Rates of shark depredation of line-caught fish on the Protea Banks, KwaZulu-Natal

by

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ABSTRACT

This study estimates rates of shark depredation in the charter boat fishery on Protea Banks, KwaZulu-Natal. Previous estimates based on fisher surveys suggested that shark depredation is a concern locally and may distort fishing mortality estimates. Methods involved quantitative data collection by an onboard observer from November 2013 to January 2014. Catch composition data were collected to enable comparisons with the commercial and recreational catch returns used in monitoring and assessment. Results revealed an average depredation rate of 8.4% that varied depending on the species fishers targeted. Depredation was highest when catching pelagic species (18.6%) and lowest when catching reef species (1.9%). Depredation rates were highest in November (19.6%) and lowest in January (5.3%). Observed rates were highest on the Banks itself and immediately offshore (9.9%), but no depredation was observed inshore of the Banks. The most commonly identified sharks involved in depredation incidents were the dusky shark (*Carcharhinus obscurus*) and the blacktip shark (*Carcharhinus limbatus*). Multi-dimensional scaling showed commercial catch composition to be significantly different from recreational and charter catch composition, mainly due to abundance of tuna in the recreational and charter sectors. No significant relationship was found between catch composition and shark depredation. Depredation is estimated to cost charter fishing operators 8% of their revenue. Depredation rates are at a level that could impact effective stock assessment and should be considered when making management decisions.

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Chapter 1 – Literature Review

1.1 Introduction

The history of fisheries worldwide is awash with tales of the ocean as an inexhaustible source of fish so abundant, that in days gone by they were scooped from the sea in baskets (DEA, 2005; Kurlansky, 1999). There are black and white pictures of fishermen proudly displaying oversized fish for the camera (Kurlansky, 1999) however, it appears that if fish stocks continue to be depleted at historic rates, then the only thing that will remain from the bygone era are those early photos and their accompanying stories (Kurlansky, 1999). An exploding human population and advances in fishery technology, coupled with widespread government subsidies, have seen a pervasive deterioration of the marine environment with over half of the world's fisheries exploited to their maximum level and close to a third already over-exploited or depleted due to excessive fishing pressure (FAO, 2010). However, over the last decade, efforts aimed at improving fisheries management worldwide have increased and some fish stocks are starting to recover.

Making effective management decisions relies on accurate data about fish stocks, which are notoriously difficult to assess. A notable case of fish stock collapse occurred in the Atlantic Northwest cod fishery. Over-exploitation was blamed on a poor understanding of its ecological structure among other things. As a result poor management decisions were made and by 1992, the cod biomass fell to 1% of previous levels (Hamilton & Butler, 2001). In an attempt to allow fish stocks to recover, a complete moratorium on fishing was introduced, which had significant and wide reaching environmental and socio-economic impacts. It is only now, more than 20 years on, that the first signs of a sustained recovery are starting to appear (Frank et al., 2011).

As the collapse of the Atlantic Northwest cod fishery highlights, managers need accurate information to enable them to make effective decisions and most importantly accurate fish mortality data. The rate of mortality in a particular fishery depends not only on the number of fish landed but a combination of other factors. By-catch and discard have an impact on fish mortality, as does shark depredation.

1.2 Depredation

Depredation is the partial or complete removal of hooked fish from a line by a predator. The majority of the current literature on the subject centres on shark and cetacean interactions in pelagic longline fisheries. This sector has suffered substantial economic impacts through damage or loss of target species and fishing gear, a reduced catch of marketable species and expenditure of time (Gilman et al., 2006; Gilman et al., 2007; NOAA, 2009; Rabearisoa et al., 2012). Although the costs of depredation are difficult to quantify, it is estimated that in 2006, losses due to cetacean depredation in the Hawaii pelagic fishery were between $13-23 million based on a depredation rate of 30% (NOAA, 2009). In a study commissioned by the Western Pacific Regional Fishery Management Council, respondents in Australia considered sharks rather than cetaceans to be responsible for the greatest loss of fishing gear costing and average of AU$100 per set and target species economic losses up to 20% (Gilman et al., 2007). In the

South African Western Cape linefishery, the interaction between the Cape fur seal (*Arctocephalus pusillus pusillus*) and linefishing operations identified depredation as a source of lost revenue. Losses of both snoek (*Thyrsites atun*) and hottentot (*Pachymetopon blochii*) to seals amounted to 3.0% and 1.5% of the total reported catch respectively. It was found that the rate of depredation was seasonal with figures increasing to 11.4% for snoek in August and 8.4% for hottentot in November with no depredation reported in January or April for either species (Meÿer et al., 1992; Wickens, 1996). Depredation is also of ecological concern as interactions may change foraging behaviour, increase fishing effort and have an impact on stock assessments (Gilman et al., 2006; Gilman et al., 2007; MacNeil et al., 2009).

Shark depredation is an issue affecting fishing sectors along the coast of KwaZulu-Natal (KZN) where there have been reports of increasing depredation, by sharks, of fish hooked on lines (Dudley, 2003; Carnie, 2007; Dudley & Cliff, 2012; Grant, 2012; Tomassen, 2013). There are several theories for the suspected increase ranging from long-term depletion of fish stocks, to the influence of the protective gillnets used at some beaches to a growth in dive operators using bait and chum as a method of attracting sharks for tourists. None of these theories have been scientifically tested.

For the last decade fishers in KZN have complained that the intensity of shark activity makes it difficult for them to catch fish with some claiming they lose anywhere between 50 and 80% of their catch to sharks, along with expensive fishing gear (Mike Milton, pers. comm., 2013). The issue of shark depredation was investigated in an unpublished, six month pilot study by the KwaZulu-Natal Sharks Board (KZNSB). During the surveys conducted, skippers reported shark activity in 62% of all fishing trips and reported fish were lost to sharks in 44% of all fishing trips. Each of the six launch sites showed a significant difference in the number of trips where it was reported that fish had been lost to sharks. The figured ranged between 6% for boats launching from Port Edward to 73% for boats launching from Shelly Beach (Dudley, 2003).

1.3 Study Area

Boats launching from Shelly Beach on the KZN South Coast, fish in the offshore waters surrounding the Protea Banks, a fossilised dune reef lying 8km offshore. At its shallowest depths the reef reaches around 25m and then drops down to 60m. The reef is approximately 3km long with a series of caves at the deeper northern end and a number of gullies and shallower formations towards the southern pinnacle. To date, there have been few scientific studies or assessments of Protea Banks yet it has been identified as an important bioregion between the Pondoland MPA in the south and Aliwal Shoal to the north (Sink et al., 2011).

Pondoland is now the biggest MPA in South Africa and incorporates large sub-tidal reefs that provide a habitat for a multitude of endemic species. It is defined as a critical area for many over-exploited linefish with some species spawning in the area and an important habitat for intertidal invertebrates that used to be extensively harvested. The Aliwal Shoal MPA incorporates a subtidal, subtropical reef which hosts a variety of species, including some tropical and warm temperate species (Tunley, 2009).

Although the neighbouring ecosystems have been studied, very little is known about Protea Banks. No benthic studies have been carried out (Olbers et al., 2009) but the reef type has been identified as currently under-protected in the bioregion and highlighted as an important area for biodiversity protection. Submarine canyons, deep reefs and cold-water coral records are just some of the features that have been identified, highlighting the need for effective seabed protection (Sink et al., 2011). Chlorophyll and sea surface temperature fronts have also been identified as important offshore processes (Ezemvelo KZN Wildlife, 2012). There are over forty species of teleosts, nine species of elasmobranch and three species of marine mammal identified as important within the bioregion, including some heavily exploited linefish such as Englishman (*Chrysoblephus anglicus*) and seventy-four *(Polysteganus undulosus*). It is thought protecting both the inshore and offshore areas could help the recovery of over-exploited linefish stocks (Sink et al., 2011).

1.4 South African Linefishery

With a coastline that stretches over 3000km encompassing cool temperate to warm tropical waters, South Africa has a long fishing history dating back to the 16th century but like so many other fisheries worldwide, certain sectors have become dangerously depleted (Penney et al., 1999; DEA, 2005). The multi-species and multi-user South African linefishery, which consists of over 200 demersal and pelagic species has seen some severe cases of over-exploitation (Penney et al., 1999; Griffiths & Lamberth, 2002; DEA, 2005; Pradervand & van der Elst, 2008). Decades of poor to non-existent management resulted in the depletion of most commercially exploited linefish to dangerously low levels. Stocks of large endemic reef fish species, such as seventy-four and red steenbras (*Petrus rupestris*) are now classed as collapsed with a catch per unit effort (CPUE) decline of 99.9% and 99.8%, respectively (Penny et al., 1999; DAFF, 2010; WWF, 2011; Mann, 2013b).

A Linefish Management Protocol (LMP) was developed to monitor, assess and revise management regulations for important linefish species (Griffiths et al., 1999) but the with situation continuing to worsen, the crisis in the linefishery prompted the Minister of Environmental Affairs and Tourism to declare fish stocks in a State of Emergency in 2000 (Attwood et al., 2013). Eventually a number of regulations and management strategies were implemented in an attempt to protect the linefishery. These included a moratorium on fishing certain species, a reduction in total allowable effort for the commercial fishery by 70% (TAE) and the declaration of more Marine Protected Areas (MPAs). In addition to size limits, bag limits and closed seasons for the recreational fishery, a licensing system was introduced in 1999. The subsistence fishery was also formally recognised in 2003 and managed through a combination of the measures designed for the commercial and recreational sectors (DEA, 2005; Pradervand & van der Elst, 2008; DAFF, 2010; Mann, 2013b).

Although an urgent need for stock rebuilding has already been identified, effective monitoring and management of the linefishery has proved problematic with annual individual status assessments unworkable due to the wide variety of species caught, each with differing life histories. In a study of 139 profiled species of South African linefish, the stock status of 60% of them was unknown and of those that had been assessed, 20% were considered overexploited or collapsed (Mann, 2013). However, the WWF paint a bleaker picture reporting that 68% of 'commercially important' linefish stocks have already collapsed (WWF, 2011).

1.5 Monitoring and Management

Historically, management decisions about the South African linefishery have been based on a combination of data including spawner-biomass per-recruit analysis and catch records logged on the National Marine Linefish System (NMLS). Commercial fishers have been required to submit their catch data to the NMLS since 1985 and a network of boat and shore inspectors also capture information from the recreational sector for the NMLS. The reduction in effort to reduce fishing pressure on threatened fish stocks means per-recruit data is no longer a useful measure in stock assessments (WWF, 2011) and greater importance has been placed on overall trends in catch and effort when making management decisions (Dunlop & Mann, 2012a; Winker et al., 2012; Dunlop & Mann, 2013; Winker et al., 2013).

The NMLS data were heavily criticised in the early years for inaccuracies with under-reporting of commercial target species estimated between 2 to 4 times the actual catch. However, catch and effort data logged in the NMLS have been instrumental in assessing the efficacy of many of the management measures implemented in the South African linefish sector (Penney et al., 1999; Dunlop & Mann, 2013). Management measures that are deemed to have had some degree of success include a reduction in commercial effort and the establishment of more restricted fishing zones (Dunlop & Mann, 2013). Areas have been identified where stocks of some linefish species are in recovery. Empirical evidence has shown that since the implementation of the Goukamma Marine Protected Area (MPA) in 1990, the adjacent fishery has benefited from an increase in CPUE for Roman (*Chrysoblephus laticeps*) (Kerwath et al., 2013). Surplus production modeling has shown the success of reducing commercial fishing effort with a ~30% recovery in biomass of slinger (*Chrysoblephus puniceus*) (Winker et al., 2012; Mann, 2013a). Indications are that the South African linefishery appears to be in a relatively stable condition, although the stock of some species, such as Englishman, one of the top five most landed species in the KZN linefishery, still remain in a critical condition with most recent assessments deeming the stocks as collapsed (Mann, 2013c).

The complexity of the multi-user, multi-species South African linefishery is particularly apparent in KZN where, in 2009, in addition to 3,331 commercial boat launches there were over 30,000 recreational and close to 6,000 charter boat launches (Dunlop & Mann, 2013). The South African Marine Living Resources Act of 1998 recognises three user-groups in the linefish sector; commercial, recreational and subsistence, but there is no recognition of the charter boat industry. The charter boat industry has recreational and commercial objectives but no formal management regime in place and there are no statutory obligations to submit catch records (Pradervand & van der Elst, 2008). In KZN there is a system of recreational boat inspections conducted by Ezemvelo KZN Wildlife (EKZNW) and the catch and effort data are logged in the NMLS however, inspections rates are only approximately 47% of the number of reported launches (Maggs, 2014).

Effective monitoring and management of multi-species linefish stocks relies on accurate catch and effort data, among other factors, so the multi-user dimension of the fishery adds additional complexity that poses problems for accurate stock assessments (Götz et al., 2007; Pradervand & van der Elst, 2008; Bennett et al., 2009; DAFF, 2012; Mann, 2013b; Winker et al., 2013).

There are a number of user-groups that utilise the resources of the Protea Banks from commercial, recreational and charter fishers to spear fishers, scuba divers and pleasure boats, the vast majority launching from the Sonny Evans Small Craft Harbour, Shelly Beach. Launches in KZN are collated in a Boat Launch Site Monitoring System (BLSMS) that records vessels type, purpose of launch and data on the species caught and landed in non-commercial fishing outings.

The BLSMS came about in 2003 after restrictions were put in place under the National Environmental Management Act to limit the coastal zone access of off-road vehicles launching small vessels into the sea. These were deemed to have a negative impact on the surrounding environment. At the same time, greater controls were also imposed on designated beach launching sites with a licensing scheme and the introduction of a mandatory launch and catch register (Mann et al., 2012).

1.6 Catch, Effort and Fish Mortality

Shelly Beach has been identified as a site with high usage and figures for 2011 show launches took place on 88% of days (Mann et al., 2012). Of the 5024 launches, 64% were for charter or recreational fishing, 10% commercial fishing and 17% scuba diving with the remainder for practice and testing or pleasure trips (Mann et al., 2012). It was reported that the recreational fishing vessels targeted pelagic fish on 64% of launches and reef fish on the remaining 36% but in reality, fishing trips often target both pelagic and reef fish during the same trip (Mann et al., 2012). In 2011, the BLSMS reported the non-commercial catch composition for Shelly Beach comprised 45 different species. Slinger (34%) and yellowfin tuna (*Thunnus albacares)* (23%) accounted for the vast majority of the catch. Little eastern tuna or bonito (*Euthynnus affinis*) (7%), Englishman (4%) and unspecified rockcod (4%) were reported as the next most frequently caught species. Low levels of compliance, only 31% of skippers reported their catch composition to the BLSMS, means data compiled from catch reports are not regarded as particularly accurate and the catch composition differs to other, more comprehensive studies (Pradervand & van der Elst, 2008; Mann et al., 2012; Dunlop & Mann, 2013).

