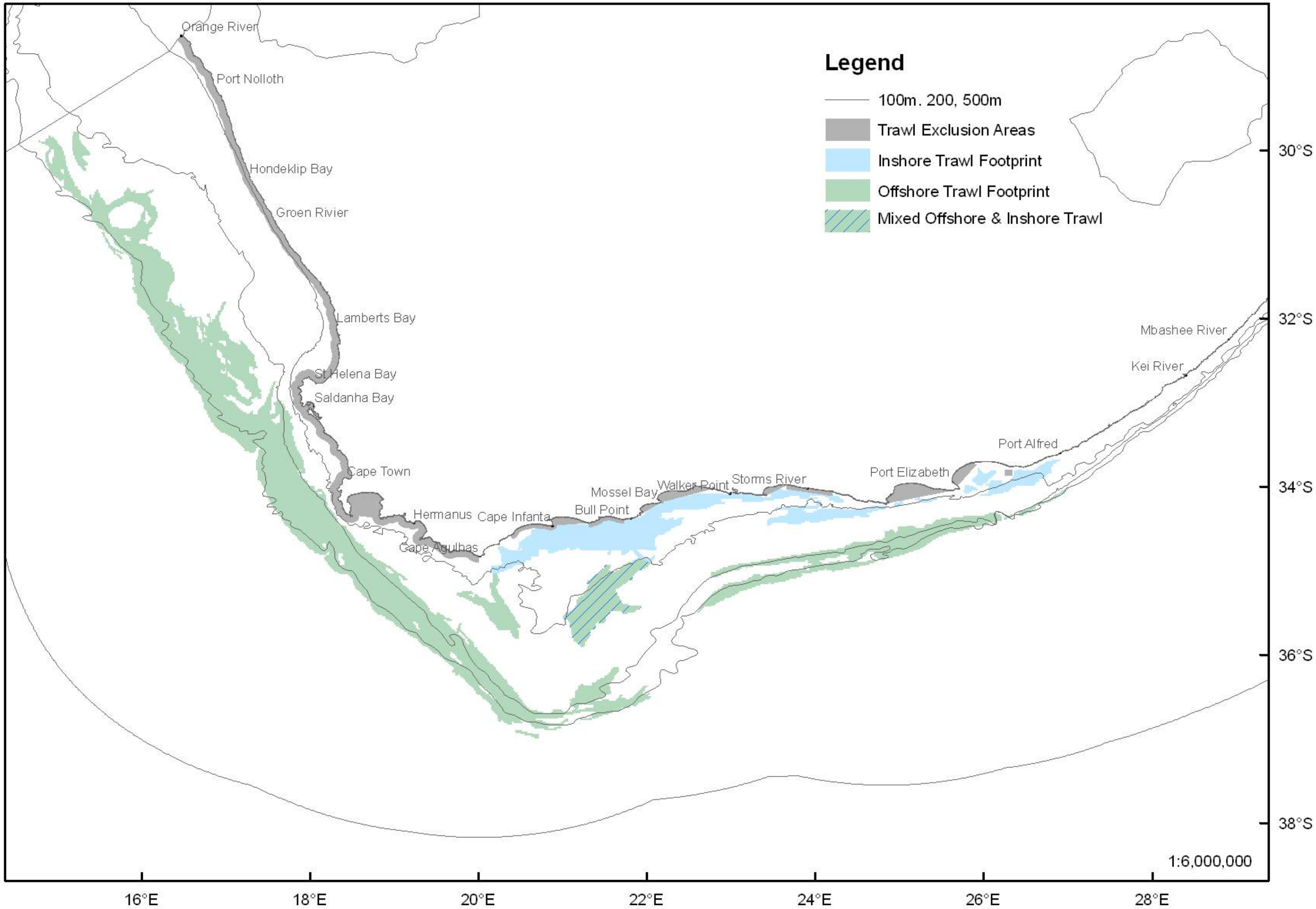


Figure 2. The recent "footprint" of the inshore and offshore sectors of the South African hake trawl fishery as determined from approximately 40 years of fishing tracks (as mapped by Wilkinson and Japp 2008). Existing MPAs and trawl exclusion areas are also shown.

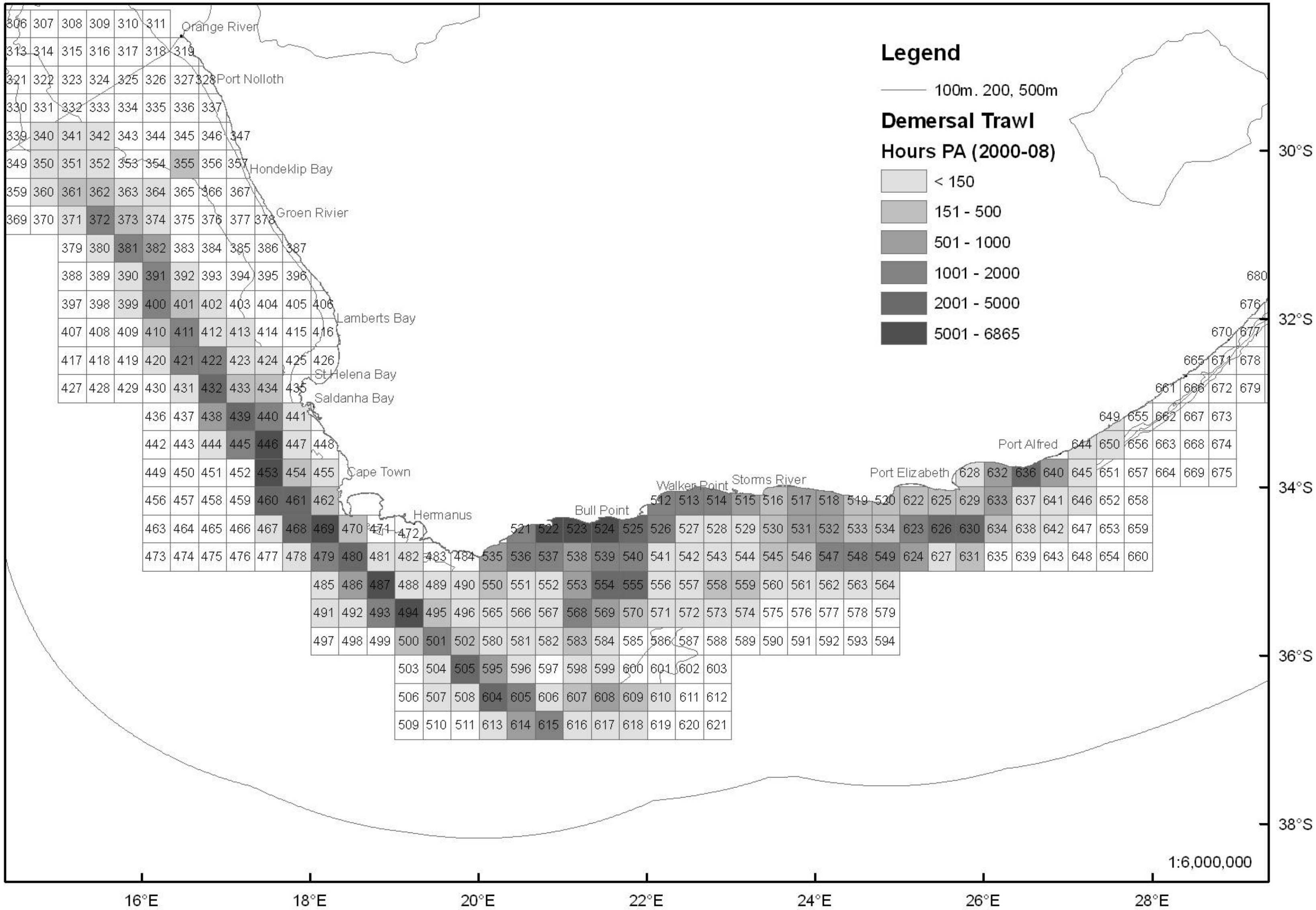


Figure 3. The distribution of trawling effort as determined by hours trawled in the commercial grid blocks for the period 2000-2008. Data provided by DAFF commercial logbook records.

