ASSESSING THE SUITABILITY OF AN INDIVIDUAL TRANSFERABLE QUOTA SYSTEM TO ADDRESS UNREGULATED BY-CATCH IN SOUTH AFRICA'S INSHORE TRAWL FISHERY

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ABSTRACT

The need for effective management measures addressing by-catch in South Africa's inshore trawl fishery, which nominally targets Cape hake (*Merluccius capensis*) and Agulhas sole (*Austroglossus pectoralis*), has been recognized by fisheries managers for over a decade. Individual transferable quota ("ITQ") systems have been successfully used to manage fisheries globally by providing secure, long-term rights to participants that are transferable. The defining feature of the system is fostering an active trade among fishery participants in select species. Landings data were analysed to identify whether there are discrete patterns of catch composition in South Africa's inshore trawl fishery that may support a trade in select by-catch species through a pilot ITQ system. A total of 3717 trawl trip records associated with trawling vessels and rights holders provided landed catch data for 14 nominal species categories over a five-year study period from 2007 through 2011. Analysis of species compositions identified clusters of catch compositions among the vessels and the rights holders. Five clusters were associated with the vessels that differentiated among sole- and hake-directed trawlers, and were distinguished by the proportion of hake, sole, and by-catch landed, as well as the by-catch species composition. The dominant by-catch species landed by the sole-directed group were skates (several species within the genus *Raja*), silver kob (*Argyrosomus inodorus*), and gurnard (two species within the genus *Chelidonichthys*). For the hake-directed groups they were panga (*Pterogymnus laniarius*), horse mackerel (*Trachurus trachurus*), and chokka squid (*Loligo vulgaris*). The vessels showed a consistency of catch patterns over time. For the rights holders, four principal clusters were similarly differentiated by the proportion of hake, sole, and by-catch landed, and by-catch species composition. The rights holders were also consistent in their participation in these groupings over the study period. Allocation of by-catch quotas for a pilot ITQ programme is recommended on the basis of these clusters rather than on the basis of quota size, as there were not strong relationships between quota allocations (of hake and sole) and the proportions of by-catch landings. Analyses of quota species landings per quarter were undertaken to identify whether high-grading is likely occurring in the fishery, as this would warrant additional

management precautions in implementing a pilot ITQ programme. There did not appear to be evidence of high grading. Significant relationships were found between hake (but not sole) landings and the quarter of landing across all trawlers, with three different patterns identified.

CHAPTER 1: LITERATURE REVIEW

I. INTRODUCTION

Humans have fished since time immemorial with little consideration of depleting ocean stocks. In 1625, the Dutch scholar Hugo Grotius remarked that "[t]he extent of the ocean is in fact so great that it suffices for any possible use on the part of all peoples for drawing water, for fishing, for sailing" (Hardin 1998). For centuries, fisheries managers continued to declare the ocean “limitless,” mistaking the vastness of the ocean’s expanse for bottomless resources (Redfern & Shulstad 1974).

By the latter half of the 20th century, however, reports of declining fish stocks were rife, and escalating (Redfern & Shulstad 1974). Technological advances during the late 19th and 20th centuries that widened human access to fish and other marine resources, along with rapidly increasing human populations, combined to push fish stocks precipitously close to collapse in many cases, and over the edge in others (Dulvy et al. 2003; Costello et al. 2008). Exploitation was identified as the greatest threat to marine extinction (Sadovy 2001) with habitat loss trailing second (Dulvy et al. 2003).

The main characters in the exploitation-extinction tragedy are frequently not the “target” fish pursued by fishers. Rather, they are the species (or undersized fish of target species) taken incidentally as “by-catch” during the fishing of more valuable or abundant species (Philippart 1998; Hall et al. 2000; Dulvy et al. 2003). These are the unregulated or unused, often discarded, fish caught incidentally to the targeted catch (Davies et al. 2009).

The aim of this study is to assess whether an Individual Transferable Quota (“ITQ”) system, a management tool used in fisheries globally, may be well suited to manage the exploitation of by-catch in the inshore trawl fishery in South Africa. This study analyzes the landings data from fishing trip records from the inshore trawl fishery over a five-year study period to determine whether there are patterns in the by-catch landings across fishery participants that lend themselves to fishery management under an ITQ system.