Dunlop & Mann (2013) conducted stratified-random access-point surveys to determine CPUE in the KZN boat based fishery and found the percentage of the most commonly caught species of fish (by number) in the commercial fishery was slinger (66.0%), santer (22.4%), blue emperor (*Lethrinus nebulosus*) (5.0%), blue hottentot (1.9%) and Englishman (1.0%). Within the charter boat fishery the percentage of the most commonly caught fish (by number) was slinger (34.4%), blue emperor (16.7%), yellowfin tuna (13.1%), Englishman (8.1%) and blue hottentot (4.6%). Pradervand and van der Elst (2008) also identified slinger, blue emperor, santer and Englishman in the most commonly retained species with dorado (*Coryphaena hippurus*) the fifth most commonly caught species.

Although the composition of the most commonly caught species in the commercial and charter fishery is not dissimilar, there are significant differences in the CPUE between the two sectors. In terms of numbers of fish landed per outing, the CPUE in the commercial sector is over ten times the CPUE measured in the charter sector. In terms of the weight of fish landed per outing, the CPUE in the commercial sector is over five times that of the CPUE in the charter sector (Dunlop & Mann, 2013). However, unlike the commercial sector where effort has been considerably reduced since 2003, the effort in the charter boat sector is unregulated although fishers are restricted to individual bag limits and closed seasons (DEA, 2005; Pradervand & van der Elst, 2008; DAFF, 2010; Mann, 2013b). In 2011 there were 3.7 times more charter launches (1,793) than commercial launches (485) from Shelly Beach. In addition there were a total of 1,405 private fishing launches (Mann et al., 2012). The CPUE of the charter fishing sector may be significantly less than that of the commercial sector but the effort is poorly monitored and at this particular location there is potential for charter and recreational fishing to have a substantial impact on fish stocks.

The CPUE figures derived by Dunlop & Mann (2013) for each of the fishing sectors are an essential tool for management decision-making but they do not give the full picture. They do not take into account the overall fish mortality rate as a direct result of fishing activity. Fishing dependent CPUE data are based solely on fish landed and do not factor in fish that have been caught and released where survival rates can vary widely (Dunlop & Mann, 2013). This is particularly relevant when considering the KZN charter fishery where 37% of the catch is returned to the ocean (Pradervand & van der Elst, 2008). The release rate is important because when fish are hooked and landed they frequently suffer from some form of barotrauma that can have an impact on post release survival rates. Barotrauma occurs when the fish is reeled in and cannot adapt physiologically to the rapid ascent rate. It often manifests in extension of the stomach through the mouth, protruding eyes or protrusion of the hind gut (Götz et al., 2007; Kerwath et al., 2013). The mortality rate of fish that caught then released is between 1.3% and 24.5% and highly species specific (Götz et al., 2007; Kerwath et al., 2013). It has been suggested catch and release mortality rate should be taken into account in stock assessments and management strategies (Pradervand & van der Elst, 2008).

It is thought that along the coast of KZN, as in the long-line fishery, depredation may play a significant role in fish mortality associated with fishing activity. Shark depredation in KZN is not a new phenomenon. The association between sharks and easy acquisition of prey was identified as far back as 1908. Since whaling began in Durban, ships bringing carcasses into harbour were followed "*by packs of hungry sharks……the scavengers would clamp their powerful jaws on the whales and tear out big chunks of blubber meat*" (Mara, 1986). The Bowman Trophy, known as the '1000 club', was awarded every year from 1948 to 1975 to the shore angler who caught the largest shark along the South African coastline and the competition was won exclusively by anglers from Durban's South Pier (Dudley & Cliff, 1993a).

Unaccounted for mortality in CPUE data could have a substantial impact in terms of management decision-making. If fish mortality is greater than reported in the CPUE data fish stocks may be healthier than reported catches would lead us to believe. However, unaccounted for fish mortality could be interpreted as serious under reporting of fish harvested from the available stock so greater restrictions may be required.

1.7 Sharks in the South African Linefishery

With 181 different species of cartilaginous fish (*Chondrichthyes*), 172 elasmobranches, found in the waters surrounding South Africa and 51 different species found in the subtropical to tropical waters of KZN, shark depredation is to be expected; especially in KZN where the diversity of shark species is considerably higher than other regions of South Africa (Compagno, 2012).

A network of protective gillnets and drumlines in KZN, designed to protect bathers from shark attack, have proved a useful resource of catch information and shark abundance at a species level. The highest mean annual catch (232) of sharks in the nets between 1978 and 2003 was of dusky sharks (*Charcarhinus obscurus*). Five other species of shark, ragged tooth (*Carcharias taurus*), blacktip (*Charcharhinus limbatus*), spinner (*Charcarhinus brevipinna*), bronze whaler (*Charcarhinus brachyurus*) and scalloped hammerhead (*Sphyrna lewini*), had a mean annual catch of over 100 (Dudley & Simpfendorfer, 2006). The blacktip, dusky, scalloped hammerhead and tiger shark (*Galeocerdo cuvier*) were the species most frequently recorded by fishers during the 2003 KZNSB pilot study of ski-boat fishing and shark activity. It was reported that the dusky and scalloped hammerhead sharks observed were juveniles and not thought to be responsible for extensive fish loss. The species most identified with fish loss was the blacktip shark (Dudley, 2003).

Sharks have a spiral intestine that is thought to govern their food consumption into short feeding bouts followed by longer periods of digestion (Wehterbee et al., 2010). Although the diets of sharks are generalised, the major prey consumed by elasmobranches is teleost fish (Bass et al., 1973; Cliff & Dudley, 1992; Dudley & Cliff, 1993b). Accurate descriptions of shark's prey are complicated by a change in feeding habit as sharks mature and move through the ocean (Wehterbee et al., 2010). The diet of blacktip, dusky and scalloped hammerhead sharks caught in the protective gillnets off the coast of KZN is also dominated by teleost fish (Bass et al., 1973; Dudley & Cliff, 1993b; de Bruyn et al., 2005; Dudley et al., 2005).

Analysis of the stomach contents of blacktips caught in the KZNSB protective gillnets over a 14-year period found teleosts in 82.7% of the stomachs that contained food constituting 73.2% by mass and 91.9% by number. African horse mackerel (*Trachurus delagoa*) and sardine (*Sardinops sagax*) were found in the largest proportion of blacktip shark's stomachs. Piggy (*Pomadasys olivacenum*), cuttlefish (*Sepia* spp.) and small, unidentified sharks were the next most abundant species of fish that could be identified. In dusky sharks, sardine, chub mackerel (*Scomber japonicus*) and spotted grunter (*Pomadasys commersonni*) contributed the largest proportion to the stomach contents. Smaller amounts of other elasmobranch and teleost species were also identified, along with cetaceans, molluscs and crustaceans (Dudley & Cliff, 1993b).

There is a certain degree of overlap between fish found in the stomach contents of blacktip sharks and the top five shore-based and commercial offshore boat-based linefish species (by number) caught in KZN (Dudley & Cliff, 1993b; Dunlop & Mann, 2012a; Dunlop & Mann, 2012b, Dunlop & Mann, 2013). Strepie (*Sarpa salpa*), the most abundant species landed in the shore-based fishery, blacktail (*Diplodus capensis*), piggy and stumpnose (*Rhabdosargus* spp.) were all found in the stomachs of the blacktip sharks' caught in protective gillnets between 1983 and 1991 (Dudley & Cliff, 1993b; Dunlop & Mann, 2012a; Dunlop & Mann, 2012b). Species landed in the commercial offshore boat based fishery that were found in the blacktip's stomachs caught in protective gillnets between 1978 and 1982, include santer (*Cheimerius nufar*), slinger and Englishman. (Dudley & Cliff, 1993b; Dunlop & Mann, 2012a; Dunlop & Mann, 2012b).
Teleost fish dominate the diet of other shark species found in the area. The same linefish species that were found in the stomachs of blacktips and caught in shore and commercial offshore boat-based catches of KZN, were also found in the stomach contents of duskys caught in the KZNSB protective gillnets between 1983 and 1999 (Dudley et al., 2005). Slinger, strepie, piggy and stumpnose were also found in the stomachs of scalloped hammerhead sharks caught in the KZNSB protective gillnets, along with blue hottentot (*Pachymetopon aeneum*), a species reported as one of the top five most commonly caught linefish in the KZN commercial offshore boat-based fishery (de Bruyn et al., 2005).

The figures suggest that fishers and the sharks species recorded during the 2003 KZNSB pilot study of ski-boat fishing and shark activity, compete for the same linefish, particularly in the shore-based fishery. Fishing bait was also identified in the stomach contents of 0.5% of the blacktips studied and in the stomachs of 3.3% of small duskys but only 0.2% of intermediate sized duskys. Fishing bait was also found in 0.1% of the stomach contents of scalloped hammerheads suggesting a degree of interaction between fishers and the three shark species.

Competition for the same depleted linefish stocks could be one explanation for the suspected increase in shark depredation incidents along the coast of KZN but data from the protective gillnets reports a significant decrease in catch and CPUE for blacktips and scalloped hammerheads suggesting these stocks have also been depleted (Dudley & Cliff, 1993b; Dudley, 2002; de Bruyn et al., 2005; Dudley et al., 2005). However, in the case of blacktips, as there was no decrease in size of sharks caught, it is thought the decrease in catch may not be biologically significant. Stock depletion may be localised to areas where the nets are deployed (Dudley & Cliff, 1993b; Dudley, 2002). Although most of the scalloped hammerheads caught in the protective gillnets were juveniles, an increase in length of individuals was also reported (Dudley, 2002; de Bruyn et al., 2005). The decline in scalloped hammerheads however, is thought to be related to the decline of the species globally (Dudley, 2002; de Bruyn et al., 2005; Baum & Blanchard, 2010). The scalloped hammerhead has been listed by the International Union for Conservation of Nature (IUCN) as endangered and restrictions in trading are expected to take force in 2014 under Appendix II of the Convention on International Trade in Endangered Species (CITES) (Baum et al., 2007; CITES, 2013).

There was an increase in catch and CPUE in one shark species recorded by fishers during the 2003 KZNSB pilot study of ski-boat fishing and shark activity; the tiger shark. Although this would suggest an increase in abundance, the trend is not statistically significant (Dudley, 2003; Dudley & Simpfendorfer, 2006).

1.8 Shark Behaviour and Adaptations

Along the coast of KZN, a combination of increasing shark depredation and decreasing CPUE of blacktip sharks could be explained by a degree of site fidelity or philopatry (Hueter, 1998; Hueter et al., 2005; Heithaus & Vaudo, 2012). Unlike non-returning roaming behaviour, philopatry is the tendency of an individual to either remain in, or travel back to, a particular geographic location. The number of blacktips staying in or returning to areas protected by gillnets, may have been depleted while other blacktips with different home ranges are untouched.

The principle of philopatry has been well studied in migratory birds, some terrestrial mammals as well as a number of fish species. There is a growing body of evidence to suggest 'homing' exists in some elasmobranch species. Tagging studies of great white sharks (*Carcharodon carcharias*) blacknose sharks (C*harcarhinus acronotus*) and blacktip sharks have all identified a degree of philopatry with these species (Pardini et al., 2001; Keeney et al., 2003; Bonfil et al., 2005; Hueter et al., 2005; Jorgensen et al., 2010). Hueter et al. (2005) reported that blacktips tagged along the Florida Gulf coast in May, June and July were recaptured in the same months for three consecutive years but typically found in feeding grounds over 100 nautical miles away during winter months. This suggests philopatric behaviour for natal nursing grounds in blacktips on an annual cycle. It is however unlikely philopatry alone can explain why some areas along the KZN coast have reported higher rates of depredation than others (Dudley, 2003).

Sharks have the ability to learn about their environment and adjust their behaviour accordingly with both classical and operant conditioning reported in different shark species (Guttridge et al., 2009). Studies of lemon sharks (*Negaprion brevirostris*) have reported a conditional response of the nictitating membrane to light flashes (Gruber & Schneiderman, 1975); free swimming sharks have exhibited either attractant or avoidance behaviour in response to differing sound stimuli depending on whether they were being rewarded with food or given an electrical shock (Nelson, 1967). Lemon sharks were also trained to bump an underwater target upon hearing a sound stimulus to receive a food reward (Clark, 1959). Similar conditioning responses have been reported in juvenile nurse shark (*Ginglymostoma cirratum*) studies (Aronson et al., 1967). Nelson and Johnson (1972) reported a decline in responsiveness to sound stimulus where habituation became apparent in sharks studied in field experiments.

With several studies reporting both classical and operant conditioning in shark species, it is likely sharks can learn to associate the sound of fishing boats with easy acquisition of prey when interacting with commercial and recreational fishers. Both positive and negative interactions have been reported between other fish species and fishing gear. Both cod (*Gadus morhua*) and rainbow trout

(*Oncorhynchus mykiss*) were found to treat baited hooks more carefully in aversion experiments however, white-spotted char (*Salvelinus leucomaenis*) were more likely to be captured having been previously hooked (Guttridge et al., 2009). It has been suggested localised shark populations may exhibit behavioural adaptations relating the sound of outboard engines to an easy meal (Wetherbee et al., 2010; Heithaus & Vaudo, 2012). An association between sharks with boats and shore anglers was observed in the Breede River, South Africa in a study of a tagged Zambezi (*Charcarhinus leucas*) shark. It was noted that the shark spent the majority of its time 11-13km upstream, near boats and around fishing activity. It was reported that the shark was swimming between three vessels that were fishing for grunter and kob before it was then observed swimming to a boat that had weighed anchor. The Zambezi was then observed following the boat as it trolled downstream (McCord & Lamberth, 2009).

1.9 Sharks of Protea Banks

The reasons behind sharks predating on fishers catches are complex and may well be related to fishing pressure on natural prey, behavioural adaptations or other anthropological factors but whatever the reasons, shark depredation is reported as an increasing problem by fishers along the coast of KZN. The pilot study conducted by the KZNSB found that there was a significant difference in the number of fish lost during fishing trips to sharks between launch sites with the highest rate recorded at Shelly Beach (76%) (Dudley, 2003)

Shark depredation has caused significant conflict between different stakeholders, especially at Shelly Beach where there is an extensive fishing and diving community. In response to user conflict, and also as a measure to protect the reef system for future generations, the Shelly Beach Ski Boat Club devised a voluntary agreement for all users of the Sonny Evans Small Craft Harbour imposing certain restrictions on activity in the area. These include an area of 18.1km^2 closed to all fishing between 1st August and 30th November where bait/reef fishing or chumming is prohibited year round. The guidelines also state that sharks that are caught should be returned to the sea unless they are intended for consumption (Shelly Beach Ski Boat Club, 2011). In addition, all boats are required to record their time of arrival, days catch and number of fish lost to sharks in the launch register at the end of each day. However, as this is a gentleman's agreement, there is no enforcement mechanism or penalty for users who fail to adhere to the restrictions. Fishers, who fish within the restricted area and those that catch sharks and discard their carcasses at sea are in violation of the guidelines issued by the Ski-boat club, as are dive operators who use bait and chum within the restricted zone.

The high site usage at Shelly Beach could be playing a role in the rate of depredation. With continued exposure and conditioning to fishing and diving activity it is quite possible that sharks have adapted their behaviour to acquire an easy meal (Guttridge et al., 2009; Heithaus & Vaudo, 2012). Both fishers and dive operators have observed that sharks in the area of Protea Banks appear to be attracted to the sound of the outboard motors. Although there have been no studies to confirm this, anecdotal evidence from the other fishing sectors where depredation is a problem have reported similar findings (Gilman et al., 2006). The suspicion is that the apex predators now relate an auditory stimulus to a source of prey that requires less energy expenditure to stalk and capture compared to their usual food source (Nelson, 1967; McCord & Lamberth, 2009; Heithaus & Vaudo, 2012).