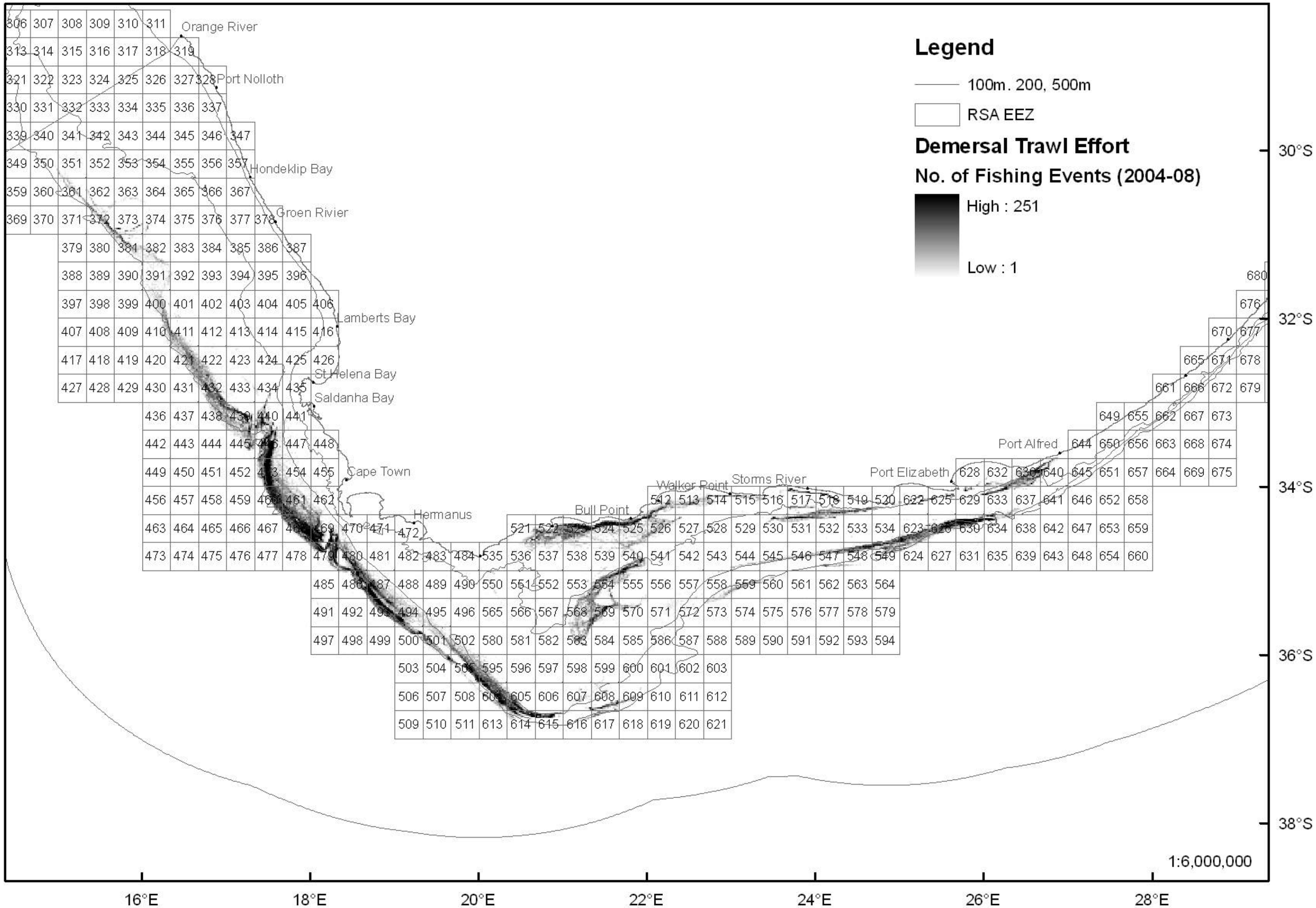


Figure 4. The distribution of trawling effort as determined by the number of trawl start positions recorded on a 1nm by 1nm resolution for the years 2004 to 2008. Data provided by DAFF commercial logbook records.

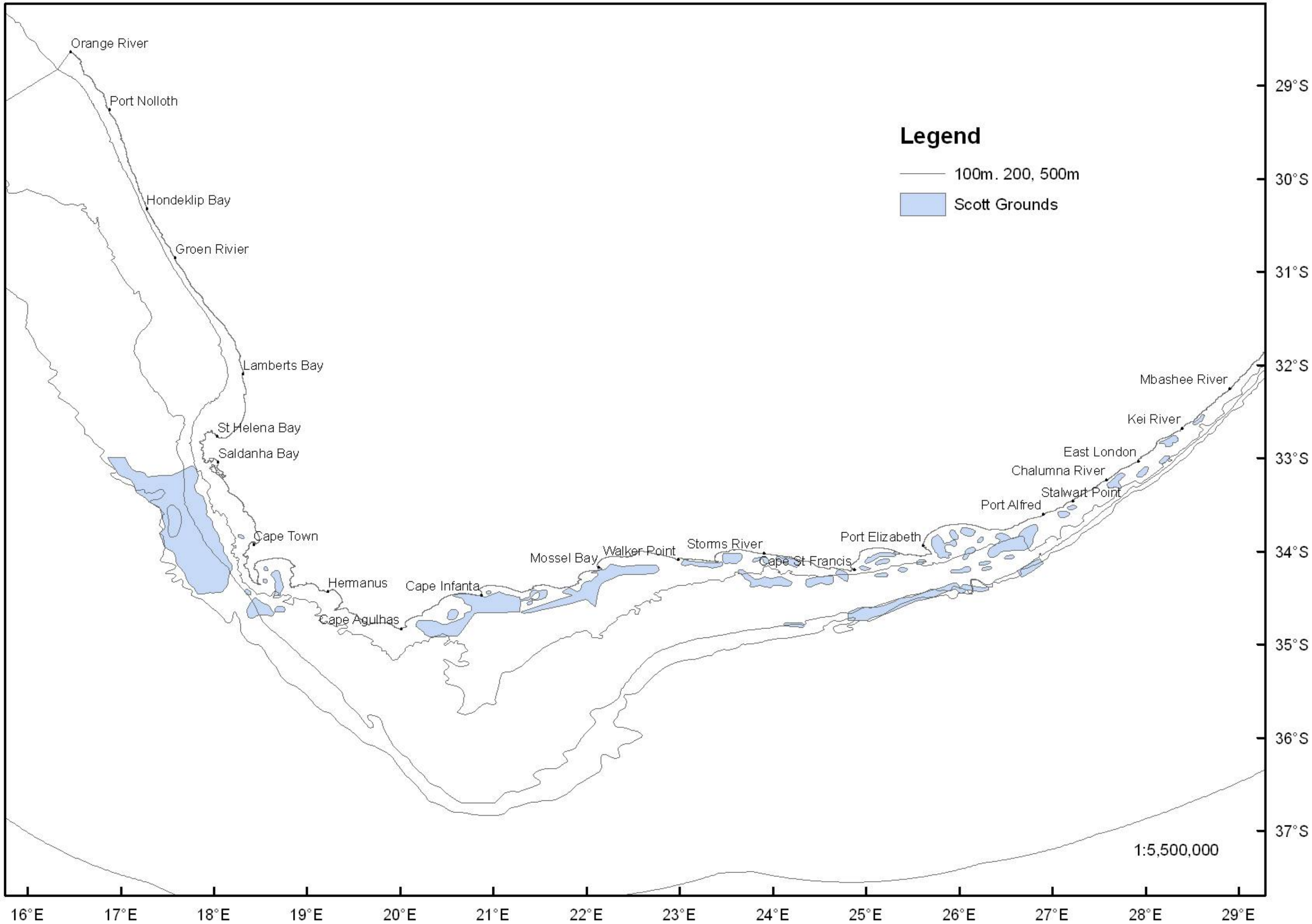


Figure 5. Overview of the demersal trawl grounds targeting hake, sole and linefish as reported by Scott (1949).