ITQ systems establish market-based trading of select quota species among fishery participants. For an ITQ system to work, there must be sufficient and consistent catches of the species to be regulated. If the species composition of the by-catch landings are highly variable or unpredictable over time, a quota-based trading programme is not anticipated to work effectively. In addition, there ought to be sufficient differences in the catches among participants that would make a trade meaningful. If these prerequisites are met, the follow-on question becomes how to allocate initial quotas of by-catch species to fishery participants in an ITQ programme.

II. The By-Catch Problem

Fishery management measures focused on target species are often insufficient to adequately protect by-catch (Hall et al. 2000; Walmsley et al. 2006; Attwood et al. 2011). This is attributed to different rates of abundance and different life history characteristics between target and by-catch species, among other things (Philippart 1998; Hall et al. 2000). Large, long-lived species with lower fecundity than the target generally will be the most at risk (Philippart 1998; Bianchi et al. 2000). However, evidence exists to suggest that even highly fecund species can be threatened by over-exploitation (Sadovy 2001).

Trawl fisheries, due to the non-selective nature of the gear, typically result in high mortality of non-target species (Philippart 1998; Hall et al. 2000; Bianchi et al. 2000; Rogers 2000; Walmsley et al. 2007). Declining by-catch populations are a common feature of trawl fisheries (Bianchi et al. 2000; Walmsley 2004). High fishing effort, either legal or by means of illegal, unreported and unregulated fishing, exacerbates the problem (Wiesmeth 2012).

a) By-catch as a common pool resource problem, tried solutions & fisheries economics

Commercial fisheries management is usually targeted to limit the catch of a single species or a small number of dominant target species. The catch incidental to the target catch, the “by-catch,” is then treated as a common pool resource – an unregulated resource available to all with the costs of mismanagement spread thinly across all resource users (Hardin 1968; Feeny et al. 1996). The by-catch may include commercially valuable species and, thus, fishers are incentivized to land the valuable non-target species.

Whether or not the by-catch is commercially valuable, the result is often over-exploitation of by-catch resources and a dissipation of economic benefits that could otherwise be gained from them (Munro & Scott 1985). Economic theory explains this tragedy of the common pool resource: In an open-access regime, what is best for the individual fisher is worst for the resource and the remaining fleet of fishers (Hardin 1968; Costello et al. 2008). Over-exploitation and excess harvesting capacity result: As long as there are fishers making a profit from the common pool resource, other fishers will be attracted and fishing effort will escalate as fishers compete with one another until a break-even point is reached (Gordon 1954; Hardin 1968; Clark 1973; Munro & Scott 1985). Importantly, the break-even point includes income and salaries to individual fishers (Anderson & Leal 1993). Thus, in areas of high unemployment and few job opportunities, the resource will continue to attract users despite low financial returns (Clark 1973).

In these situations, interventions, regulatory or otherwise, are critical to prevent further overuse of the resource (Hardin 1968). The regulatory approaches concerning marine common pool resources are diverse but generally fall within two categories: Input restrictions and output restrictions (Munro & Scott 1985). Input restrictions regulate the effort exerted by fishers to catch fish (Munro & Scott 1985). Popular targets of input regulation are the number of fishers allowed to fish (e.g., through license schemes), vessel size, vessel gear, and the number of sea days for fishing. Input restrictions frequently result in a game of cat-and-mouse between the regulator and the fishers, e.g., limitations on vessel size foster a greater number of boats and limits on sea days lead to increased effort on days allowed (Anderson & Leal 1993). Contrary to the regulator's goal of reducing fishing effort, input restrictions can result in over capitalization of the fleet (Branch & Clark 2006).