Divers frequently observe sharks with fishing hooks attached to the side of their mouths or in their gills as well as trace wrapped around their bodies. Due to the nature of baited diving where 'chum', a mixture consisting mainly of sardine and tuna, is used to attract sharks, the prolonged interactions in close diver proximity have allowed individual sharks to be identified with two, sometimes three hooks, usually at the corners of the mouth.

1.10 Socio-economic Impacts of Shark Depredation

The impact of losing fish to sharks is more than an annoyance for fishers and has a financial impact. Commercial fishermen face reduced sales revenue when target species are lost to sharks and suffer financially through the loss of fishing gear including lures, hooks and trace. Charter and recreational fishers are prohibited from selling their catch so their direct financial losses are restricted to the cost of lost fishing gear.

The attitude to shark depredation also varies within and between the different user-groups. It is the differing opinions between mainly fishers and divers that have led to a degree of user conflict, especially when fishers land sharks that dive operators rely on to attract the tourists and maintain their livelihoods (Aylward, 2013). Sharks have a negative impact on commercial, charter and recreational fishing whereas shark sightings and interactions are the basis of the revenue stream for dive operators (Dicken & Hosking, 2009; Tomassen, 2013).

1.11 Rationale

Sharks stealing fish from fisher's lines is a complex problem that will require extensive studies in ecosystem balance, shark behaviour and fishing pressure to unravel. However, this pilot study will provide a snapshot of shark depredation rates for line-caught fish on the Protea Banks. This will allow an initial exploration of the impact shark depredation has on the data that are used when making management decisions in the South African line-fishery. The study will estimate a rate of depredation based on how many hooked fish are lost to sharks using onboard observer data. In addition to quantifying a rate of depredation, the study will investigate the hypothesis that there is a significant difference in the depredation rate between fishing tactics used when catching pelagic species and fishing tactics used when catching reef species. Using additional commercial and charter NMLS data, the study also aims to identify any significant overlap in the species landed in the commercial and charter fishing sectors to gain a clearer picture of the effects of shark depredation in the KZN linefishery.

Chapter 2 – Shark Depredation on Protea Banks

2.1 Introduction

Depredation is a common, extensively researched global problem within the fishery sector. It is defined as the partial or complete removal of hooked fish, from a line, by a predator. Interactions with sharks and cetaceans pose problems for fisheries that have resulted in substantial economic impacts through damage or loss of target species and fishing gear, a reduced catch of marketable species and expenditure of time (Meÿer et al., 1992; Gilman et al., 2006; Gilman et al., 2007; Rabearisoa et al., 2012). The majority of research in South Africa has concentrated on the pelagic longline fishery however, depredation is not a new phenomenon (Gilman et al., 2007). As far back at the early 1900s, sharks were documented predating on the whale carcasses being towed back into the Durban Harbour (Mara, 1986). More recent studies investigating conflict between the Cape fur seal (*Arctocephalus pusillus pusillus*) and linefishing operations in the Western Cape identified depredation as a concern, costing between 3.3-7% of the annual landed value of the catch (Meÿer et al., 1992; Wickens, 1996). There is growing concern that interactions between predators and fishing activity may have a widespread ecological impact and may change foraging behavior, increase effort and have an impact on stock assessments, particularly within the South African linefishery (Gilman et al., 2006; Gilman et al., 2007; MacNeil et al., 2009).

The multi-species, multi-user South African linefishery consists of over 200 demersal and pelagic species (Penney et al., 1999; Griffiths & Lamberth, 2002; DEA, 2005; Pradervand & van der Elst, 2008) and depredation within this sector has been reported as a problem that has been increasing for the past decade (Dudley, 2003; Carnie, 2007; Dudley & Cliff, 2012; Grant, 2012; Tomassen, 2013). The fishery has a long history dating back to 16th century. Linefishing was already a thriving industry but after the Second World War, the construction of small boat harbours, the introduction of motorized vessels and availability of new technology saw fishing effort and catches increase considerably. The increase in effort placed increasing pressure on linefish stocks with decreasing catch trends in the latter half of the 20th century (Penney et al., 1999; DEA, 2005).

The collapse of several important linefish species highlighted the need for stock rebuilding. In 1985 the Linefish Management Protocol (LMP) was developed to monitor, assess and revise management regulations for important linefish species (Griffiths, Attwood & Thomson, 1999). Despite the implementation of control measures introduced in the LMP, the situation regarding linefish stocks continued to worsen and in 2000 the Minister of Environmental Affairs and Tourism to declared fish stocks in a State of Emergency prompting a raft of new management measures (Attwood et al., 2013). These included a moratorium on fishing certain species, a reduction in the commercial sector total allowable effort by 70% (TAE) and the declaration of new Marine Protected Areas (MPAs). Further to size limits, bag limits and closed seasons imposed on the recreational sector, a licensing system was also introduced in 2001 (DEA, 2005; Pradervand & van der Elst, 2008; DAFF, 2010; Mann, 2013b). There is empirical evidence that some of those measures have been successful in improving linefish stocks.

The creation of the Goukamma MPA in 1990 has provided a refuge for Roman (*Chrysoblephus laticeps*) and the adjacent fishery now benefits from an increase in CPUE (Kerwath et al., 2013). The reduction in commercial fishing effort has allowed some species to recover and production modeling has shown a ~30% recovery in biomass of slinger (*Chrysoblephus puniceus*) (Winker et al., 2012; Mann, 2013a).

Effective monitoring of the linefishery has proved problematic with annual, individual species assessments unworkable. Of the 139 South African marine linefish species studied in the 2013 assessment, the stock status of 60% of them was unknown. Of the few species that were assessed, 20% were considered overexploited or collapsed (Mann, 2013b).

With a lack of species specific data, management decisions rely heavily on catch records logged in the National Marine Linefish System (NMLS) (Bennett et al., 2009; Goetz et al., 2011; DAFF, 2012; Winker et al., 2013). Commercial fishers have been required to submit their catch data to the NMLS since 1985 and a network of boat and shore inspectors also capture information from the recreational sector which are incorporated in the NMLS database (Dunlop & Mann, 2012b; Winker et al., 2012; Dunlop & Mann, 2013; Winker et al., 2013).

Management of South Africa's multi-species linefish relies heavily on the accuracy of catch and effort data but the multi-user dimension of the fishery adds additional complexity when it comes to making accurate stock assessments (Pradervand & van der Elst, 2008).

The South African Marine Living Resources Act of 1998 recognises three user-groups; commercial, recreational and subsistence but there is no official recognition for the ever more popular charter boat industry. Charter fishing is a linefishing activity where recreational anglers pay a fee to fish from a vessel but there is no formal management regime in place and no statutory obligation to submit catch records (Pradervand & van der Elst, 2008). Charter fishing effort is a particular issue along the coast of KwaZulu-Natal (KZN) where, in addition to the 3,331 commercial launches in 2009, there were over 30,000 recreational and close to 6,000 charter boat launches (Dunlop & Mann, 2013). In KZN there is a system of recreational boat inspections conducted by Ezemvelo KZN Wildlife (EKZNW) and recorded data are also logged in the NMLS however, not all vessels are inspected.

NMLS data have been heavily criticised for being inaccurate. Under-reporting of catches, non-reporting of unimportant by-catch species and a complete failure to submit returns were just some of the issues identified when comparing submitted catch data and scientific observer data. Under reporting of some commercial target species has been estimated between 2 to 4 times the actual catch (Sauer et al., 1997; Penney et al., 1999; Dunlop & Mann, 2013). In addition, the NMLS data are not a true reflection of fish mortality.

Catch per unit effort (CPUE) data are based on fish landed and fail to take into account fish that are caught and released or those predated from the line by sharks (Pradervand & van der Elst, 2008; Dunlop & Mann, 2013). The mortality rate of fish that are caught then released was found to be between 1.3% and

24.5% and highly species specific (Goetz et al., 2011; Kerwath et al., 2013). The rate of fish mortality in the South African linefishery due to depredation has not been quantified but has been reported by fishers in KZN at between 50 and 80%.

A pilot study by the KwaZulu-Natal Sharks Board (KZNSB) found that the number of fishing trips where fish were lost to sharks was significantly different between different launch sites along the coast. The highest rate (76%) was reported at Shelly Beach where boats fish the inshore and offshore waters surrounding the Protea Banks (Dudley, 2003). Fishermen exploiting the resources of the Protea Banks, a fossilsed dune reef lying 8km of the coast, have reported that shark depredation is a problem and they regularly lose more than half their catch to depredation events. Depredation rates even approaching that figure would have serious implications for line fishery management.

Here, we look at the shark depredation rate within charter boat sector for vessels launching from Shelly Beach and fishing the inshore and offshore waters surrounding the Protea Banks. The shark depredation rate between target species (pelagic and reef) is explored spatially. Furthermore, the overlap in species composition between catches in the commercial, charter and recreational fisheries was investigated.

2.2 Materials and Methods

2.2.1 Study Area

Along the narrow continental shelf of the 564km of KwaZulu-Natal coastline there is a network of scattered reefs, roughly following the 50m isobath contour (Penney et al., 1999). The Protea Banks, a series of submerged, fossilised sand dunes, is one of the most southerly of the KZN reefs lying 8km offshore of Shelly Beach, within a voluntary protected area (*Figure 2.1*). The area surrounding Protea Banks is a heavily exploited, multi-user and multi-species line fishery.

Figure 2.1 – Map of the study area from Port Shepstone to Southbroom, KwaZulu-Natal extending 15km offshore with points A1 (S 30°48’34”, E30°29’02”), A2 (S30°49’17”, E30°30’45”), A3 (S30°51’56”, E30°29’07”) and A4 (S30°51’14”, E30°27’27”) marking a voluntary protected area (red zone) surrounding the Protea Banks submerged reef system (Google Earth Pro v7.2.1.2041, 2013a).

In addition to its popularity among fishers, the Banks are a popular location for recreational scuba divers and spearfishers.
The Protea Banks are approximately 25m at the shallowest depth extending down to 60m and have been highlighted as important area for biodiversity protection with submarine canyons, deep reefs and cold-water corals all identified as under-protected in the bioregion (Sink et al., 2011). Vessels accessing the Protea Banks, and the surrounding inshore and offshore waters, launch from the Sonny Evans Small Craft Harbour, Shelly Beach, where an informal user agreement has been put in place in an attempt to protect the area from fishing pressure and from damage through diving activities.

The voluntary agreement sets out an area of 18.1km^2 where restrictions are in place that include no bottom or bait fishing within the marked zone at any time of year. Chumming is also prohibited in the red zone, year round, and applies not only to fishing but baited diving activity. During the closed season, between 1st August and 30th November, no fishing is permitted in the marked area defined by the points A1 (S 30°48’34”, E30°29’02”), A2 (S30°49’17”, E30°30’45”), A3 (S30°51’56”, E30°29’07”) and A4 (S30°51’14”, E30°27’27”) (Figure 2.1). The user guidelines are no more than a gentleman’s agreement and with no power of enforcement and the recommendations laid down, are frequently violated by fishers and divers.

The study area was divided into two, inshore and offshore. A further subdivision was made in the offshore area defined by the boundaries of the voluntary protected red zone designated by the Shelly Beach Ski Boat Club. The boundary between the inshore and offshore areas was defined by an extension of the westerly limit of the red zone to the north and south (Figure 2.2).

Figure 2.2 – Map of fishing grounds for boats launching from Sonny Evans Small Craft Harbour, Shelly Beach divided into areas; inshore, offshore and voluntary protected red zone. Red zone defined by markers A1 (S 30°48'34", E30°29'02"), A2 (S30°49'17", E30°30'45"), A3 (S30°51'56", E30°29'07") and A4 (S30°51'14", E30°27'27") (Google Earth Pro v7.2.1.2041, 2013b).

2.2.2 Survey Methods

Quantative data were collected from November 2013 to January 2014. Data were recorded for boat, launch and fishing trials by an independent observer onboard charter fishing vessels launching from the Sonny Evans Small Craft Harbour, Shelly Beach.

On each trip the type of boat, the name, length, registration number, engine size and manufacturer were recorded. For each launch, the date, departure and return time and number of anglers onboard were logged. The fish finder on board the charter vessel was used to record the sea surface temperature and make an estimate of surface current.

2.2.3 Fishing Methods

Charter fishing typically takes place on twin-engine, twin hull (one vessel that took part in the study was a tri hull), ski-boats where customers pay a fee of an average of R600 to fish recreationally but prices vary between R550 - R1450. Individual catch limits are set through closed seasons, daily bag limits and size restrictions. Smaller (<6 m) vessels carry anywhere between one and four charter customers and typically fish for pelagic species. Larger vessels (>6 m) are licensed to carry up to 11 charter customers and generally combine a mix of pelagic and reef fishing. Irrespective of the numbers of anglers on board, the boats troll between 4 to 8 lines when catching pelagic species and effort remains relatively constant. Trolling with a lure was the most popular fishing tactic for catching pelagic species although casting with a lure and drifting with baited hooks were also employed. Effort varied when catching reef species and depended on the number of anglers on board. Lines had between two and four hooks baited with squid and sardine. Live bait and wire trace were used when catching sharks.

2.2.4 Fishing Outcomes

For each fish hooked, the location was recorded on a handheld GPS and one of three possible outcomes (captured, lost or shark) and logged as an individual trial. Where fish were captured they were identified to species level and the pre-caudal length recorded to the nearest 5cm. Fish were deemed to have been lost through either ineffective placement of the hook (hook pull) so the fish came free from the line, where the fishing line parted or where sharks took the bait and fishing tackle. The first sign of a depredation event was a noticeable change in activity on the fishing line. The rod would visibly bow and fishers reported they could no longer feel the fish running but a "dead weight". On occasion partial fish remains were brought onboard and this was logged as a depredation event, even if the damage was minor. Where the whole fish was taken from the line, along with the terminal tackle, the remaining trace was inspected for roughness attributed to rubbing against the shark's skin and this was used as a key indicator the fish had been predated by sharks.

Other predators known to be involved in depredation include cetaceans, pinnipeds and large predatory fish. In most cases, the damage to the catch and to the fishing gear gives a good indication of which species was involved in depredation. Some cetacean species are highly selective, preferentially eating flesh and leaving the head and gills whereas sharks tend to take clean bites (Gilman et al., 2006). In the waters surrounding Protea Banks other species known to take hooked fish are potato bass (*Epinephelus tukula*) and game fish, such as king mackerel (*Scomberomorus cavalla*). Predation by potato bass was logged if macerated fish remains were left on the end of the lure or bait. Predation by king mackerel, or other large game fish, was logged when the fish was lost but line showed no roughness and had been cleanly severed.