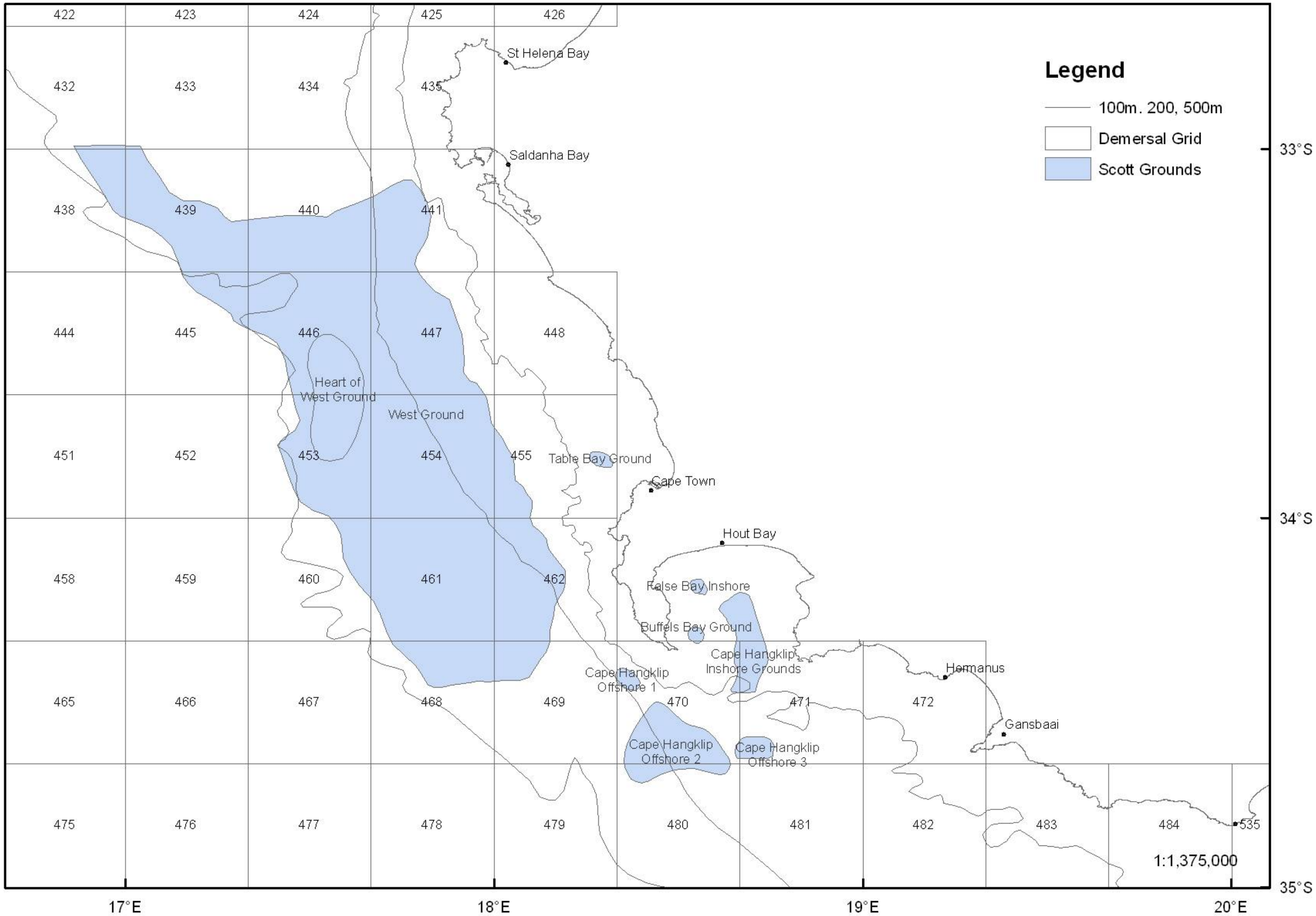


Figure 6. Overview of the West ground, Cape Hangklip grounds and False Bay grounds as reported by Scott (1949).

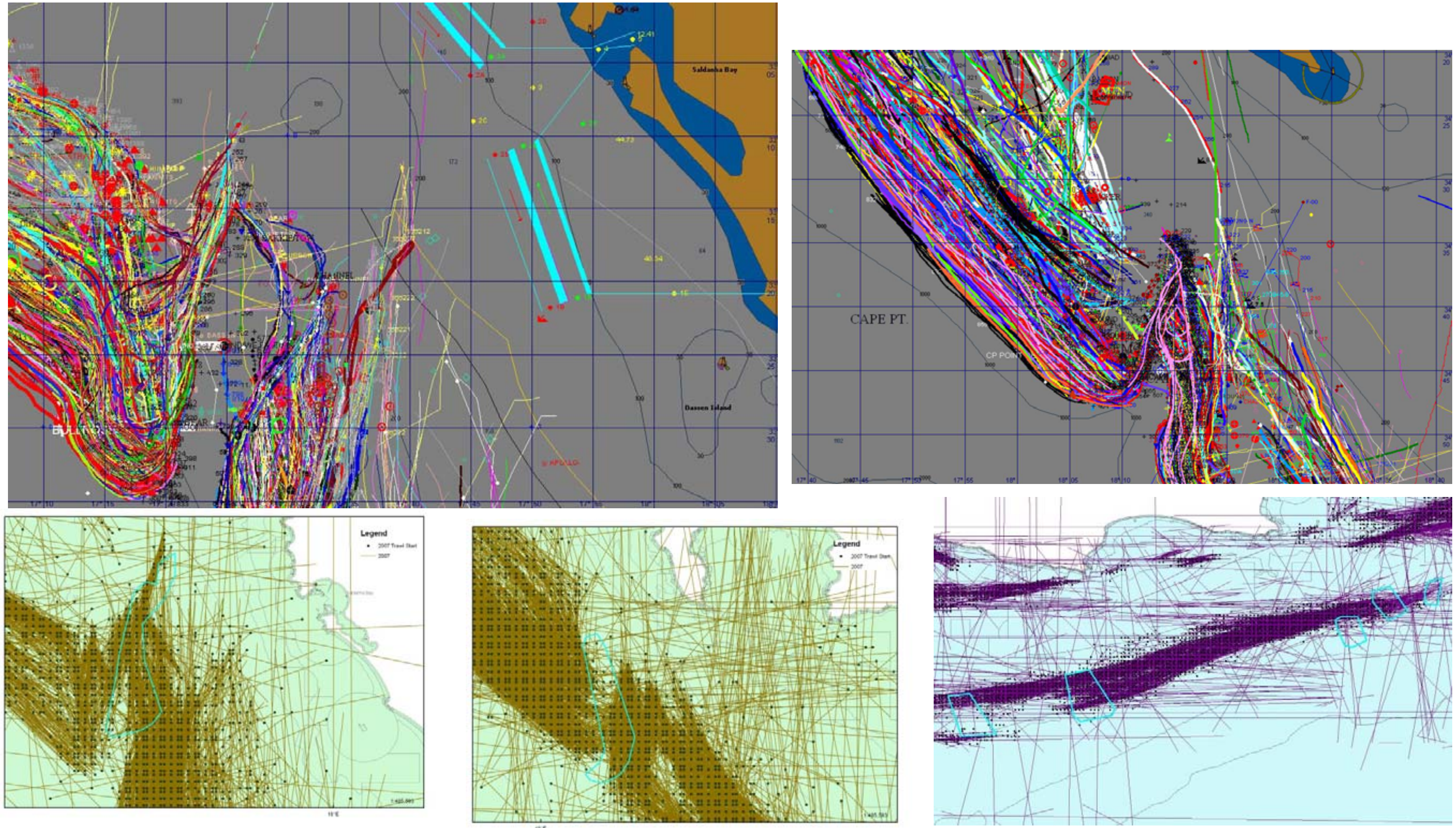


Figure 7 Maxsea plots around the Cape Canyon (top left) off Saldahna and Cape Valley off Cape Point (top right) respectively. An overlay of the approximate locations of these two canyons and the Agulhas canyons (far right) and trawl tracks plotted from trawl start and end positions is shown below.