Output restrictions focus on the fish coming out of the sea, rather than the effort input to catch them (Munro & Scott 1985). These restrictions typically allow the industry to figure out the most efficient manner to catch the prescribed resource levels (e.g., what gear to use and when to fish). A popular output restriction used in fisheries globally is the setting of a total allowable catch ("TAC"), which sets the total volume of catch allowed for a given species, often annually (Beddington et al. 2007). TACs have evolved from fishery-wide limits to individual quotas ("IQs") – catch limits imposed on individual fishers or vessels – due to undesirable consequences frequently associated with fishery-wide TACs. These include fishing "derbies" – frenzied efforts among fishers to catch as many fish as quickly as possible before the TAC is filled and the fishery closed – and "capital stuffing" on vessels to enhance fish catches (Copes 1986; McCay 1996; Festa et al. 2008).

While the management of fisheries concerning wild fish stocks implies biological management, an economic understanding of the resource *user* – the fisher – is necessary to create effective management plans that will be complied with (Beddington et al. 2007). The aforementioned management approaches share a fundamental shortcoming in their inability to adequately address the root cause of overcapacity and overfishing: The deep-seated insecurity of each individual fisher as to whether he will obtain sufficient catch before the resource is either closed and/or overfished by his competitors (Beddington et al. 2007; Costello et al. 2008).

As famously put by H. Scott Gordon in 1956: the "economic justification of conservation is the same as that of any capital investment" (Munro & Scott 1985). The economic perspective of fishers and their firms is that they are rational and will continually try to maximize the returns of their effort, subject to the constraints under which they operate (Arnason 1994). IQs, which provide a right to each participant for a fixed quota of fish, are generally viewed as an improvement on fishery-wide TACs by fisheries economists, as they provide a secure right to the resource (Schlager & Ostrom 1992; Criddle & Macinko 2000; Beddington et al. 2007; Festa et al. 2008).

The theory is that fishers secured with a private allocation, will not engage in a race to fish for their catch and will spread their effort optimally across the entire fishing season and through use of selective fishing gear (Copes 1986; Scorse 2010). As long as the quota rights are granted over a sufficiently long period, this creates incentives not to overfish since the fisher will benefit from healthy stocks in the future (Beddington et al. 2007; Scorse 2010).

The IQ, however, is not without fault. Imperfections and complications arise in the design and application of the quota (Arnason 1994). Common problems found in IQ schemes are "high grading", selective discarding of unmarketable fish, and cheating the quota by catching and selling more than is allotted (Copes 1986; Scorse 2010). High grading consists of discarding less valuable fish for more valuable fish, often of the same species, whereas selective discarding is the discarding of unmarketable catch (Copes 1986; Kingsley 2002; Scorse 2010). The incentive to high grade and selectively discard arise in "differentiated" fisheries where there is more than one economic grade of catch, such as marketable versus unmarketable species or, within a species, larger fish or fish in better condition (Arnason 1994; Buck 1995). The marginal benefit of high grading can be determined by subtracting the expected costs of discarding (i.e., costs associated with discarding fish at sea and the replacement fishing effort) from the expected return (i.e., the marginal value of the desired catch, accounting for the probability of catching it) (Kingsley 2002).

The differentiation of grades means that fishers can increase total revenue per unit of quota if they have more or less of certain types of fish and if the costs of catching the desired fish do not overwhelm the marginal benefits of landing more of the desired fish (Squires et al. 1998; Kingsley 2002). Different grades of fish may arise not only from consumer preference for fish of a given condition or size, but also the upstream processing and on-deck handling of the fish. By way of example, factory equipment may better handle fish of a certain size class and, therefore, this grade will be preferred (Casey et al. 1995; Walmsley et al. 2007). Similarly, if it is more costly to bring to dock a given class of fish, this would also lead to a differentiation. Fishing capacity on a vessel can further influence the degree of high grading or selective discarding (Gillis et al. 1995a). For example, a limited hold space on a vessel could incentivise high grading to maximise profits from a trip.

Alternatively, a limited fishing season could equally incentivise high grading from the sea days available.

Discarding may be economically efficient from the perspective of the fishers but it is inefficient from a resource use perspective (Arnason 1994). Furthermore, it complicates management as it introduces an unknown bias into estimates of fishing mortality based on landings data (Arnason 1994; Squires et al. 1998). Discarding at sea typically occurs beyond the purview of most regulatory schemes unless there is sea-based monitoring (Squires et al. 1998).