For each shark depredation, the time of the event was recorded and where possible, a visual identification of the species made. Distinguishing between different *Carcharhinus* species can be a challenge as many of their physical features are quite similar. However, the independent observer had extensive experience identifying sharks on Protea Banks. Where the shark was seen from the boat it was identified to species level. Where possible, the observer used an underwater video camera attached to a 3m pole to film depredation events and identify the shark from the footage at a later date. The observer also made a visual count of any sharks seen around the boat during fishing activity and made a note of any seabirds in the vicinity of fishing activity.

2.2.5 Catch Data

Since 1985 it has been compulsory for commercial skippers to report their daily catch, to be logged on the NMLS database. Historic data have been criticised for non-reporting of unimportant species and under-reporting of commercially important species. Comparing reported commercial catch returns with scientific observer data, Sauer *et al.* (1997) estimated that the average national catch exceeded the reported catch by a ratio of 2.87 (±0.94). However, more recent data logged on the NMLS are thought to provide reliable estimates of species composition, seasonal and inter-annual catch trend as well as geographic and sector specific catch distribution patterns (Penney et al., 1999).

2.2.5.1 Commercial NMLS Data

Commercial catch and effort data for the period 2003 to 2011 were extracted from the NMLS database for fishing grounds extending 15km offshore between Port Shepstone (30^{0}43’16”) and Southbroom (30^{0}56’05”) encompassing an overall area of approximately 400km^2. Data extracted comprises the date, fishing location, compulsory commercial catch returns (kg) per species, vessel number, crew and number of hours fishing.

Not all data were included in analyses. Catch (kg) reported as 'fish', 'red fish' and 'bottom fish' were excluded, however, these made up less than 0.01% of the total catch (332840kg). As commercial catch data logged in the NMLS is often not recorded at species level and identification between species can be difficult resulting in incorrect reporting, catches of some individual species were incorporated into general categories for the purposes of data analyses (Appendix A). Rockcods and sea bass, stumpnose, sharks and tuna all contained catch records for multiple individual species. The incorporation of individual species into grouped categories also allows data to be compared to recreational catch data logged in the NMLS.

2.2.5.2 Recreational (including charter) NMLS Data

NMLS recreational data are sourced through voluntary returns cards completed by recreational anglers, tournament records from angling organisations, shore patrols and roving creel surveys. Since 2000, boat based fishing data have been recorded by trained EKZNW inspectors during access point surveys (APS) at popular launch sites along the KZN coast. Vessel ID, number of anglers, fishing license numbers are recorded with the number and weight of fish captured per species. Recreational catch data from the Sonny Evans Small Craft Harbour for the period 2003 to 2011 were extracted from the NMLS recreational database. Data comprises the month, launch site and access point inspection catch returns (number) per species. Not all of the recreational launches are inspected and the data represent approximately 47% of the number of launches undertake so catch composition was altered accordingly.

Records of weight are thought to be poorly estimated and incomplete, so for the purpose of this study catch composition by number was used. To allow a direct comparison with commercial NMLS catch (kg), the recreational NMLS catch returns (number) were converted to kilograms (Appendix B). Catches of some individual species were incorporated into general categories for the purposes of data analyses (Appendix A). Barracuda, emperor, galjoen, kingfish, kob, rockcods and sea bass, stumpnose, sharks, tuna and yellowtail all contained catch records for multiple individual species.

2.2.5.3 Observer Recorded Data

The number of fish hooked and brought onboard was recorded by number and logged in species level for each vessel launch. Data were arranged into categories defined for commercial and recreational catches logged in NMLS database. Two additional categories, BGEY - 'big eye' (*Priacanthidae*) and BRMO 'other bream' (*Sparidae*), were devised for the purpose of this study to incorporate individual species that were not reported in either commercial or recreational catch records logged in NMLS.

To allow the onboard observer data to be compared to commercial and recreational NMLS catch returns, the number of fish landed (numbers) was converted to kilograms (Appendix B). Catches of some individual species were incorporated into general categories for the purposes of data analyses (Appendix A). Barracuda, emperor, galjoen, kingfish, kob, rockcods and sea bass, stumpnose, sharks, tuna and yellowtail all contained catch records for multiple individual species.

For the purpose of this study all captured fish were included in data analyses, including undersized fish and non-target species that were released as well as fish that had to be released as the daily bag limit had been reached.

2.2.6 Statistical Methods

2.2.6.1 Descriptive Statistics

Depredation rates were calculated at launch level ie. the *total* number of fish hooked during each launch were apportioned into the three categories; *captured, lost* and *shark*. The depredation rate per launch was therefore:

$$s_i/c_i = d_i, \qquad \text{Eq.1}$$

where c_i is the number of fish that were captured during launch i, s_i is the total number of fish lost to sharks during launch i, and d_i is the depredation rate during launch i.

Depredation rates were aggregated at the level of fishing tactic, across all launches, as follows:

$$s_t/c_t = d_t, \qquad \text{Eq.2}$$

where c_t is the number of fish that were captured while employing fishing tactic t, s_t is the total number of fish lost to sharks while employing fishing tactic t, and d_t is the depredation rate while employing fishing tactic t.

Depredation rates were aggregated by month, across all launches, as follows:

$$s_m/c_m = d_m, \qquad \text{Eq.3}$$

where c_m is the number of fish that were captured during month m, s_i is the total number of fish lost to sharks during month m, and d_m is the depredation rate during month m.

Depredation rates were aggregated at the level of fishing tactic, across each month, as follows:

$$s_{tm}/c_{tm} = d_{tm}, \qquad \text{Eq.4}$$

where c_{tm} is the number of fish that were captured while employing fishing tactic t during month m, s_{tm} is the total number of fish lost to sharks while employing fishing tactic t during month m, and d_{tm} is the depredation rate while employing fishing tactic t during month m.

The overall depredation rate was calculated by summing across all launches as follows:

$$\Sigma s_i/\Sigma c_i = \Sigma d_i, \qquad \text{Eq.5}$$

The species composition of the commercial catch expressed as biomass (kg) was calculated per vessel per month. This was done as follows:

$$\sum_i b_{isvm} = b_{svm}, \qquad \text{Eq.6}$$

where $\sum_i b_{isvm}$ is the commercial *biomass* (kg) of fish landed for each species s, by vessel v, during month m for launch i and b_{svm} is the commercial *biomass* for each species s, by vessel v, during month m.

The species composition of the observed catch expressed by number was calculated per vessel per month. This was done as follows:

$\sum_i n_{isvm} = n_{svm}$, Eq.7

where $\sum_i n_{isvm}$ is the observed number of fish landed for each species s, by vessel v, during month m for launch i and n_{svm} is the observed number for each species s, by vessel v, during month m.

The species composition of the recreational catch, expressed by number per month, was calculated across all vessels that were inspected.

To compare commercial catch measured as biomass with recreational and observed catch measured by number, recreational and observed catch were multiplied by a nominal average mass per species (Appendix B).

2.2.6.2 Inferential Statistics

The independence of the depredation rate among launches and also between fishing tactics was tested using the Pearson chi-squared goodness of fit test. Analyses of temporal and spatial factors were also tested with a Pearson chi-squared goodness of fit test.

Binomial theory was used to determine confidence intervals (95%) for the shark depredation rate among launches, between fishing tactics (pelagic and fishing) and spatially (Clopper & Pearson, 1934).

Similarity was tested between commercial NMLS, recreational NMLS and observed charter species biomass (kg) by boat per month (recreational NMLS data by month only). Data were analysed using non-metric multidimensional scaling (nMDS) to illustrate areas of similarity among the three fishing sectors. Data were standardised and then transformed using a square root transformation. MDS plots were generated from a resemblance matrix (S17 Bray Curtis similarity) for the biomass samples.

An ANOSIM pairwise comparison run over 999 permutations on the commercial, recreational and charter vessel catch records was used to test the null hypothesis that there is no difference between the different fishing sectors.

One-way SIMPER analysis (S17 Bray Curtis similarity) was used to determine similarity percentages of the species contributions within and between the sectors.

Principle Component Analysis (PCA) was used to test for a relationship between species composition and depredation rate within the onboard observer data. The data were standardised and transformed using a square root transformation and two vectors, PC1 and PC2, were generated. PC1 and PC2, which represent the majority of variation in the species composition among samples, were separately regressed against the depredation rate to test a significant relationship. Any significant relationship would imply the habitat selected by the fishermen or the fishing tactics employed were related to the depredation rate.

2.3 Results

2.3.1 Observed

A total of 16 fishing trips were undertaken during the onboard observer study from November 2013 to January 2014. All observations were carried out on charter boats launching from the Sonny Evans Small Craft Harbour, Shelly Beach and fishing the inshore and offshore waters surrounding the Protea Banks. The sampling effort over time was not uniform, with the highest number of launches recorded in December (n=7) and the least during November (n=4).

The observer data recorded the catch outcome of fish hooked by charter anglers. Trips that employed fishing tactics to catch pelagic species accounted for 31.2% of launches (n=5), the remaining 68.8% of trips (n=11) employed fishing tactics to catch both pelagic and reef species. The highest number of trials was recorded in December (n=355) and the least number of trials was recorded in January (n=105). Of the 599 trials, 44.6% targeted pelagic species (including sharks) and 55.4% targeted reef fish.

Fish were successfully captured in 61.6% of trials (n=469), taken by a shark in 7% of trials (n=43) and lost from the hook in 14.5% of trials (n=87). The fishing tactic employed varied depending on the target species. Results for each launch were separated into trials where fishing tactics were aimed at catching pelagic species (Figure 2.3a) and trials where fishing tactics were aimed at catching reef species (Figure 2.3b).

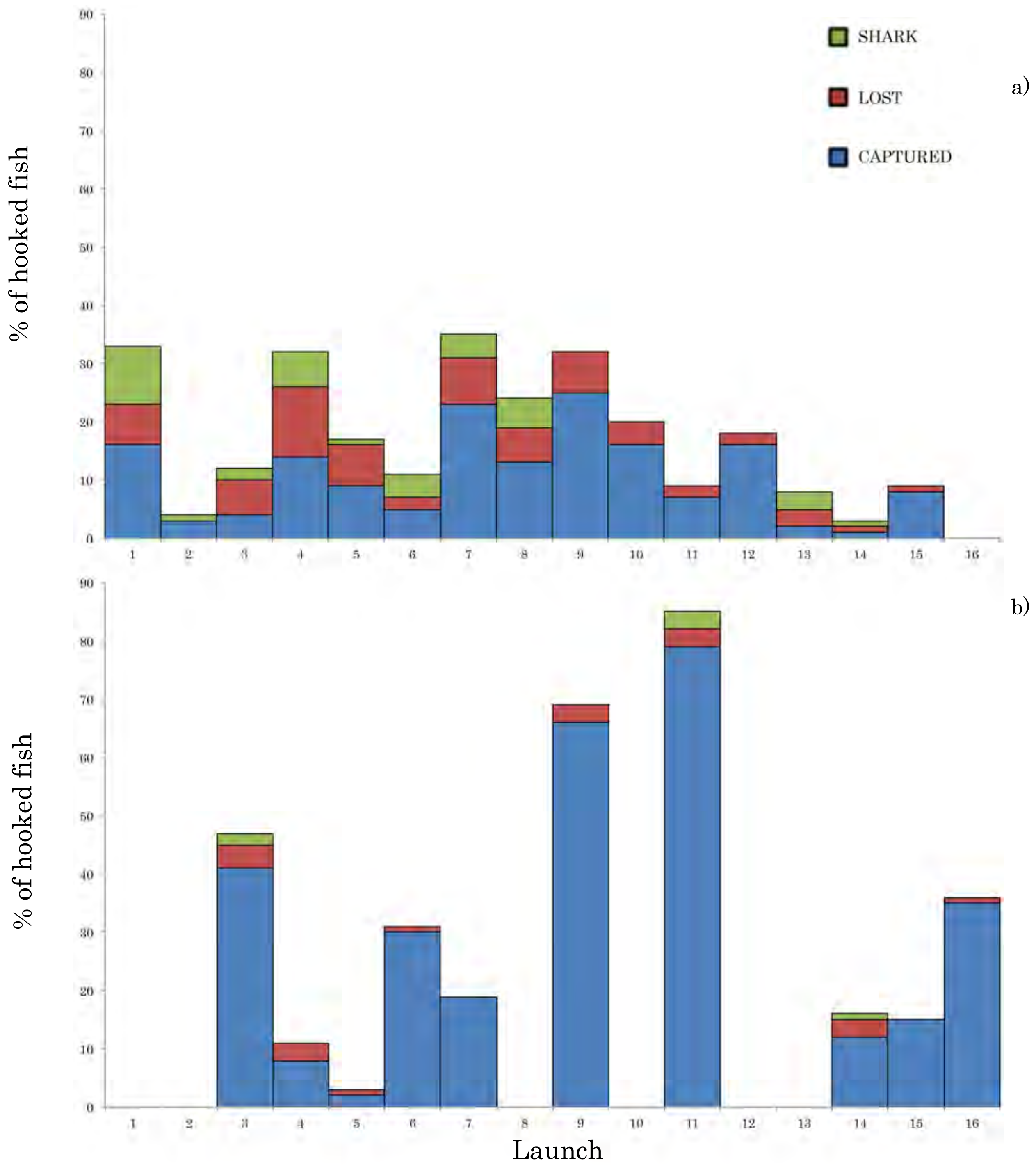


Figure 2.3 – Outcomes of trials recorded in the study area from November 2013 – January 2014 by launch for a) tactics to catch pelagic species and b) tactics to catch reef species.

Depredation events, where hooked fish were taken from the line by sharks, were recorded in 75% of all fishing trips (n=16). Data where the outcome was recorded as lost or where bait/fishing tackle was taken by sharks were excluded from depredation analyses as there was no impact on fish mortality.

The average rate of depredation across all launches was 14.1%. There was a significant difference (X^2=84.428, df=15, p<0.01) in depredation rate between launches with no depredation recorded in five of the fishing trips surveyed. The highest reported depredation rate was 60% recorded during launch 13 in January 2014 (Figure 2.4).

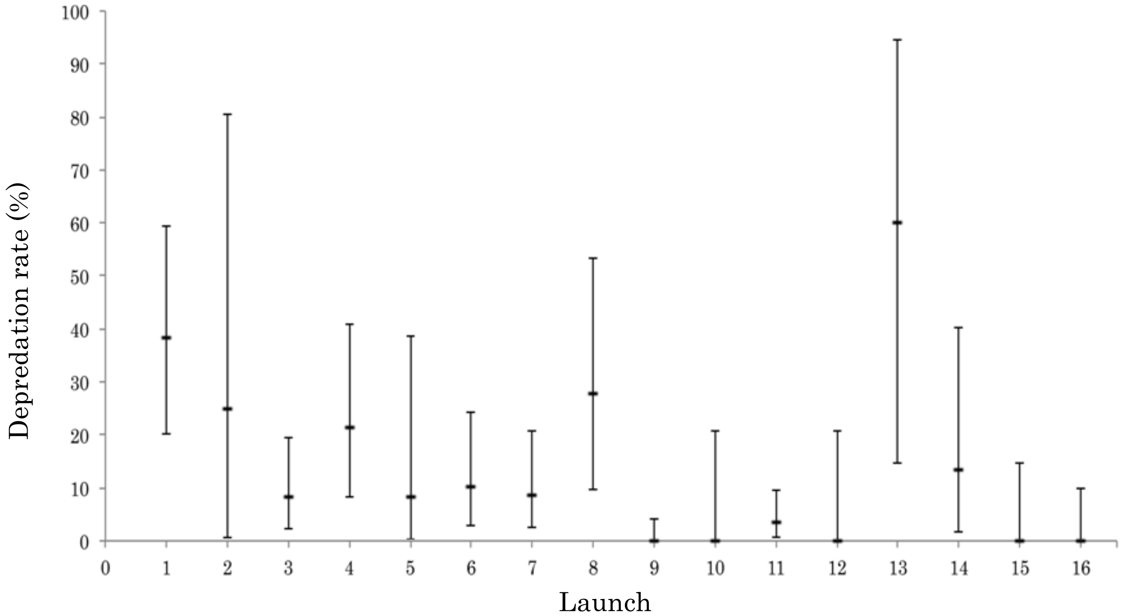


Figure 2.4 – Shark depredation rate for all species (pelagic and reef) by launch recorded in the study area from November 2013 – January 2014 with upper and lower confidence intervals (95%).