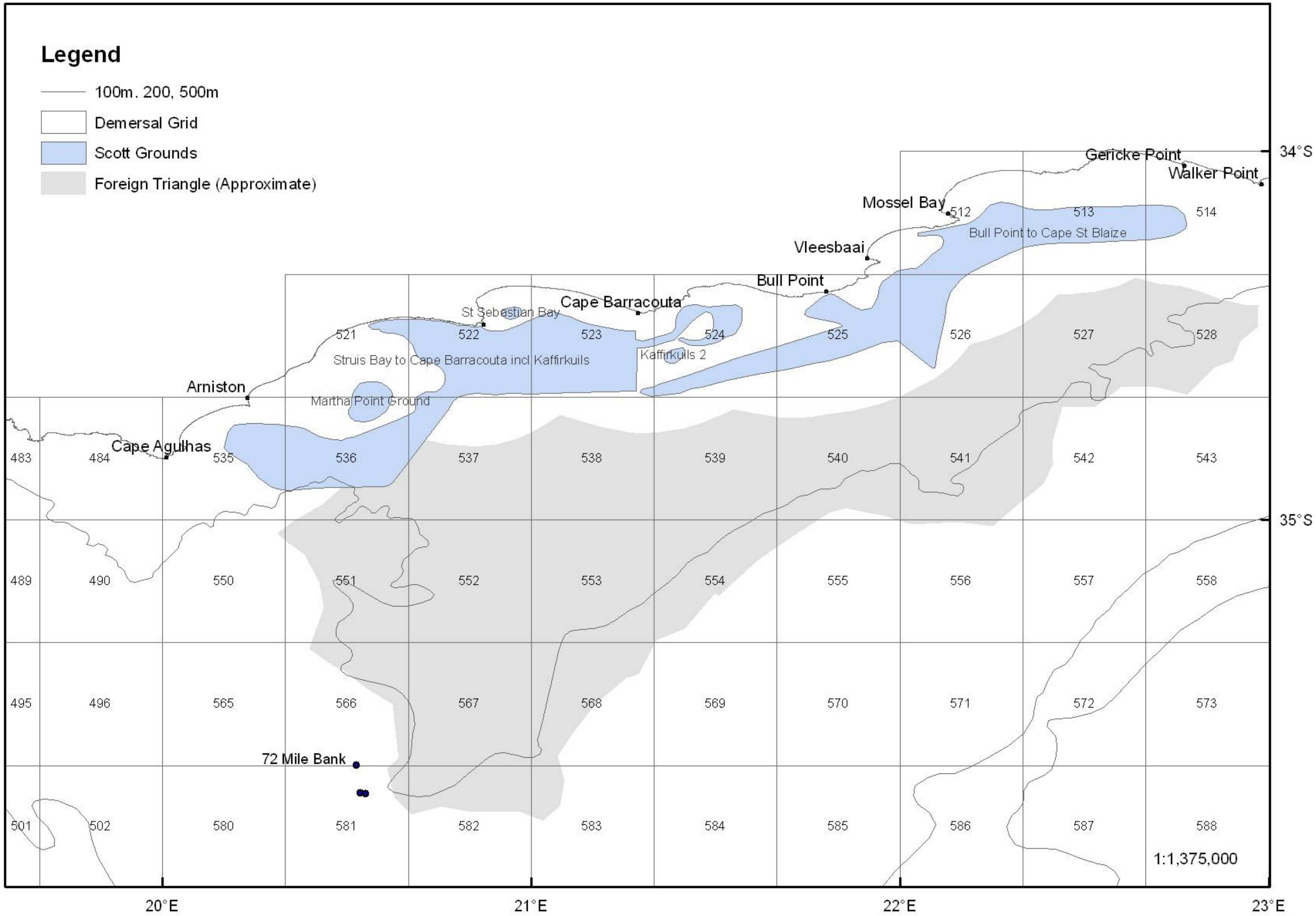
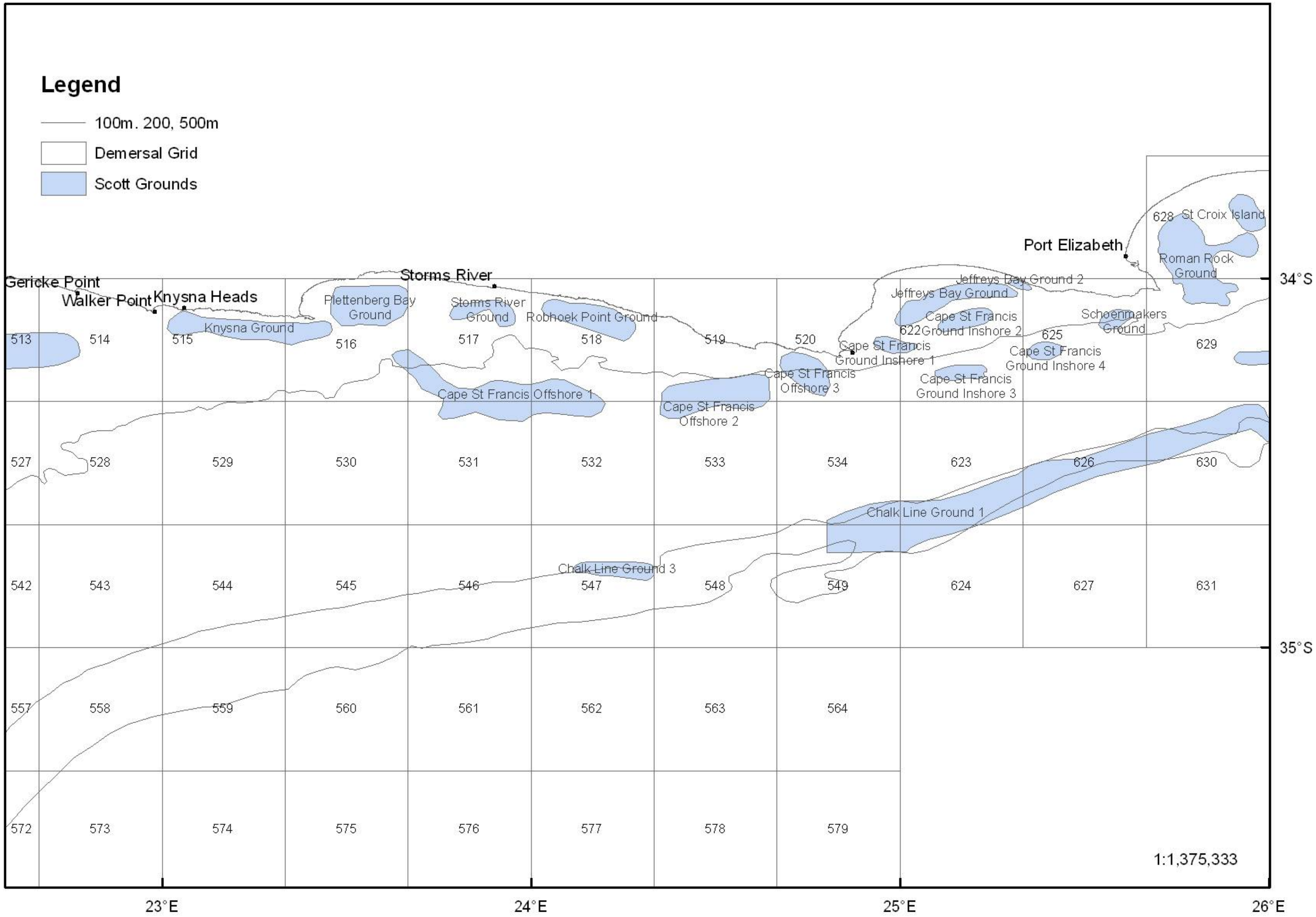


Figure 8. Overview of the south coast inshore trawl grounds between Cape Agulhas and Knysna including Cape Infanta and Mossel Bay grounds as reported by Scott (1949). The approximate location of the so called “Foreign triangle” is also shown.



Figures 9. Historical inshore trawl grounds of the south coast between Knysna and Port Elizabeth as reported by Scott (1949).