III. Individual Transferable Quota Programmes – A Potential Solution?

Individual transferable quota ("ITQ") programmes are potentially effective solutions to managing commercial fisheries because they foster the development of long-term interests of fishery participants in the sustainability of the resource (Dewees 1998; Grafton et al. 2005; Costello et al. 2008). Implementation of an ITQ programme has been found to substantially reduce the probability of fishery collapse and, in some cases, reverse the downward trend of catches (Costello et al. 2008).

ITQs evolved relatively recently with the pioneering programs beginning in the late 1970s and 1980s (Arnason 1993; Arbuckle & Drummond 2000; Sigler & Lunsford 2001; Armstrong 2007). The impetus for the development of ITQ systems was to reduce excess capacity in fisheries, in many cases the product of government subsidies and the use of ineffective management strategies such as those outlined above (McCay 1996; Arbuckle & Drummond 2000).

The ITQ system is based around the award of IQs to fishery participants (Beddington et al. 2007). It is distinguished from generic IQ systems, however, in that rights are granted for a long period and the rights are freely transferable (with few restrictions) (McCay 1996). Some scholars assert that this transferability feature is essential for rights holders to undertake long-term investment because it is through their ability to transfer or alienate the right, by sale or lease, that the quota develops a meaningful market value and long-term investments in resource sustainability are rewarded (Schlager & Ostrom 1992; Sanchirico et al. 2006). Transferability also allows more efficient fishers to purchase the allocations awarded to less efficient fishers, thereby providing profits to existing fishers (Squires et al. 1998).

Some authors question whether transferability aids the development of long-term interests because of the uncertainty over the value of future fish stocks (Bromley 2009). For a rational fisher to forego catch today, the benefit of catching tomorrow must be at least as great as the benefits he were to receive from selling that catch today (Clark 1973). To make this calculation, a "discount rate" must be applied to anticipated future revenue streams that approximates the opportunity cost of capital invested in alternatives today (Clark 1973). There are competing methodologies for calculating the applicable discount rate that could substantially alter the opportunity cost of conserving resources (Sumaila & Walters 2005). In any case, if the discount rate is sufficiently high (i.e., if the fishers could make more money by fishing excess stock today and investing the profit, rather than leaving it for the future), a fisher may have a rational incentive to harvest at unsustainable levels today, even if he or she has a long-term right to fish in the future (Clark 1973). Whether a private owner may be incentivized to overexploit a fishery to extinction, however, has been questioned as bio-economic models have shown that under reasonable prices, costs and discount rates, it is not economic to exploit fisheries to extinction (Grafton et al. 2007). ITQ programmes (and other ownership- or rights-based programmes) presume that discount rates will not overwhelm future benefits perceived by fishers, i.e., that the value of foregoing catch today has meaningful value tomorrow.

Catch-quota balancing is a key aspect of ITQ programmes to ensure that fishing stays within sustainable limits set by the fisheries managers (Copes 1986; Sanchirico et al. 2006). To enhance fishery compliance, several mechanisms can be included in ITQ programmes to provide flexibility in the matching of actual catches to quotas. Transfer or rollover of quota across seasons is an important flexibility mechanism to provide additional incentives not to selectively discard (Sanchirico et al. 2006). "Carry forward" mechanisms permit the unused quota from the present season to be transferred to the following season (Townsend et al. 2006; Sanchirico et al. 2006). The amount that can be carried forward varies across programs, typically ranging from 10% to 30% (Sanchirico et al. 2006).