2.3.2 Temporal and Spatial Analysis

A significant difference (X^2=20.153, df=2, p<0.01) was found between the average depredation rate for each of the months surveyed. The highest average monthly depredation rate (19.6%) was reported in November and the lowest (5.3%) was reported in January (Figure 2.5).

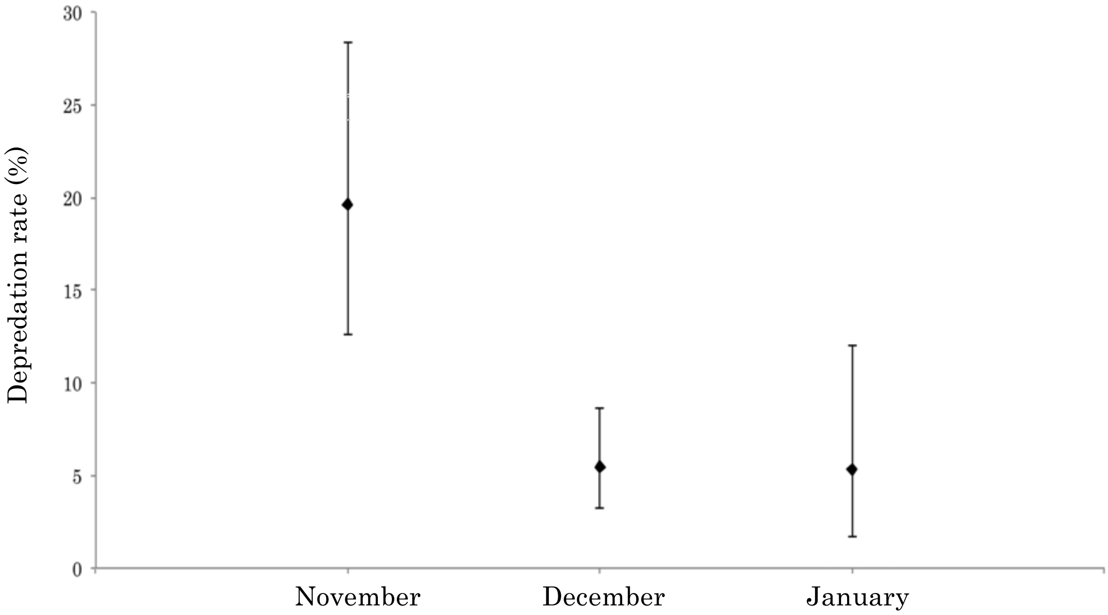


Figure 2.5 – Average shark depredation rate for all species (pelagic and reef) by launch recorded in the study area from November 2013 – January 2014 with upper and lower confidence intervals (95%).

Of the 512 trials where fish were captured or lost to sharks, 15.2% of all fish were captured or lost in inshore waters and 84.8% captured or lost in offshore waters. Of the fish captured or lost in the offshore waters (n=434), 69.3% were recorded within the red zone (voluntary protected area) (52.9% of the total number of fish captured or lost). Of the 43 recorded shark depredation incidents all took place in offshore waters. There was a significant difference between the inshore depredation rate (0%) and offshore depredation rate (9.9%) across all launches (X^2=9.231, p<0.01) (Figure 2.6).

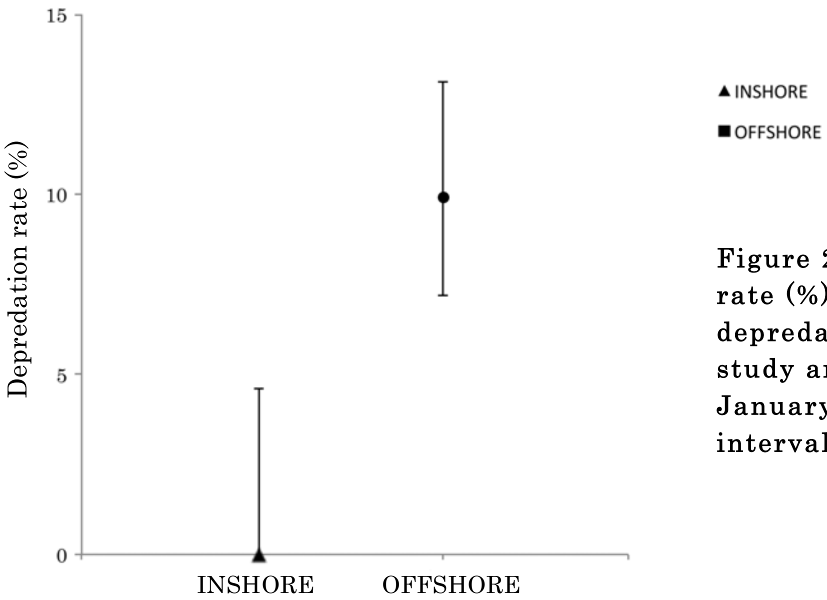


Figure 2.6 – Average depredation rate (%) inshore and average depredation rate offshore for the study area from November 2013 – January 2014 with confidence intervals (95%).

Fishing activity was separated by the tactic used to catch certain species; pelagic or reef. There was a significant difference (X^2=43.601, df=1, $p<0.01$) in the average shark depredation rate between fishing tactics used to catch pelagic and reef species (Figure 2.7). The average depredation rate for catching pelagic species was 18.6% and the average depredation rate when catching reef species was 1.9%.

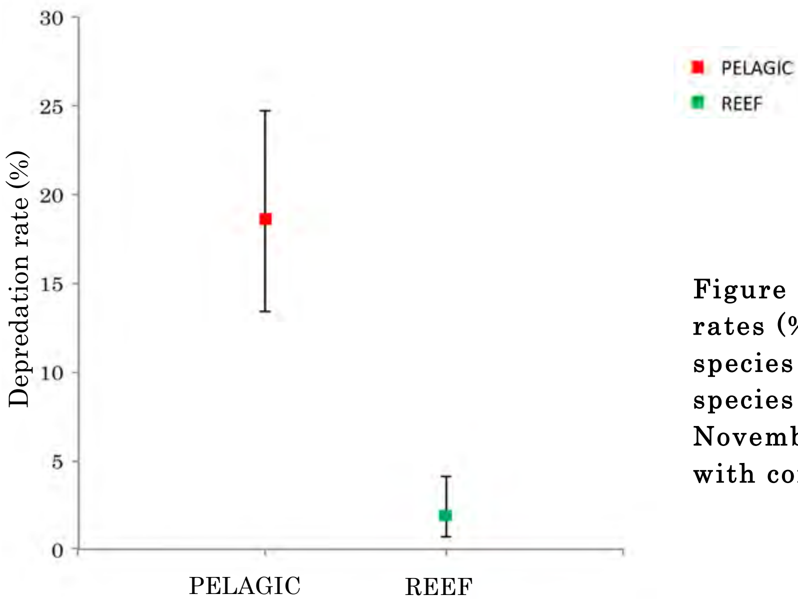


Figure 2.7 – Average depredation rates (%) when catching pelagic species and when catching reef species for the study area from November 2013 – January 2014 with confidence intervals (95%).

For each of the three months surveyed, there was a significant difference (X^2=11.109, df=2, p<0.01) in average monthly depredation rate when catching pelagic species (Figure 2.8). The highest average monthly depredation rate was reported in November (33.9%) and the lowest in December (12.5%). When catching reef species, the average monthly depredation rate was highest in November (3.9%) and lowest in December (1.5%) however, there was no significant difference (X^2=0.780, df=2 p>0.01) (Figure 2.8).

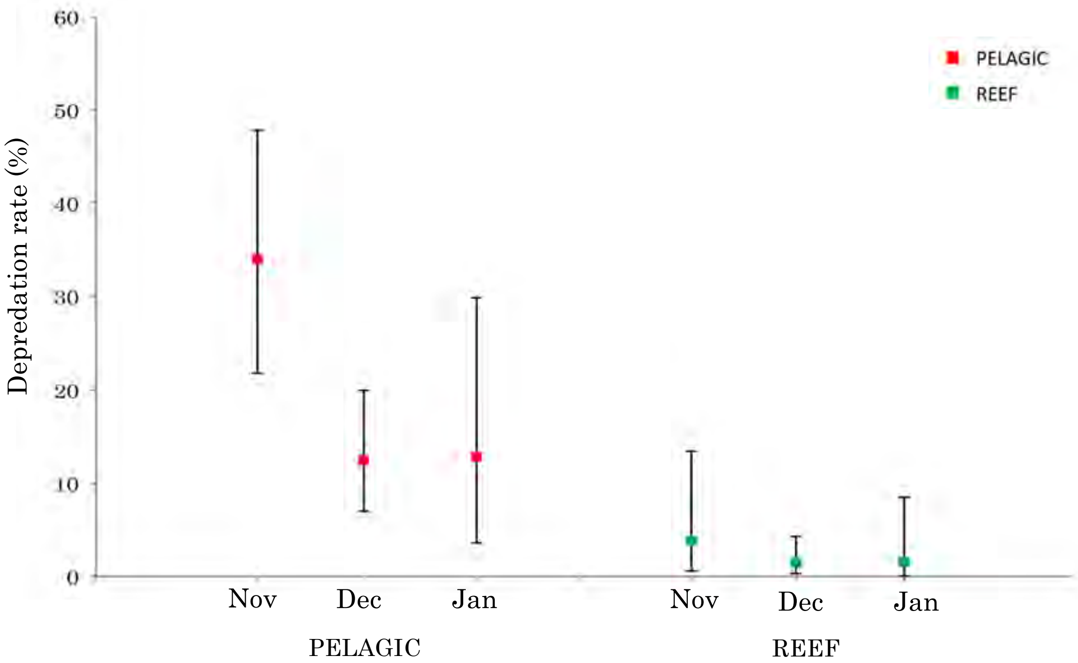


Figure 2.8 – Average monthly depredation rate when catching pelagic species and when catching reef species for trials conducted in the study area from November 2013 – January 2014 with confidence intervals (95%).

2.3.2.1 Catching Pelagic Species

Four pelagic fishing tactics were employed. Three of those tactics were directed at catching game fish such as tuna, dorado (*Coryphaena hippurus*) or king mackerel. Of the trials where fish were captured or depredated, trolling was the most common pelagic fishing tactic (87.7%) (Figure 2.9). Fishing using hook baited with sardine (drift) was recorded in 11.7% of trials where pelagic fish were captured or depredated. Casting a lure was the least common pelagic fishing tactic accounting for just 0.5% of captured or depredated fish. The fourth pelagic fishing tactic observed was directed at catching sharks and accounted for 3.1% of the outcomes recorded as either captured or depredated.

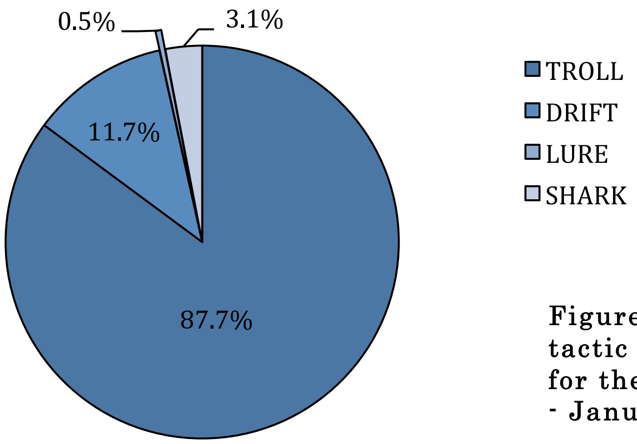
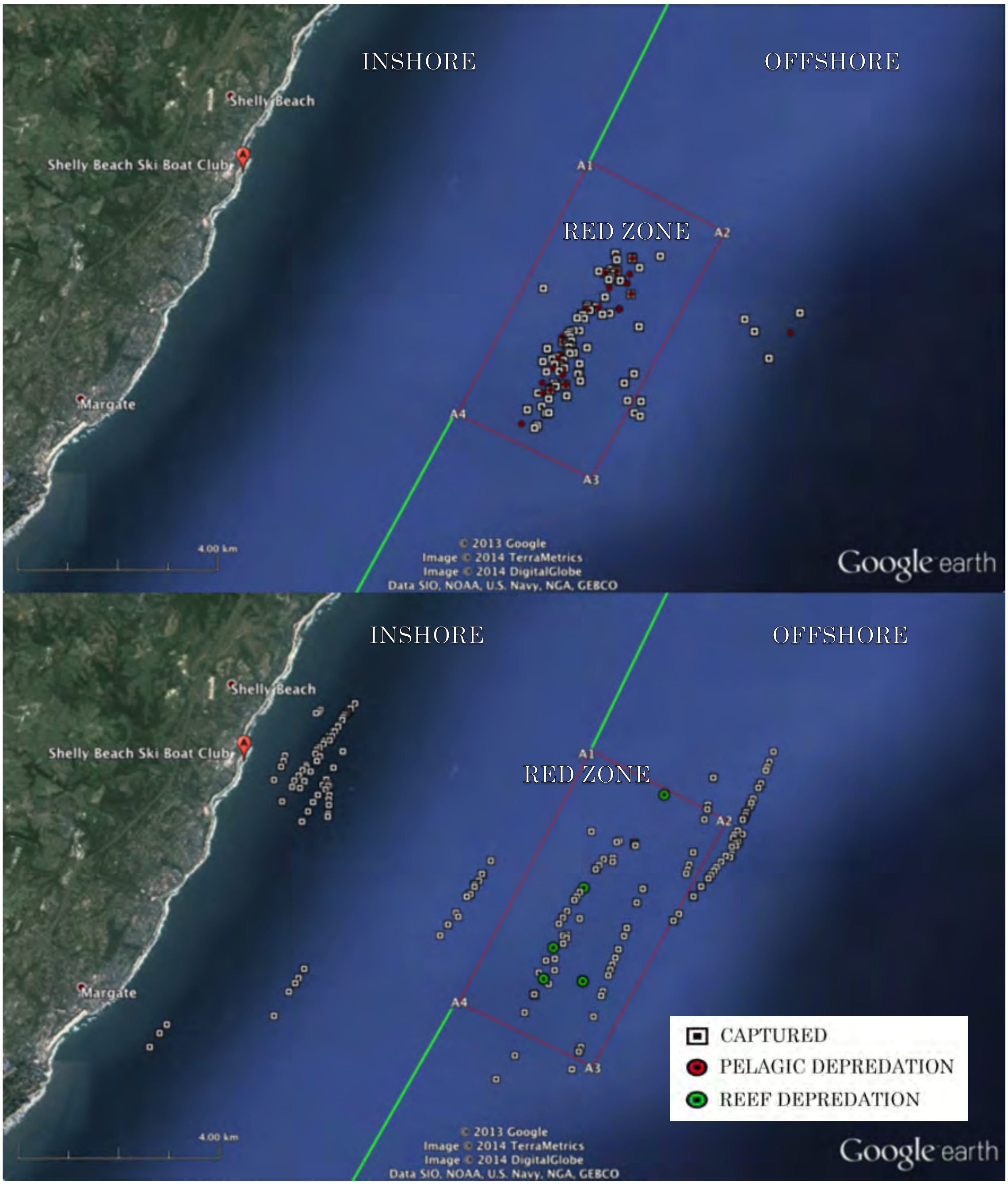


Figure 2.9 - Pelagic fishing trial by tactic (troll, drift, casting a lure, shark) for the study area from November 2013 - January 2014.