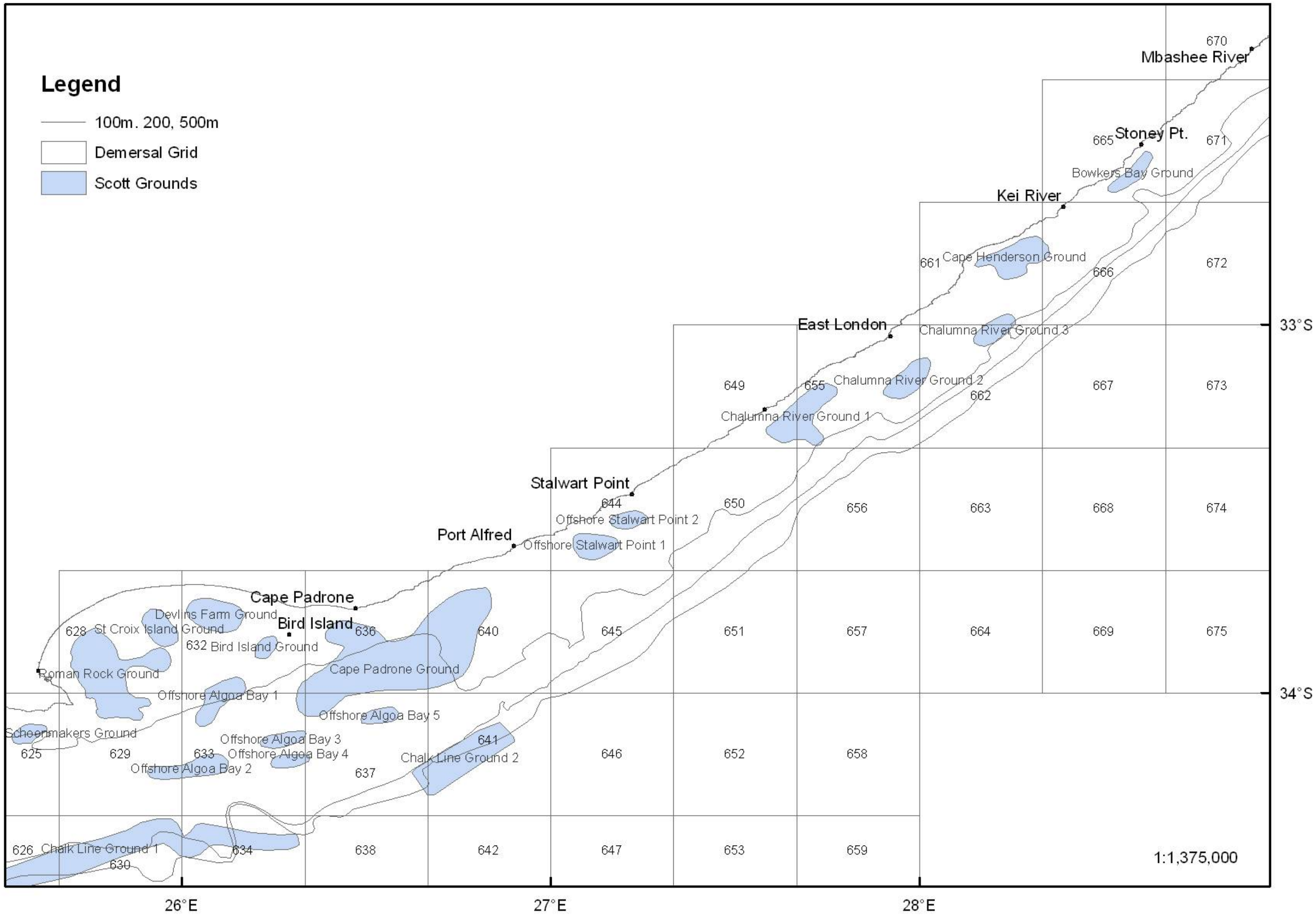


Figure 10. Historical inshore trawl grounds of the south east coast between between Port Elizabeth and the Mbashe River as reported by Scott (1949).

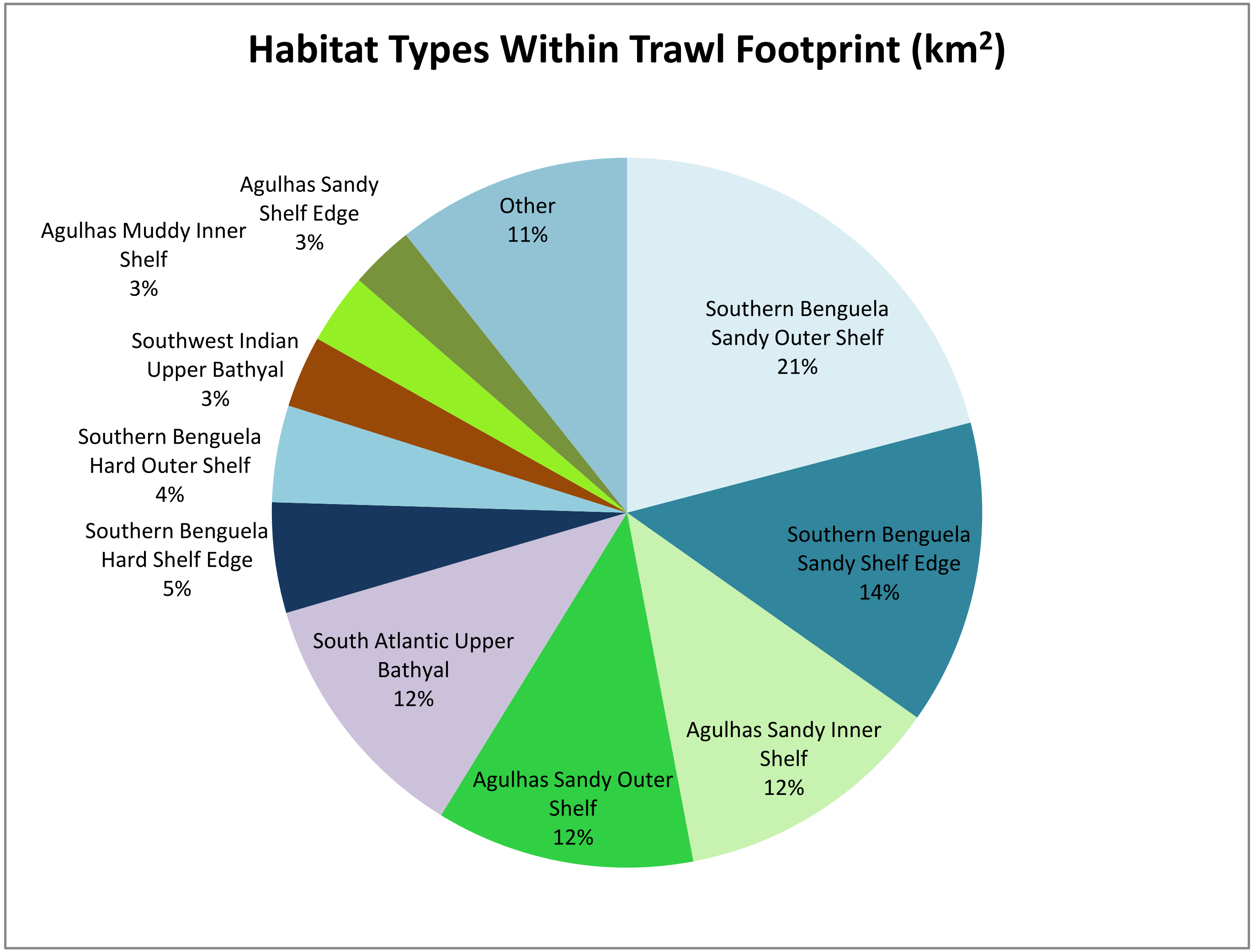


Figure 11. The habitat composition within the 70 160 km^2 South African hake trawl footprint. The percentages indicate the relative proportion of each habitat type within the footprint but give no indication of how much of the total extent each habitat type is trawled.