"Carry back" mechanisms are less widely adopted as they allow a fisher to borrow a portion of the next season's anticipated allocation to cover an exceedance experienced in the present season (Sanchirico et al. 2006). There are typically limits on any carry back mechanisms (Sanchirico et al. 2006). Notably, New Zealand eliminated its 10% carry back provision in 2001 and replaced it with a "deemed value payments" system in which a price set by the authority is paid for excess catches that is intended to neither punish nor reward overfishing. The early experience in New Zealand with the deemed value payments appears to have resulted in TAC overruns of select stocks (Sanchirico et al. 2006). As a result, New Zealand revised the payment rate for the system so that an owner's payments increase with use of the system to limit excessive use of the system and TAC overruns (Sanchirico et al. 2006).

a) *THE GOOD AND THE BAD*

Several fisheries attribute benefits to ITQ systems such as reduced fishing effort (Buck 1995; Dupont & Grafton 2001; Grafton et al. 2005), reduced catches of smaller and immature fish of the target species (longline fishery) (Sigler & Lunsford 2001), a longer fishing season and increased quality of landed catches (Dewees 1998; Grafton et al. 2005), increased revenues (Buck 1995; Dewees 1998; Dupont & Grafton 2001; Grafton et al. 2005; Branch 2006) and changes in fishing behaviour that reduce by-catch, discards and quota exceedances (Sigler & Lunsford 2001; Grafton et al. 2005; Festa et al. 2008).

The "big picture" concern with an ITQ system is that it devolves responsibility for natural resources typically held in the public interest (e.g., marine common pool resources) to private hands in large part (Sigler & Lunsford 2001). Some argue that there is no reason to believe these public goods will fare better if fisheries are privately managed, whereas others argue that governmental (and other large) institutions lack appropriate incentive and capacity to manage fisheries appropriately, sparking heated debate (Copes 1986; Edwards 1994; Feeny et al. 1996; McCay 1996; Bromley 2009).

Further criticisms include that ITQ holders may be incentivized to cheat by exceeding the quota. These scholars assert that "[i]t remains an open question whether the incentives to discard and high-grade can be counterbalanced by other features of ITQ programs, including the possible creation of a 'conservation ethic'" (McCay 1996). Another criticism concerns the management costs inherent in administering and enforcing the programme (Dupont & Grafton 2001). The British Colombia groundfish trawl ITQ system, recognized for successfully managing the fishery, has a 100% observer coverage programme (Branch & Hilborn 2008) that is approximately two-thirds funded by fishery participants (Sanchirico et al. 2006). The Australia Southeast Trawl Fishery introduced compulsory satellite transponders due to a perceived misreporting of catch locations and underreporting of catches post-ITQ implementation (Sanchirico et al. 2006).

The South African Constitution and Marine Living Resources Act ("MLRA") provide the country's policy objectives with regards to its marine resources. Themes that emerge from these documents are the long-term sustainable use of resources to provide for future generations, equitable use and exploitation of resources that redresses historical inequities, and economic development (Branch & Clark 2006).

A successful ITQ programme largely meets these policy goals. Sustainable use of fish resources that facilitates long-term conservation goals are associated with ITQ programmes (Costello et al. 2008). Economic development through increased fishery revenues is also associated with ITQ programmes (Grafton et al. 2005). It should be noted, however, that greater revenues do not necessarily indicate increased employment, a goal of South African policies. A by-product of ITQ implementation in some cases is a reduction in overcapitalization, which often means job losses as fishing effort is reduced (McCay 1996; Dupont & Grafton 2001; Scorse 2010). The reduction in capitalization, however, may be less substantial in fisheries where there are already substantial limits on the number of authorized (licensed) trawl fishers, as is the case in South Africa.

Equitable use of resources that redresses historical inequities is not necessarily furthered by an ITQ system but it also not impeded by one. An ITQ system concerns the manner in which the fish resources are exploited by fishery participants, it does not provide any standards regarding who the fishery participants should be. It firmly remains the responsibility of the government to provide for equitable participation in the fishery through the licensing and rights allocation processes.

b) MIXED-SPECIES FISHERIES

The challenge of applying an ITQ system to multispecies or "mixed-species" fisheries is significant and its effectiveness in managing mixed fisheries has been the subject of debate (Copes 1986, 2000; Squires et al. 1998; Branch 2006; Sanchirico et al. 2006). The main reason for this debate is that a fisher does not have perfect control over what species, and the amounts of each, he will land in a mixed fishery (Sanchirico et al. 2006).