The rate of shark depredation differed among the four pelagic fishing tactics. Only one trial is available for casting a lure, and the fish was taken by a shark. The lowest rate of depredation (0%) was reported when catching shark species, but again, the sample size was very small (n=3). Sample sizes for fishing by casting a lure and shark fishing were too small to statistically test the difference in depredation rate among the four pelagic fishing tactics.

When catching pelagic species, all observations (Figure 2.10a) of captured fish or those lost to sharks were recorded in the offshore area (n=199). Of those observations, 94.0% were made within the voluntary protected red zone. Only one depredation event was recorded outside the red zone, the remaining 97.3% occurred within the red zone where the depredation rate was 19.3%. There was no significant difference (X^2=27.752, df=1, p>0.01) in depredation rate between the red zone and offshore areas when catching pelagic species.

a)



b)

Figure 2.10 – Map of a) pelagic and b) reef fishing trials divided by area; inshore, offshore and voluntary protected red zone. Red zone defined by markers A1 (S 30°48’34”, E30°29’02”), A2 (S30°49’17”, E30°30’45”), A3 (S30°51’56”, E30°29’07”) and A4 (S30°51’14”, E30°27’27”) (Google Earth Pro v 7.2.1.2041, 2013c; Google Earth Pro v7.2.1.2041, 2013d).

2.3.2.2 Catching Reef Species

Only one fishing tactic was employed to catch reef species. 24.9% of trials where fish were captured or lost to sharks (n=78) were recorded within the inshore area (Figure 2.10b). However, this figure comprised caught fish only as no shark depredation events were observed in the inshore area. Of the reef fish recorded as captured or lost to sharks in the offshore area (n=235), 35.7% fell within the red zone. There was no significant difference (X^2=13.706, df=1, p>0.01) between the rate of depredation inshore and offshore when fishing for reef species.

The depredation rate for trials recorded in the offshore area was 2.6% and rose to 7.1% for trials recorded inside the red zone. A significant difference in depredation rate between the two areas was found (X^2=9.924, df=1, p<0.01) however, the Clopper Pearson confidence intervals suggested suggest substantial overlap in confidence intervals (Figure 2.11).

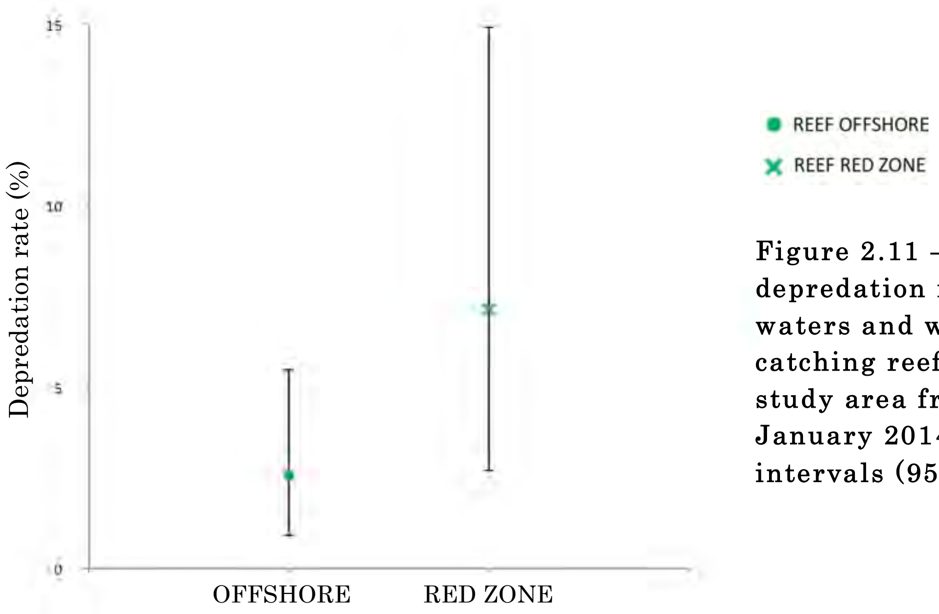


Figure 2.11 – Average depredation rate (%) in offshore waters and within red zone when catching reef species for the study area from November 2013 – January 2014 with confidence intervals (95%).

2.3.3 Shark Species Identification

Sharks activity was not only recorded during depredation events but sharks were directly targeted as a pelagic species where the outcome was recorded as either captured or lost. All of the captured sharks were caught and released after hook removal. Shark interactions where fishing tackle (lures or baited hooks) was taken by sharks, without a fish being hooked, were recorded within the lost category. Observations of shark activity around the boat, where there was no interaction with hooked fish or tackle, were recorded as sightings (Table 2.1).

Table 2.1 – shark observations for launches conducted in the study area from November 2013 – January 2014 (captured, depredation, lost or sighted).

Species	*Captured*	*Depredation*	*Lost*	*Sighted*
Dusky shark (*Carcharhinus obscurus*)		4		
Blacktip (*Carcharhinus limbatus*)	4	2	1	
Dusky or blacktip shark		2		2
Spinner (*Carcharhinus brevipinna*)		2		
Scalloped Hammerhead (*Sphyrna lewini*)		1		
Great Hammerhead (*Sphyrna mokarran*)				5
Unknown		32	15	3

Most depredation events (74.4%) occurred at depth or out of sight of the onboard observer and the species was recorded as unknown. It was possible to identity all of the sharks (n=4) directly targeted and captured during pelagic fishing activity to species level. Nine (20.9%) sharks involved in depredation events were identified to species level. Five of those (11.6%) were identified from one trip where a fishing line was fitted with wire trace while trolling for pelagic species. Sharks were unable to break free from wire trace easily making it possible for them to be brought close enough to the surface for visual identification by the onboard observer. During one recorded depredation event, three sharks were seen chasing a hooked yellowfin tuna (*Thunnus albacares*) as it was being reeled in. The observer identified the species as either dusky shark or blacktip shark but was unable to confidently distinguish between the two on this occasion. The shark that took the fish from the hook was recorded as a depredation. The other two sharks seen from the boat were recorded as sightings. A further shark was identified at a later date from video footage recorded during a depredation event.

2.3.4 Cost of Depredation and Equipment Damage

The sale of fish landed on charter fishing vessels is prohibited under recreational fishing restrictions. As a result shark depredation has no direct financial impact through loss of fish stock. There are costs associated with the loss of fishing gear. Lures used when trolling for pelagic fish species retail between R100 to R170 but information gathered from charter boat skippers suggested the average price they paid was approximately R110 (FishingStore.co.za, 2014). Hooks used when drifting for pelagic species, catching sharks or reef fish cost approximately R2 to R5 each. Swivels used to attach hooks to the trace cost between R1 to R1.50. When catching reef fish, lines were set with between two and four hooks. Sinkers cost between R15 to R25 and were used when catching reef fish.

The loss of fishing gear varied among the different launches (Table 2.2) The highest financial cost of fishing gear lost to shark depredation in a single trip was R802. Across the 11 trips where gear was lost to sharks, the average cost was R250.

Table 2.2 – fishing gear lost for launches conducted in the study area from November 2013 – January 2014.

Launch	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*Total*
Lures	2	1	2	7		4	4						3	1			24
Hooks & swivel	12		9	7	1				3		6			2			40
Sinkers			2								3			1			6

Not all fishing gear lost was attributed to sharks. In addition to gear lost through interaction with sharks, two lures were lost to other species. The lack of roughness on the fishing line and clean cut of the trace indicated that the loss was not due to interaction with sharks. Evidence on the trace suggested the predator species involved could have been king mackerel or wahoo (*Acanthocybium solandri).*

2.3.5 NMLS Data and Species Composition

There were a total of 137 different species caught or landed in the 400km^2 study area through a combination of commercial, charter and recreational fishing activity. Not all species were included in data analyses. For each sector only the species that made up 95% of total abundance was included (Table 2.3). For the commercial sector, 95% of total abundance was calculated by weight (kg), for the recreational sector abundance was calculated by number of fish landed and for the observed charter results abundance was calculated by number of fish caught.

Data from the NMLS showed that the recreational sector had the greatest species diversity with 87 different species logged in the NMLS from 2003 and 2011. Observations made during the study from charter fishing boats showed the least amount of species diversity across the three sectors.

Table 2.3 – species composition (biomass) for the commercial NMLS, recreational NMLS and observed charter fishing data.

Data source	*Total number of species logged in NMLS or observed*	*Number of species recorded in 95% of total abundance*	*Percentage of total number of species reported/observed*
Commercial NMLS	34	13	38.2%
Recreational NMLS	87	11	12.6%
Observed (*Charter*)	27	13	48.1%

The total number of species included in data analysis from the recreational sector was a much smaller percentage of the total number of species compared to either the commercial sector or onboard observations.

Data were analysed using non-metric multidimensional scaling (nMDS) for commercial, recreational and charter catches to illustrate areas of similarity among the sectors (Figure 2.9). It can be clearly seen that catch analysis of catch records from the recreational and charter sector show high similarities of species biomass that both differ from catch records reported in the commercial sector (stress 0.16).

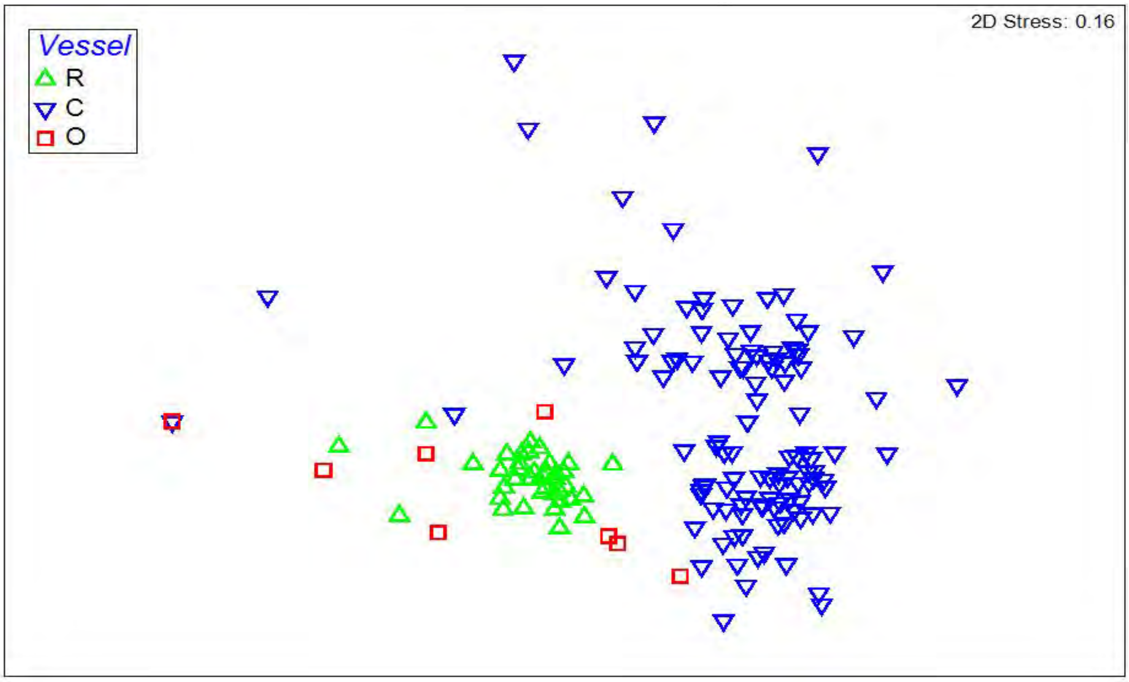


Figure 2.9 – Three factor nMDS plot of species biomass for commercial and recreational NMLS data for the study area (2003 - 2011) and observed charter data.

Results from the ANOSIM analysis showed a highly statistically significant difference among all sectors (Global R = 0.546, p=0.01). The greatest dissimilarity (R=0.54) was observed between the commercial and recreational catch records. The least dissimilarity was reported between the recreational and charter catch records (Table 2.4).

Table 2.4 – ANOSIM pairwise comparison for the commercial NMLS, recreational NMLS and observed charter fishing data by species composition (biomass) over 999 permutations.

Group	*R Statistic*	*Significance level %*	*Possible permutations*	*Actual Permutations*	*Number >= observed*
R, C	0.546	0.1	Very large	999	0
R, O	0.834	0.1	Very large	999	0
C, O	0.643	0.1	Very large	999	0

The results of SIMPER analysis (Table 2.5) showed that two species, tunas (TUNA) and slinger (SLNG) contributed most to the dissimilarity in biomass among all fishing sectors. Emperors (EMPR) also contributed to the dissimilarity in biomass between the recreational and commercial sectors and the recreational and observed commercial sectors. Englishman (*Chrysoblephus anglicus*) (ENGL) was found to contribute to the dissimilarity between the commercial and charter sector. Tuna had the highest average abundance (6.97) in the onboard observer charter catch records and in the recreational sector (6.18). The highest average dissimilarity was for tuna between both the recreational and commercial sectors (12.29%) and the charter and commercial sectors (18.43%). The species with the greatest average dissimilarity between the recreational and charter sectors was slinger (7.31%).

Table 2.5 – SIMPER results for commercial NMLS, recreational NMLS and observed charter fishing data for the top three species with greatest average dissimilarity.