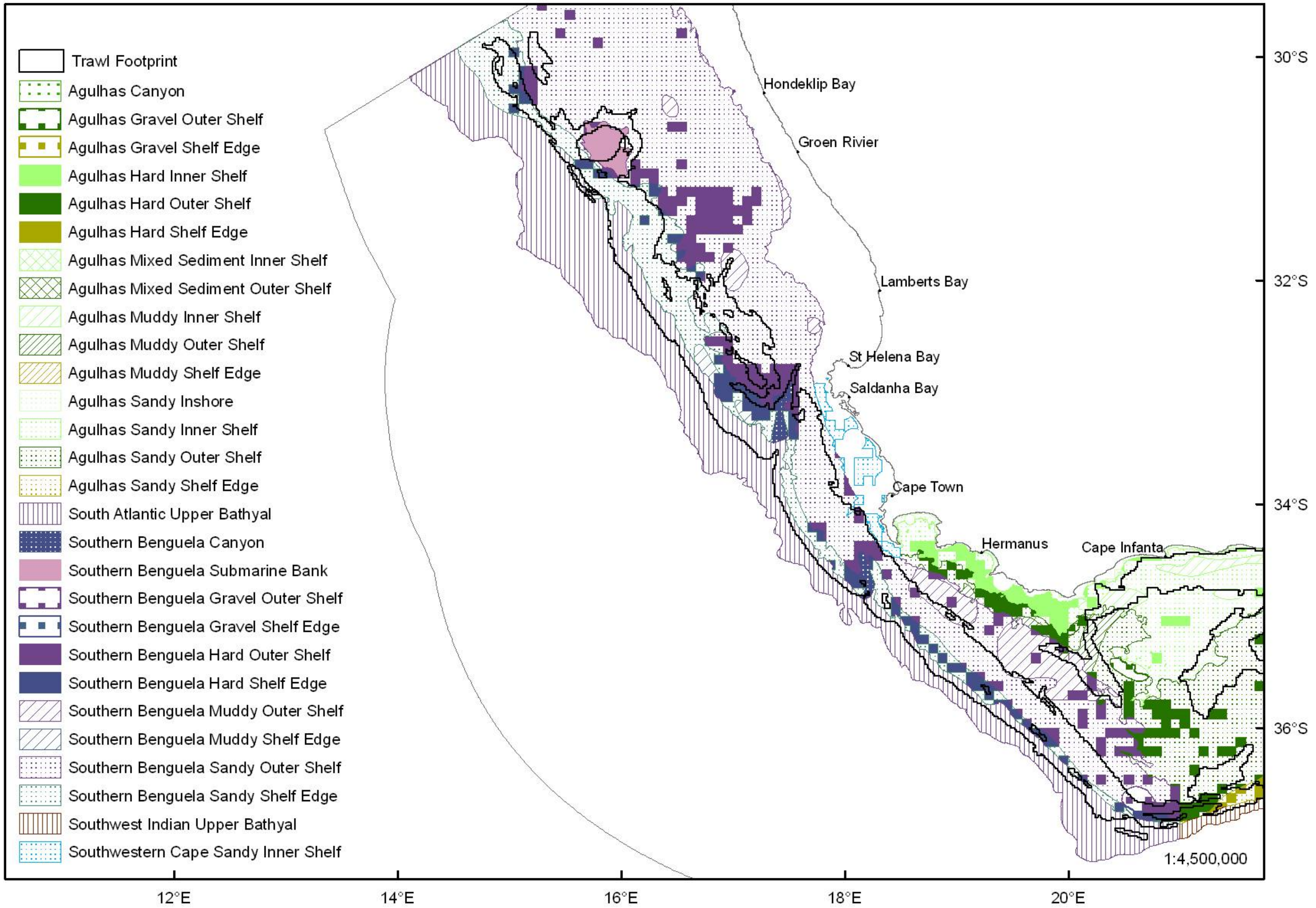


Figure 12. The distribution of habitat types that are included in the demersal hake trawl fishery in the Benguella and South Atlantic ecoregions in South Africa. Habitats as classified and mapped through the 2011 National Biodiversity assessment (Sink *et al.* in prep) and the trawl footprint as Wilkinson and Japp (2008).

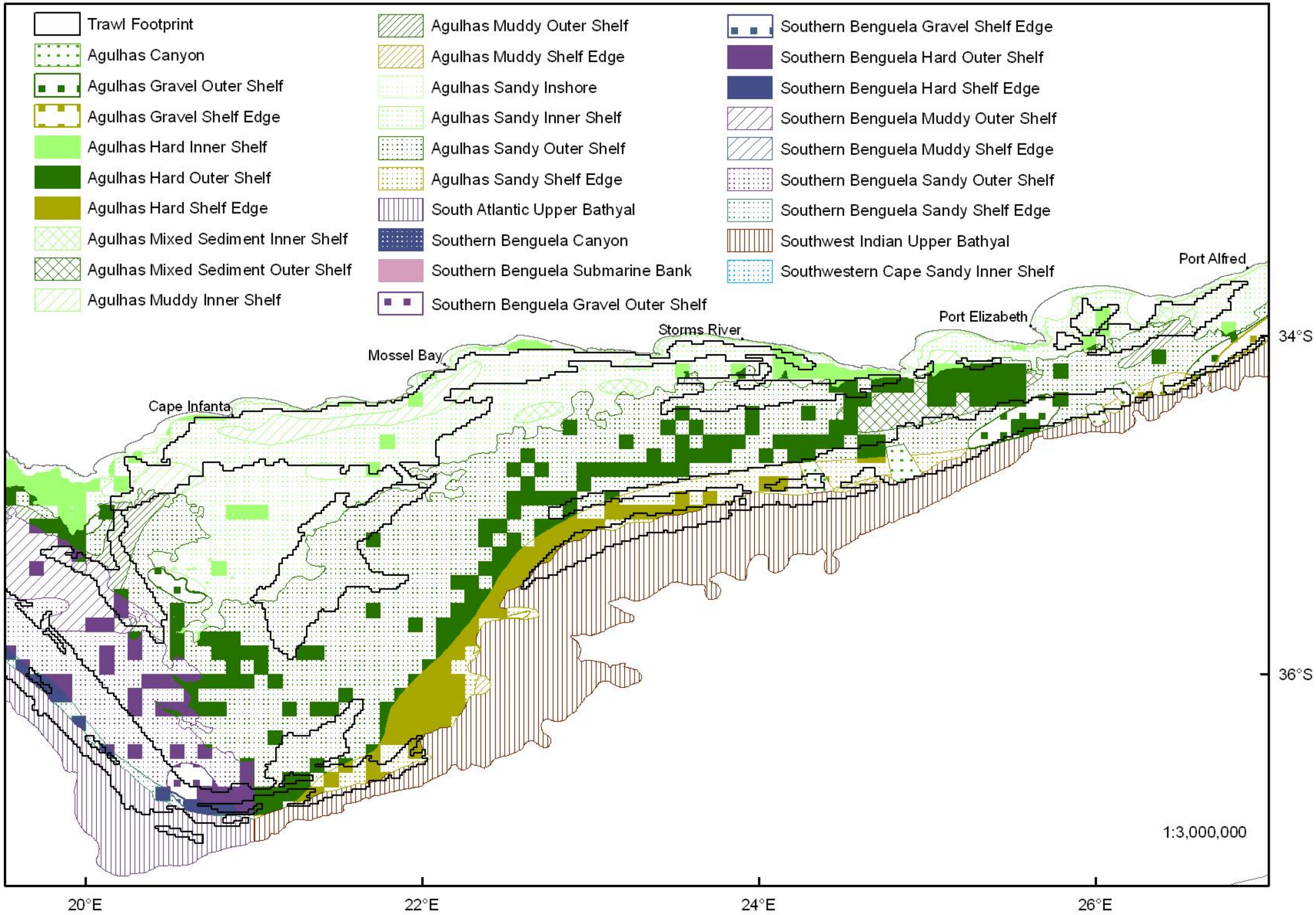


Figure 13. The distribution of habitat types that are included in the demersal hake trawl fishery in the Agulhas and Southwest Indian ecoregions. Habitats as classified and mapped through the 2011 National Biodiversity assessment (Sink *et al.* 2011) and the trawl footprint as defined by Wilkinson and Japp (2008).

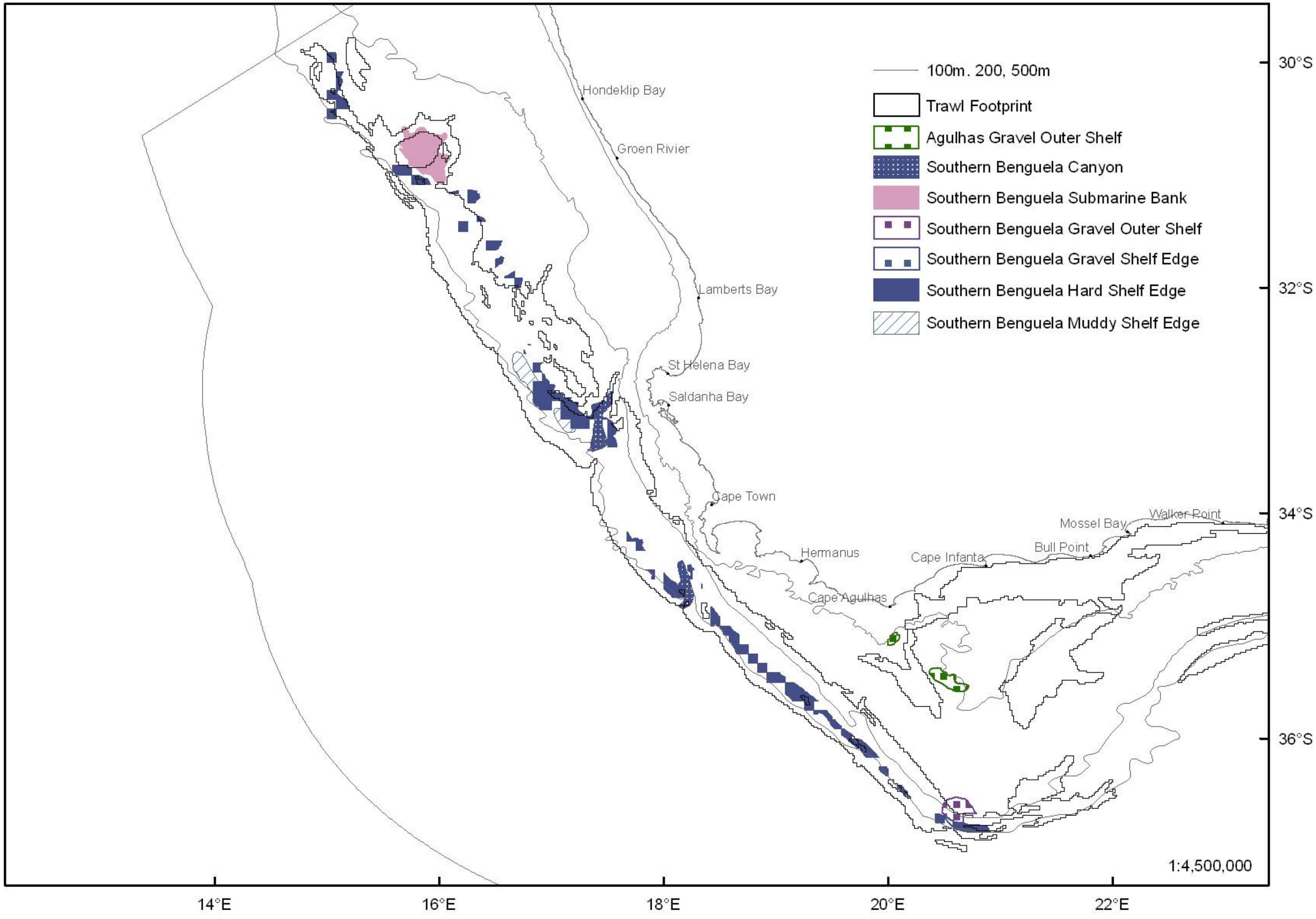


Figure 14. Priority habitats on the west coast.