Trawl fisheries are mixed fisheries with joint harvesting technology: all species are harvested using the same economic inputs, i.e., the vessel, labour, gear, equipment and fuel all support the same catch (Squires et al. 1998). This means that at least some vessels may not be able to easily target or avoid particular species at will. This may render management through an ITQ regime difficult for a number of reasons. First, because fishers may not be able to predict the catch composition ahead of time, catch-quota balancing could be difficult (Copes 1986; Sanchirico et al. 2006). There is countervailing evidence, however, that fishers can influence the catch composition in a number of ways, as described in further detail below (Branch et al. 2005; Branch & Hilborn 2008).

Second, the regulatory framework commonly requires that once a quota for a given species is reached, fishers cease fishing that stock. In a multispecies fishery, this could effectively terminate the fishing activity for the rest of the season if the fisher is unable to satisfy regulators that he can avoid catching the species for which the quota has been filled. This would lead to the undesirable situation where fish species that could still be harvested sustainably are not, leaving the fishers without a source of revenue (Boyce 1996; Hilborn et al. 2004; Gerritsen et al. 2012).

Obviously, such a situation heightens the incentive to cheat (Gillis et al. 1995b; Boyce 1996). A fisher seeking to avoid this quandary may be motivated to discard and/or high grade the limiting species in order to continue fishing for other species that are not yet near the quota limit. Third, it is argued that setting ITQs for some but not all species within a fishery may lead to increased fishing pressure on those species not subject to the quotas (Dupont & Grafton 2001).

Despite these difficulties, ITQ programmes have been found to successfully manage mixed-species fisheries (Branch 2006; Sanchirico et al. 2006). There is evidence that when profitable to do so, fishers in multispecies fisheries can exert some control over the species composition by changing location of fishing grounds, trawl depth, and the timing of trips, among other things (Squires & Kirkley 1991; Squires et al. 1998; Branch et al. 2005; Branch 2006; Sanchirico et al. 2006; Branch & Hilborn 2008). If the fishers are able to target and/or avoid some species, the problem of matching catches to quotas is substantially diminished (Squires et al. 1998). Furthermore, the discarding and high-grading problems are present under traditional IQ systems that do not provide the benefits associated with ITQ systems. Several ITQ programmes have taken steps to reduce discarding and high-grading (Branch & Hilborn 2008; Aranda & Christensen 2009). Observer programmes have proven successful at reducing at-sea discards with the fishing industry often bearing some, if not all, of the programme costs (Diamond 2004; Grafton et al. 2005; Sanchirico et al. 2006; Branch & Hilborn 2008).

IV. Consideration Of An ITQ Programme To Manage South Africa's Inshore Trawl Fishery

South Africa boasts rich marine resources, with its coasts supporting some of the most productive marine ecosystems in the world (Diemont 2013). Trawling began in South Africa at the end of the 19th century (Attwood et al. 2011), chiefly targeting abundant sole stocks (Walmsley

2004). The demersal trawl sector is today recognized as South Africa's most important fishery, representing more than 50% of the fishing value in the country (DEAT 2005a).

The trawl fishery can be divided into a south coast inshore fishery, principally operated out of Mossel Bay and Port Elizabeth (Attwood et al. 2011), and an offshore fishery, principally operated out of Cape Town and Saldhana Bay (Walmsley et al. 2007). The inshore areas extend along the coast from Cape Agulhas to the mouth of the Great Kei River (DEAT 2005a; DAFF 2010; Attwood et al. 2011).

The two fisheries are further distinguished by their species composition, species abundance, operating depth, and size (Walmsley et al. 2007). The offshore fleet fishes at depths greater than 110 meters and targets the deep-water hake species (*Merluccius paradoxus*), whereas the inshore fleet generally fishes at depths less than 110 meters, is centred around the Agulhas Bank, and primarily targets the shallow-water hake species (*Merluccius capensis*) (Japp et al. 1994; Walmsley et al. 2007). In addition to shallow-water hake, the inshore fleet also targets Agulhas sole (*Austroglossus pectoralis*). The fishery receives approximately 6% of South Africa's total allowable catch for hake and the total allowable catch for Agulhas sole (DEAT 2005a; Walmsley et al. 2006).