Groups R & C – Average dissimilarity = 54.31

Species	*Group R avg. abundance*	*Group C avg. abundance*	*Avg. dissimilarity*	*Dissimilarity/SD*	*Contribution*	*Cumulative %*
TUNA	6.18	0.68	12.29	2.93	22.64	22.64
EMPR	3.91	0.54	7.21	2.73	13.28	35.91
SLNG	4.49	7.04	6.68	1.66	12.30	48.21

Groups R & O - Average dissimilarity = 45.67

Species	*Group R avg. abundance*	*Group O avg. abundance*	*Avg. dissimilarity*	*Dissimilarity/SD*	*Contribution*	*Cumulative %*
SLNG	4.49	3.53	7.31	1.59	16.00	16.00
TUNA	6.18	6.97	7.27	1.55	15.92	31.92
EMPR	3.91	1.80	5.88	1.40	12.88	44.80

Groups C & O - Average dissimilarity = 69.59

Species	*Group C avg. abundance*	*Group O avg. abundance*	*Avg. dissimilarity*	*Dissimilarity/SD*	*Contribution*	*Cumulative %*
TUNA	0.68	6.97	18.43	1.66	26.49	26.49
SLNG	7.04	3.53	12.27	1.28	17.63	44.12
ENGL	2.08	1.39	5.62	1.11	8.08	52.20

The results of principle components analysis showed that neither PC1 (n=16, r^2=0.0005 p=0.93) nor PC2 (n=16, r^2=0.0058 p=0.37), which represent the vast majority of variation in the species composition among samples, yielded a significant regression against the depredation rate.

2.4 Discussion

2.4.1 Review of Current Study

Along the coast of KZN the majority of charter fishing effort takes place on the lower south coast with the highest number of launches reported at the Sonny Evans Small Craft Harbour, Shelly Beach. According to BLSMS data there were 5,024 launches from Shelly Beach, 36% of those were for the purpose of charter fishing (Mann et al., 2012). The high number of launches provided motivation for the location of the study site. Furthermore, data from a 2003 pilot study on shark depredation along the coast of KZN conducted by the KZN Sharks Board (KZNSB) found Shelly Beach had the highest number of fishing trips where fish were lost to sharks (Dudley, 2003). Fishing activity in and around Protea Banks takes place year round however, 32.0% of the launches take place from November – January with the highest number recorded in December (18.0%) (Mann et al., 2012).

With onboard observer data recorded on charter boat launches from the Sonny Evans Small Craft Harbour, Shelly Beach, it has been possible to make an accurate quantitative estimate of shark depredation in the inshore and offshore waters surrounding Protea Banks. The average number of fishing trips where fish were lost to sharks (75%) was consistent with the findings from the only other study of shark depredation in the South African linefishery. Dudley (2003) reported that fish were lost to sharks during 73% of fishing trips from Shelly Beach, however, the average depredation rate reported for this site varied between the two studies. The average depredation rate in this study was reported at 8.4% [95% C.I. 6.1% to 11.1%] but the Dudley (2003) reported a depredation rate of 26% with a much bigger sample size of 126 launches. Both these figures are considerably lower than the rates of depredation reported by local fishermen who claim they lose between 50 and 80% of their catch to sharks.

The Dudley (2003) pilot survey reported a significant difference in depredation rate across six different study sites along the coast of KZN. Although this study focused on a single site, a spatial variation in depredation rate was found between fishing activity that took place inshore and fishing activity that took place in offshore waters. All incidents of shark depredation were reported in offshore waters with the vast majority (97.7%) reported within the red zone.

Results from this study and Dudley (2003) suggest that shark depredation is a localised phenomenon. Studies in the long-line sector have also highlighted depredation hotspots. NOAA (2009) found that depredation hotspots in the Hawaii long-line fishery were located near to islands and submerged seamounts.

In this study it was reported that skippers knew of sharks 'hotspots' but still fished in these areas however, they often moved from the area when the depredation rate became unacceptably high. On one occasion when a skipper was catching pelagic species, although the fish strike rate was high in the area where fishing was taking place, incidents of depredation were also high. When three sharks were spotted chasing and a single tuna that was being reeled in, the skipper made the decision to move to new fishing grounds.

Onboard observations took place during sixteen launches and from five different fishing vessels during the study. The depredation rate varied significantly among the launches but there was no significant difference in the average depredation rate among the charter fishing vessels that took part in the study. The observer did however report that there was wide variation in the quality of fishing gear used between the different boats. Some skippers commented that poor quality tackle would decrease the retrieval rate resulting in an increase in the opportunity for sharks to steal the hooked fish. They also commented that the experience level of the fisher was a factor in the depredation rate. Charter fishing vessels have a mix of paying customers who have a wide variety of fishing experience. For some fishers it was their first time at sea whereas others were more experienced, regular customers. Neither factor was investigated in this study.

What did have a significant effect on the depredation rate were the different fishing tactics employed during the charted fishing trips to target either pelagic or reef species. Although a minority of smaller charter boats (6m) only fished for pelagic species, the majority of charter fishing vessels targeted both pelagic and reef fish. Typically a charter fishing trip will start the day trolling for game fish, primarily looking for schools of yellowfin tuna. All skippers commented that due to the problem of shark depredation, they use much heavier tackle (24 and 37kg line classes) than required for the weight of the fish they catch. This is because the amount of time taken to catch a fish decreases as the breaking strain of the line increases. The less time the hooked fish is in the water, the less chance there is for a shark to steal it. Vessels equipped for catching both pelagic and reef species would tend to switch to reef fishing only when the troll was unsuccessful.

Fishing effort was separated by target species, pelagic or reef, and the depredation rates between the two were found to be significantly different. The average depredation rate when catching pelagic species (18.6%) was considerably higher than when reef species were targeted (1.9%). These results contrast those presented by Dudley (2003) where both shark activity and fish loss was higher on bottom (reef) fishing trips than on game (pelagic) fishing trips, although there was no significant difference between the two. However, the survey methodology between the two studies differed. Where this study used onboard observer data that allowed the target species to be identified for each hooked fish when there was a mix of pelagic and reef fishing, Dudley (2003) relied on ski-boat anglers to record shark activity and data recorded from 'mixed' fishing trips (where both pelagic and reef species were targeted) were excluded from statistical analysis.

Only one fishing tactic was employed when catching reef species, bottom fishing. The vessels that took part in bottom fishing for reef species used a Scarborough reel with anywhere from 2 to 4 baited hooks attached to the terminal tackle. A mixture of squid and sardine were used for bait. In the long-line sector studies have shown that the use of squid for bait contributed to higher shark catch rates. Sharks comprised 50% of the Hawaii based long-line swordfish fishery however, after a ban on the use of squid bait was introduced, the number fell to 32% of the catch (Gilman et al., 2007; NOAA, 2009). It is possible that the use of squid as bait during the deployment of multiple reels from the same vessel for the purpose of bottom fishing on Protea Banks could attract sharks when catching reef fish. No analysis of bait and depredation rate was undertaken in this study and the issue needs further investigation.

Four different fishing tactics were used when catching pelagic species and the rate of depredation varied significantly among them. The most common was trolling (87.7% of the fish captured or lost to sharks when catching pelagic species) which reported depredation rates of 15%. Drifting, the second most common of the pelagic fishing tactics, had a considerably higher rate of depredation (48%) than trolling. When drifting the boat flows with the current and sardine (*Sardinops sagax)* is used as bait. The sardine in the water attracts target and non-target species to the hook, especially sharks due to their advanced sense of smell. Recreational dive operators use the shark's ability to sniff out sardines to their advantage. A sardine and tuna filled drum is hung at a depth of approximately 8m to attract the sharks and vastly increase the diver's likelihood of a shark encounter. Furthermore, sharks are fed between 5 and 15kg of sardine over the duration of the dive to increase the shark interaction time for the customers. With sharks attracted to the area from the use of bait in both fishing and diving it could explain why the depredation rate is higher when drifting compared to trolling. However, if an attraction to bait were the reason depredations rates were higher when drifting, the reported depredation rate when catching reef species, which also uses bait, should be higher than 1.9%. Furthermore, the least common fishing tactic (0.5% of the fish captured or lost to sharks when catching pelagic species), casting a lure, had the highest depredation rate (100%) without the use of bait. However, this result is based on one trial only. The final fishing tactic employed was catching sharks species where no depredation was reported. Throughout the study there was only one fishing trip that launched for the purpose of shark fishing. The tactics used were very similar to those when catching reef fish but live bait was used. It would be incorrect to assume that low depredation rate when catching sharks was due to sharks being unlikely to predate on each other. Studies of the stomach contents of sharks caught in the protective gillnets off the coast of KZN have shown that although teleost fish make up the largest percentage of stomach contents, other elasmobranch species are frequently identified (Dudley & Cliff, 1993b; de Bruyn et al., 2005; Dudley et al., 2005). Fishers have also reported that when a shark is hooked on the line, depredation by other sharks is not uncommon.

2.4.2 Spatial Analysis

Spatially, pelagic fishing trials where fish were captured or lost to sharks were only recorded in offshore waters. This explains why there was no significant difference in the depredation rate reported between inshore and offshore waters when catching pelagic species. Fishing for pelagic species was not restricted to offshore waters however, vessels would only fish inshore waters when a distinct colour line was present. The colour line separates murky, poor visibility water closest to the shore from cleaner water with much better visibility further offshore and is an area where skippers target dorado. Although there were no successful catches of dorado, one was hooked in inshore waters. This study did not provide sufficient data for comprehensive investigation of the inshore depredation rate when catching pelagic species. Further spatial analysis of the offshore waters found that when catching pelagic species, 94% of trials where fish were captured or lost to sharks were recorded within the red zone, an area designated by the Shelly Beach Ski Boat Club as restricted. Just one depredation event was recorded outside the red zone for all fishing trials. Although the difference in depredation in the offshore area and within the red zone was not significant when catching pelagic species, this may have been due to a lack of data as the majority of pelagic fishing effort was targeted within the red zone.

The red zone is defined in a voluntary agreement put in place by members of the Shelly Beach Ski Boat Club to protect the reef for future generations. Restrictions include no bottom fishing within the red zone at any time of year and a closed season within the red zone for all types of fishing from 1st August to 30th November (Shelly Beach Ski Boat Club, 2011). Results from this study show that current levels of compliance are poor which could be attributed to a lack of enforcement of the restrictions that are no more than a gentleman's agreement. For the observations made in November, during the closed fishing season, all captured fish and all depredation events were recorded in the voluntary protected area. Across the three months of the study, 25% of the fish captured while bottom fishing were recorded within the red zone where bottom fishing is prohibited year round.

Spatial analysis of results recorded when catching reef fish showed no significant difference in the depredation rate between inshore waters and offshore waters. Skippers report that depredation does occur within inshore waters, when catching reef fish but all incidents of depredation occurred in offshore waters and within the red-zone. The depredation rate recorded for fish captured within offshore waters was 2.6% and increased to 7.1% for fish captured within the red zone. The difference between the two was significant. During the trials offshore fishing was limited due to sea conditions. Strong currents often made it impossible to get lines to the bottom and customers frequently experienced sea-sickness, which caused skippers to move to calmer inshore waters. It is therefore possible that depredation rates could be worse than reported in this study.

The skippers preferred fishing grounds are offshore, in the waters surrounding Protea Banks, where they report fish are larger than those caught inshore. Although this study has shown levels of compliance for the restricted zone are poor, there are some fishers who adhere to the restrictions set out by the Shelly beach Ski Boat club. Studies have shown that protected areas can provide a benefit to fisheries. For example, the Goukamma MPA, a formally protected area where fishing is prohibited, has provided a positive benefit to the adjacent fishery with an increase in CPUE for Roman (*Chrysoblephus laticeps*) (Kerwath et al., 2013).

It is not possible to make any assumptions about fish, or shark, abundance in the waters surrounding Protea Banks as no extensive ecosystem studies have been undertaken. Very little is known about species richness or abundance and although submarine canyons, deep reefs and cold water coral have been identified as features in need of protection, no benthic studies have been carried out on Protea Banks (Olbers, Celliers & Schleyer, 2009; Sink et al., 2011). The area has also been identified as an important bio-geographic region between the Aliwal Shoal MPA to the north and the Pondoland MPA to the south with over forty species of teleosts, nine species of elasmobranch and three species of marine mammals which are all deemed as important for biodiversity (Ezemvelo KZN Wildlife, 2012). These include some heavily exploited linefish species such as Englishman (*Chrysoblephus anglicus*) and poenskop (*Cymatoceps nasutus*) (Sink et al., 2011; Mann, 2013b).

2.4.3 Temporal Analysis

Temporal analysis of survey results showed that the shark depredation rate varied significantly among the three months in which the survey was conducted. The highest average monthly depredation rate (19.6%) was reported in November however, this is also the month with the least number of fishing trips that targeted reef fish. As the depredation rate when reef fish were targeted was significantly lower than the depredation rate when pelagic species were targeted, this could explain the variation. Further analysis showed that there was a significant difference in average monthly depredation rate when catching pelagic species. The highest average monthly depredation rate when catching pelagic species (31.7%) was also recorded in November. A seasonal variation in average monthly depredation was found when cape fur seals interacted with line fishermen. When catching snoek (*Thyrsites atun*), the average depredation rate was 3.1% but increased up to 11.4% in August (Meÿer et al., 1992; Wickens, 1996). Half of the skippers and boat owners interviewed in a study of the pelagic long-line fishery in Hawaii also reported that depredation by cetaceans was seasonal although there was no consensus on the months where depredation was worst. The interviewees did however consistently report no depredation events taking place in either April or May (NOAA, 2009). There was no significant difference in the average monthly depredation rate when catching reef fish but ideally the study should be carried out over twelve months to properly test any suspected variation in average monthly depredation rate.

2.4.4 Shark Depredation and Fish Mortality

The results of this study show that shark depredation in the waters surrounding Protea Banks will have a significant impact on the calculated catch per unit effort (CPUE) for the charter fishing sector in KZN. Overall, for charter fishing trips that launch from the Sonny Evans Small Craft Harbour, Shelly Beach, for every 100 pelagic fish captured the mortality of a further 18.6 is unaccounted for. Although the figure is much lower when reef fish are targeted the study has shown that mortality, unaccounted for when calculating CPUE, ranges from 0% in inshore waters to 7.1% for fish captured within the voluntary protected red zone. Through access point surveys conducted at launch sites along the coast of KZN, Dunlop (2013) calculated the CPUE for the charter sector in KZN to be 26.6 fish outing^{-1} or 41.6kg outing^{-1}. If the average fish mortality due to shark depredation reported from charter boats launching at Shelly Beach (8.4%) were taken into account, then the actual mortality per unit effort (MPUE) would increase to 30.4 fish outing^{-1} or 47.5kg outing^{-1}. However, unlike the temporal variation in the average monthly depredation rate, there was no significant difference found in the monthly CPUE. To enable a more accurate assessment, an average monthly depredation rate needs to be calculated. This could then be applied as a useful management tool to determining a MPUE rather than CPUE that does not take into account mortality of fish through shark depredation. The accuracy of the MPUE could be further improved by applying the monthly depredation rate across target species, either pelagic or reef, to CPUE data that is already logged in the NMLS.

Implications of the MPUE being considerably higher than the calculated CPUE can be interpreted in a number of different ways when making management decisions. As fish mortality is higher than reported by the CPUE figures, it could be inferred that the abundance of fish is greater than had been previously assumed. However, the problem is primarily equivalent systematic under-reporting in that region. This would infer that fishers are responsible for higher rate of fish mortality than is reported and fish may be depleted at a higher rate than expected. The greatest problem associated with taking shark depredation into account is that we have no idea if the rate of shark depredation has changed with time. If fishers' assumptions are correct and the rate of depredation has not remained constant but is in fact increasing over time, it would be impossible to apply depredation rates ascertained now, retrospectively. This would make any assessment of the change abundance in a particular species over time based on MPUE that includes rates of shark depredation impossible.