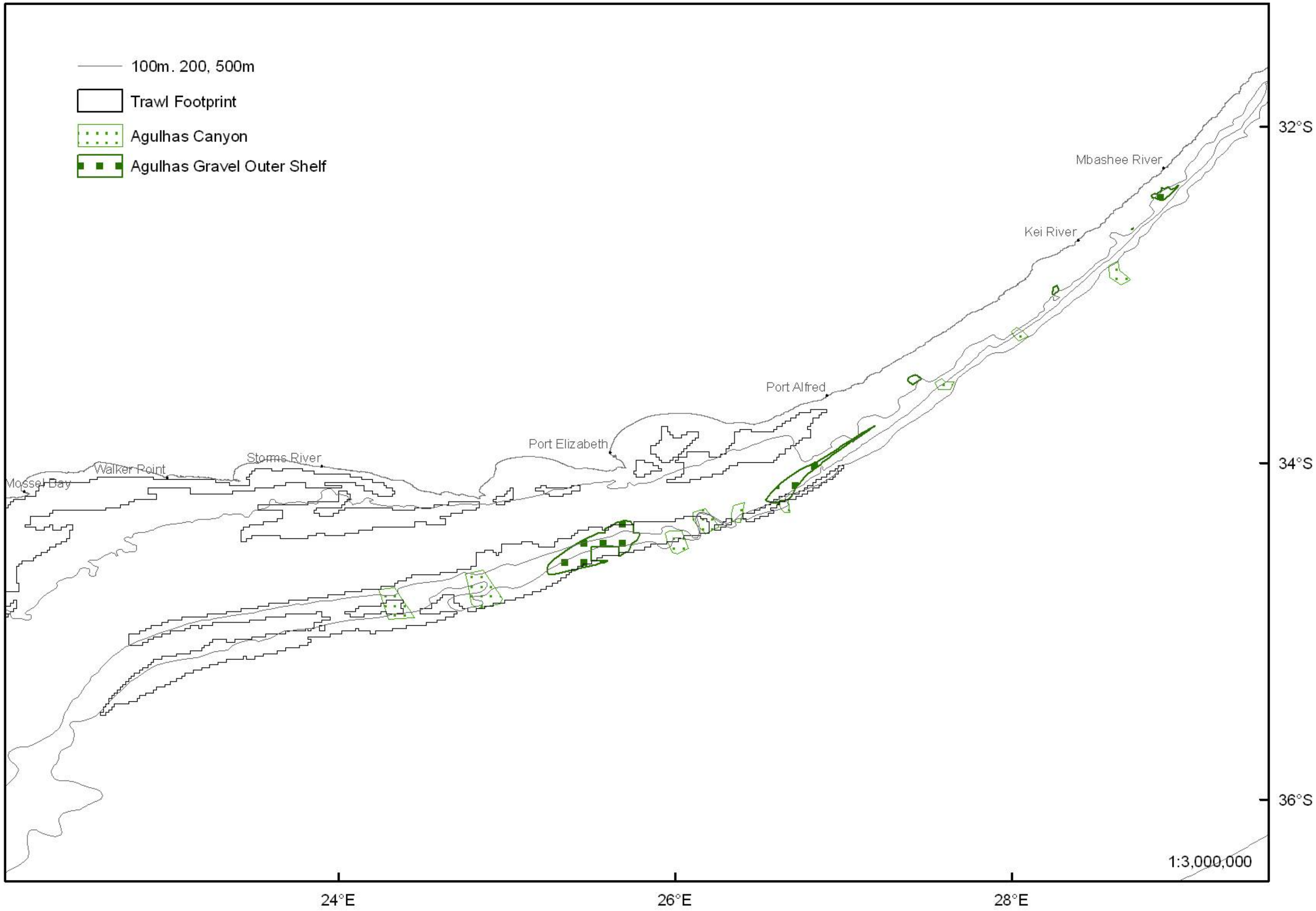


Figure 15. Priority habitats on the south coast.

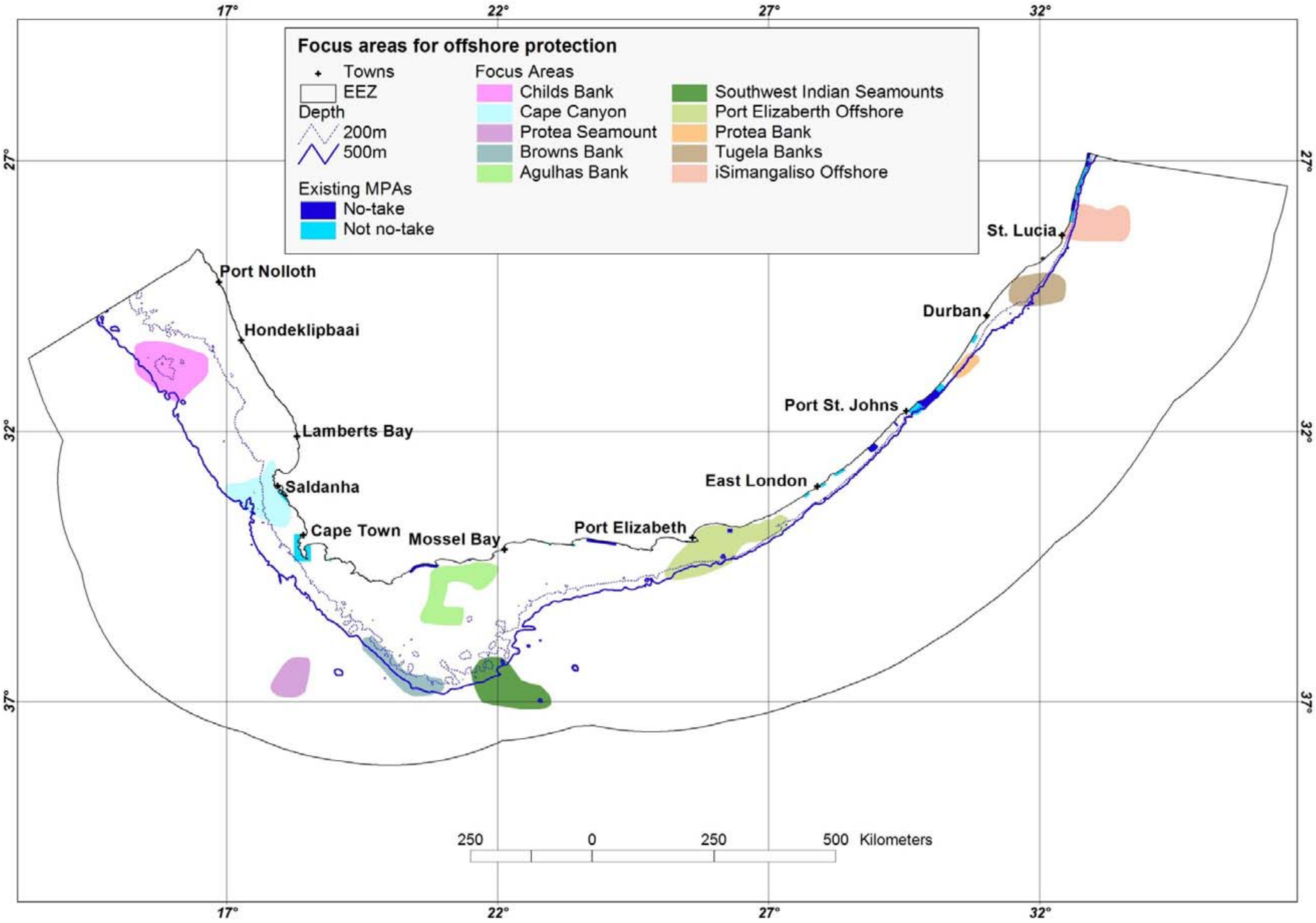


Figure 16. Focus areas for offshore protection as determined by systematic biodiversity analyses (From Sink et al. 2011). Note that focus areas include multiple features of importance. Actual proposed boundaries for offshore spatial management will differ from these focus areas.

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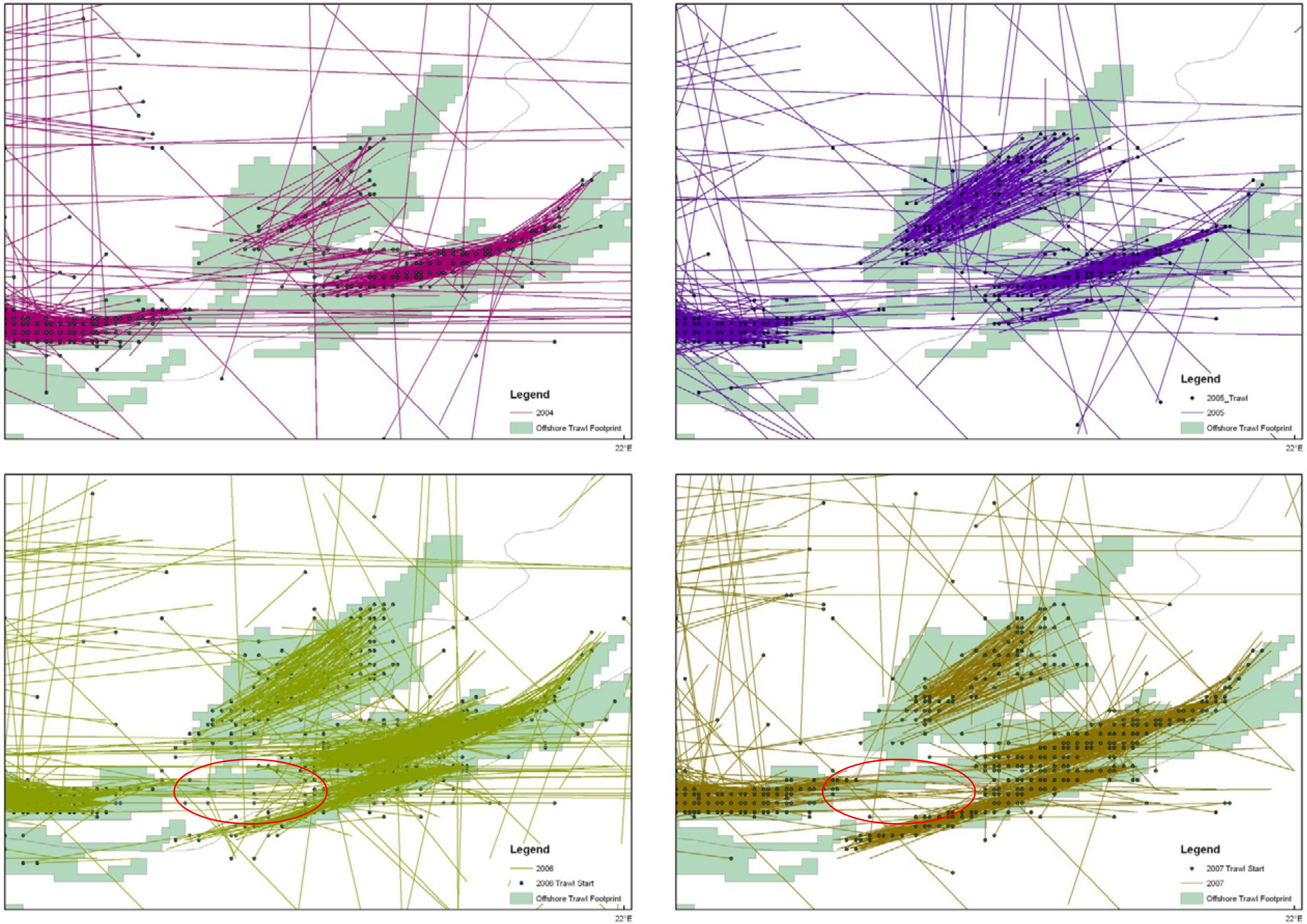
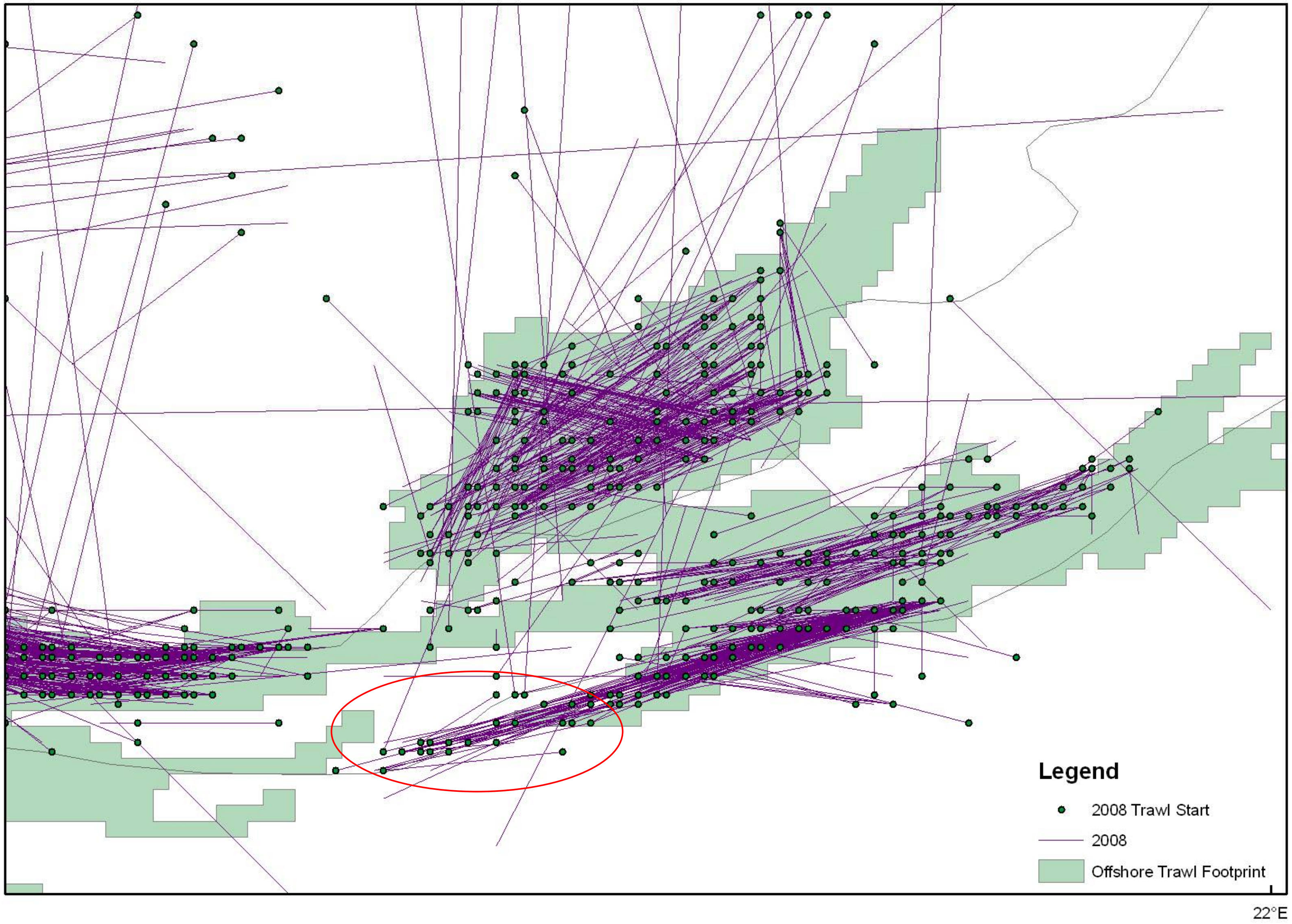
Appendix 1. Commercial hake trawl fishing outside of the trawl footprint in the vicinity of the southern tip of the South African shelf edge (Grid 616, Figure 3).




Legend
2008 Trawl Start
2008
Offshore Trawl Footprint
22°E