2.4.5 Comparison of the Depredation Rate Among the Different Fishery Sectors

The survey was limited to observations made on charter fishing boats as access to commercial vessels was not possible. However, an attempt was made compare the results with those recorded in the commercial and recreational sectors from data logged in the NMLS using nMDS. Mandatory catch and effort returns for the commercial sector have been logged in the NMLS since 1985, however, this study only included data from 2003 onwards, after the reduction in fishing effort was imposed (DEA, 2005; DAFF, 2010). In KZN, a network of trained observers conduct random access point surveys however, it is estimated that only 47% of the total number of launches are logged in the NMLS.

The resulting nMDS spatial diagrams showed a significant dissimilarity in the species composition of the commercial NMLS catch reports compared to the recreational NMLS catch reports and charter data. Similarities between the recreational and charter sector were to be expected as the data from the recreational sector contains catch returns logged in the NMLS through EKZNW boat inspections.

The greatest dissimilarity was found between the commercial NMLS data and data from the charter results and the least dissimilarity was found between the recreational NMLS data and the charter sector. Further analysis of the data showed that the dissimilarity among all three sectors could be explained largely as a result of the abundance of tuna.

The tuna abundance in both the recreational and charter sector was in the region of ten times that of the abundance of tuna within the commercial sector. Over a quarter (26.5%) of the dissimilarity between the commercial and charter sector was accounted for by tuna spp. Tuna spp. also accounted for 22.6% of the dissimilarity between the commercial and recreational sector.

Species composition carries information that can be related to certain factors such as abundance and rates of depredation, indices of which can be difficult to ascertain in a multi-species fishery. Winker et al. (2013) used CPUE data to successfully model abundance indices for two commercially important species, carpenter (*Argyrozozona argyrozozona*) and silver kob (*Argyrosomus indodorus*) taking into account different catching strategies. Using a direct principle component derived from PCA they were able to account for shifts in the species fishers target and remove substantial variation from the CPUE data providing the potential for more accurate stock assessment.

Modeling of shark depredation (MacNeil et al, 2009) in the US Atlantic longline fishery showed a correlation between depredation counts and catch composition. Although depredating sharks contribute to the catch composition in longline fisheries, MacNeil et al. (2009) found that the correlation between depredation counts and catch composition went beyond the presence of the depredating animals and was related to the composition of their prey. However, in this study PCA failed to show a relationship between catch composition and depredation rates.

Determining true species composition is itself complicated. A factor that may need to be taken into consideration when making comparisons among the commercial, charter and recreational sectors are the restrictions placed on recreational fishing. Where the commercial sector is managed by limiting effort, the charter and recreational sectors are managed through daily bag limits, size limits and closed seasons. For example, there are bag limits on two of the reef fish most commonly caught by charter boat fishers, Englishman and slinger. Fishers are limited to landing one Englishman and five slinger per day. Size limits apply to both pelagic and reef species and are specified in either length (cm) or weight (kg). The minimum total length for the pelagic species most commonly landed by charter fishers, the yellowfin tuna is 3.2kg and the minimum total length for a slinger is 25cm (SANParks, 2008).

The study did not find enough data to support dissimilarity among the three sectors as a result of bag limits. Unlike the recreational sector, bag limits were not taken into consideration when recording catch data for the charter sector. If bag limits were playing a part, it would be expected that the abundance of a species like slinger (bag limit of five per day) should be lower than in the recreational sector than both the commercial and charter sectors however, this was not the case. Although the recreational abundance of slinger was lower than that of the commercial sector, the abundance of slinger in the charter sector was slightly lower than that of the recreational.

However, from onboard observations it is clear that bag limits fail to successfully limit fish mortality. Observations from the onboard surveys noted that it was not uncommon for undersize Englishman and slinger to be caught and then used as bait rather than being released. If the bag limit had been reached and fish were released it often had an impact on unreported fish mortality. Studies have shown the survival rate of released fish can vary between 1.3% and 24.5% and is highly species specific (Götz et al., 2007; Kerwath et al., 2013). It has been suggested catch and release mortality rate should also be taken into account in stock assessments and management strategies, particularly in the charter fishery where release rates are in the region of 37% (Pradervand & van der Elst, 2008).

On very rare occasions, if a fisher reached the bag limit for a particular species but then went on to catch fish of the same species which was considerably larger than one of those already onboard the boat, a smaller individual would be discarded and the larger individual retained.

2.4.6 Cost of Shark Depredation

The problem of shark depredation extends beyond effective management of the linefishery as there is a financial impact for fishers across all sectors. Within the commercial sector financial losses associated with shark depredation occur through a reduction in marketable catch and the loss of fishing gear. Figures from 1996, estimated that seal depredation cost the snoek fishery between R0.5 and 1 million rand annually (Wickens, 1996). Although it is difficult to quantify, losses due to cetacean depredation in the Hawaii pelagic fishery in 2006 were estimated between $13-23 million based on a depredation rate of 30% (NOAA, 2009). Charter fishermen are not legally allowed to sell their catch so the direct cost of depredation is due to the loss of fishing gear. In this study the average launch lost R250 of fishing tackle. With each fishing trip accommodating and average of 5 anglers, each paying an average of R600, the loss equates to 8% of the daily revenue. Skippers report indirect costs with lower rates of customer satisfaction when rates of depredation are high which mean fewer repeat bookings. In a fishing sector where it is reported that only 60% of operators make a profit from fishing activity, even low rates of depredation can make a big difference (Pradervand & van der Elst, 2008).

2.4.7 Shark Behaviour and Depredation

The reasons behind shark depredation and factors that influence the rate of shark depredation remain unexplored but offer multiple opportunities for future research. Hypotheses include everything from behavioral conditioning to a decrease in available prey and even the effect of the bather protection nets deployed by the KZNSB. It has even been suggested that in KZN the shark population is increasing.

Both charter boat fishers and recreational dive operators report that sharks have become habituated to fishing and diving activity and are found following the sounds of the outboard motors in anticipation of a food reward. Although this study did not observe sharks following individual boats, a tagged Zambezi shark (*Charcarhinus leucas*) in the Breede River, South Africa, spent the majority of the study period around fishing activity 11-13km upstream. An acoustic tag allowed the shark to be tracked as it swam among three vessels fishing for grunter and kob. The Zambezi shark was then observed following a boat that had weighed anchor and trolled downstream (McCord & Lamberth, 2009).

Shelly Beach has a high level of site usage so it is possible continued exposure to boat activity has conditioned sharks to adapt their natural behavior to acquire an easy meal and it is a localised population of sharks responsible for the majority of depredation incidents (Guttridge et al., 2009; Heithaus & Vaudo, 2012; Mann et al., 2012). Divers frequently report sightings of sharks with fishing gear in their mouths, gills and trace trailing behind them and often spot individuals with multiple hooks. It can therefore be assumed that individual sharks are responsible for multiple depredation incidents. However, as five different species of shark were visually identified during this study on Protea Banks, behavioral conditioning seems unlikely to fully explain all incidents of shark depredation in the area. This is supported by Dudley (2003) who identified a further six species responsible for incidents of shark depredation along the coast of KZN. The additional species included the tiger shark (*Galeocerdo cuvier*) and great white shark (*Carcharodon carcharias*), both of which migrate significant distances so conditioning would be unexpected (Heithaus, 2001; Pardini et al., 2001). Tagging studies would be needed to test the hypothesis that a few habituated individual sharks are responsible for the majority of depredation incidents.

Studies of the stomach contents of sharks caught in KZNSB protective gillnets have shown a high degree of overlap with commercially important linefish species (Dudley & Cliff, 1993b; de Bruyn et al., 2005; Dudley et al., 2005; Dunlop & Mann, 2012a; Dunlop & Mann, 2013). One hypothesis to explain shark depredation is that as fish stocks have become seriously depleted, sharks have adapted their feeding strategies and now target a more abundant source of prey, hooked fish. Due to a lack of data on shark abundance and depredation rates it would not be possible to test this hypothesis retrospectively but it would be possible to study if future depredation rates decrease if linefish stocks recover.

The same lack of shark population and depredation baseline data means it is not possible to test the assumption that the KZNSB have an impact on depredation rate. The assumption is that the shark nets have been responsible for removing larger sharks from the ecosystem that would ordinarily control the population of mid-sized sharks through predation. In the late 1960s and early 1970s an increase in abundance of juvenile dusky sharks in near shore waters along the coast of KZN was attributed to the removal of large apex predators in the shark nets (van der Elst, 1979). Although Dudley & Cliff (1993a) agreed a reduction in predation had occurred they commented that the van der Elst (1979) study relied on feeding data from captive Zambezi and ragged tooth sharks and juvenile sharks were not as important in the diet of wild sharks as they appeared to be in captive sharks. In addition the evidence from sharks caught in the protective gillnets did not show an increase in the adult dusky shark numbers over time. Data from the protective gillnets also fail to suggest any overall increase in shark abundance in the area.

In the absence of data to explain why shark depredation rates are thought to be on the increase, solutions to the problem remain elusive. Some fishers believe that the solution would be to reduce the shark population, however, divers travel from all over the world to see the sharks and this solution is highly emotive and creates a degree of conflict among the different stakeholders that exploit the resources of the Protea Banks. There is evidence to suggest apex predators actually promote species richness so removing them from the ecosystem may have unforeseen impacts on the abundance of the target species (Sergio et al., 2008). The loss of sharks has been shown to have an impact that propagates down the food chain altering the number of primary consumers altering fish communities (Ruppert et al., 2013).

Chapter 3 - Conclusion

The sampling method in this study provided accurate, high quality quantative data but would be very expensive to reproduce on a wider scale. In addition, although the similarity between the charter and recreational sector means that the depredation rate reported in this study could be applied to data logged in the NMLS for recreational catches. However, the depredation rate reported in this study should not be applied to the commercial sector without further investigation as the dissimilarities shown on the nMDS plot were significant.

With results of this and other studies showing that shark depredation appears to be localised, a reduction in depredation could be achieved through better management practices by limiting fishing activity in areas where shark activity is high. This study has shown that when catching reef fish, the depredation inside the voluntary protected red zone was more than two and a half times higher than the depredation rate just outside the red zone. Enforcement of the existing gentleman's agreement may help to reduce the rate of depredation. Although unpopular with many fishers, the implementation of a formal MPA prohibiting all fishing activity in areas where rates of depredation are highest may provide a benefit to the CPUE in adjacent waters in the long-term (Kerwath et al., 2013).

This study has made the first steps in quantifying a rate of shark depredation and gives a snapshot of shark depredation in the charter fishery on Protea Banks. The results show that fish mortality due to shark depredation can have wide ranging implications for effective management of depleted South African linefish stocks. The study needs to be extended both temporally and spatially to give a clearer picture of the overall impact of shark depredation in the South African line fishery.

It is recommended that the access point surveys be extended to limited onboard observer surveys on commercial, recreational and charter vessel which would allow for a baseline depredation rate to be ascertained across several launch sites and over a longer timeframe. Once baseline data have been established, future monitoring of shark depredation rates could be conducted by a combination of access point surveys with questionnaires completed by skippers.

Chapter 4 - References

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APPENDIX A – NMLS Fish Species Codes

Spp. code	Category	Incorporated species
BRRC	Barracudas	Barracudas (*Sphyraena spp.*)
		Pickhandle Barracuda (*Sphyraena jello*)
EMPR	Emperor	Blue Emperor (*Lethrinus nebulosus*)
		Emperors
		Yellowfin emperor (*Lethrinus crocineus*)
GLJN	Galjoen	Banded galjoen (*Coracinus multifasciatus*)
		Galjoen (*Coracinus capensis*)
KNFS	Kinfgish	Bigeye kingfish (*Caranx sexfasciatus*)
		Black kingfish (Caranx lugubris)
		Blacktip kingfish (*Caranx sem*)
		Giant kingfish (*Caranx ignobilis*)
		Kingfish (*Caranx spp.*)
KOB	Kobs	Dusky kob (*Argyrosomus japonicus*)
		Kobs (*Argyrosomus, Atrobucca and Johnius spp.*)
		Snapper kob (*Otolithes ruber*)
		Squaretail kob (*Argyromus thorpei*)
RCCD	Rockcod and sea bass	Brown-spotted/Catface rockcod (*Epinephelus andersoni*)
		Halfmoon rockcod (*Epinephelus rivulatus*)
		Malabar *rockcod* (*Epinephelus malabaricus*)
		Potato bass (*Epinephelus tukula*)
		Rockcods and seabass
		Tomato rockcod (*Cephalopholis sonnerati*)
		White edged/Captain Fine rockcod *(Epinephelus albomarginatus)*
		Yellowbelly rockcod (*Epinephelus marginatus*)
		Yellow-edged lyretail/Swallowtail (*Variola louti*)

STMP	Stumpnose	Cape Stumpnose (*Rhabdosargus holubi*)
		Natal stumpnose (*Rhabdosargus sarba*)
		Red stumpnose (*Chrysoblephus gibbiceps*)
		Stumpnose (Rhabdosargus spp.)
		White stumpnose (*Rhabdosargus globiceps*)
SHRK	Shark	Blacktip shark (*Carcharhinus limbatus*)
		Copper/Bronze whaler shark (*Carcharhinus brachyurus*)
		Dusky shark (*Carcharhinus obscurus*)
		Hammerhead sharks (*Sphyrna spp.*)
		Ragged-tooth shark (*Carcharias taurus*)
		Sharks
		Spotted gully shark (*Triakis megalopterus*)
		Tiger shark (*Galeocerdo cuvier*)
		Zambezi shark (*Carcharhinus leucas*)
TUNA	Tuna	Eastern little tuna (*Euthynnus affinis*)
		Skipjack tuna (*Katsuwonus pelamisi)*
		Striped bonito (*Sarda orientalis*)
		Yellowfin tuna (*Thunnus albacares*)
		Tunas and mackerels
YLTL	Yellowtail	Giant yellowtail (*Seriola lalandi*)
		Longfin yellowtail (*Seriola rivoliana*)

APPENDIX B – NMLS Average Weight by Species

Species code	*Species*	*Average weight (kg)*
BBRM	Bronze bream (*Pachymetopon grande*)	0.75
BLHT	Blue hottentot (*Pachymetopon aeneum*)	0.75
BLSK	Blueskin (*Polysteganus coeruleopunctatus*)	0.5
BRMO	Other Bream	0.5
DANE	Dane (*Porcostoma dentate*)	0.5
DLFS	Dorado (*Coryphaena hippurus*)	2.0
EMPR	Emperors	1.5
ENGL	Englishman (*Chrysoblephus anglicus*)	0.6
GRMN	German (*Polyamblyodon germanum*)	0.5
KOB	Kobs	1.0
LPFS	Lampfish/cavebass (*Dinoperca petersi*)	0.75
RCCD	Rockcod and seabass	2.0
SCTS	Scotsman (*polysteganus praeorbitalis*)	1.5
SLNG	Slinger (*Chrysoblephus puniceus*)	0.75
SSLD	Sand Soldier (*pagellus bellottii natalensis*)	0.3
STMP	Stumpnose	0.5
TUNA	Tunas	3.0