The total value of assets in the inshore trawl fishery are estimated to be greater than R 100 million with the annual market value of catch worth approximately R 60 million (DEAT 2005a). This is substantially less than the hake offshore trawl fishery, with the total value of offshore assets estimated to be approximately R 2.2 billion and the market value of the landed catch worth approximately R 2 billion annually (DEAT 2005c), and the hake longline fishery, with a market value of operating vessels approximately R 750 million and the total value of landed catch approximately R 280 million per year (DEAT 2005d).

The annual hake catch by the fishery has been relatively stable for over 80 years (Attwood et al. 2011). While the inshore fleet is considered to be sustainably managed regarding hake and sole stocks, managers and scientists have been concerned for decades about by-catch stocks (DEAT 2005a; Attwood et al. 2011).

a) Concerns regarding by-catch in the inshore trawl fishery

The catch of species other than hake or sole, irrespective of whether the catch is landed (and subsequently sold) or discarded, is considered “by-catch” in the inshore trawl fishery. The fishery has the second highest by-catch of any South African fishery (Attwood et al. 2011). Recent analyses concluded that by-catch constitutes approximately 42% of the catch across both hake- and sole-directed vessels in the inshore fishery (Attwood et al. 2011). Prior estimates found a lower by-catch proportion in the sole-directed fisheries (approximately 22%) as compared to the hake-directed fisheries (approximately 47%) (Walmsley 2006).

The species comprising by-catch are diverse, with recent observations identifying 137 nominal species (Attwood et al. 2011). Simplifying matters, however, is that 20 species were found to account for approximately 98% of the by-catch by weight (Attwood et al. 2011). A large proportion of this by-catch is marketable (Attwood et al. 2011).

Several of the by-catch species are targeted by other fisheries, some with depressed population sizes, generating both conservation concern and conflicts (Attwood et al. 2011). By way of example of such a conflict, silver kob (*Argyrosomus inodorus*) is a key species in the line fishery and is listed as “heavily depleted” in the recent Status of the South African Marine Fisheries Resources report (DAFF 2012). In response to over-exploitation concerns, the government drastically reduced line fishing effort by declaring the fishery in a state of emergency in 2000 (DAFF 2012). Yet, similar quantities of silver kob are caught in both the handline and trawl fisheries without equivalent restrictions on the latter. Further, the trawl fishery operates in part in the nursery grounds of line fish species (Nel et al. 2007), and often catches juvenile fish, frequently below the legal size limit for the handline fishery (Attwood et al. 2011).

Market demand incentivises high by-catch capture and fuels this inter-fishery conflict. Specifically, strategies increasing the targeting of high value by-catch species such as monkfish and kingklip have been observed, particularly among rights holders with limited hake allocations (Walmsley 2004). The economic importance of by-catch is well-recognized within the industry, preferring to refer to these catches as "joint product" (South African Deep Sea Trawling Industry Association 2010). In the south coast fishery, by-catch has been estimated to generate 15 to 36% of total revenues (Walmsley et al. 2006).

A market influence on fishing behaviour is observed through differential pricing, both on different grades within a species, and across different species (Walmsley 2004). Grading is often determined by size corresponding to increased market demand for larger sizes (Leslie 2004). Measures to limit catches of high-valued by-catch species have been noted by regulatory officials as a "matter of urgency" due to the targeting of these species (Leslie 2004). In addition to silver kob, two species that have been singled out are kingklip and monkfish due to preliminary assessments that indicate both stocks as depressed and catches being above sustainable levels (Leslie 2004). The concerns over kingklip and monkfish by-catch, however, are largely in the offshore fishery (P. Sims, personal communication). The "incidental" catch of monkfish and kingklip for the inshore trawl fishery was estimated to be 0.41% and 0.51%, respectively, of the hake catch (Leslie 2004).

Department personnel provide a rule of thumb to identify fishing strategies targeting by-catch: where hake catch is less than 75% of the catch, it is assumed that a species other than hake is being targeted or semi-targeted (Leslie 2004). Further, where the landings of horse mackerel are greater than 25% or landings of sole are greater than 10%, those trawls are likely targeted at horse mackerel and sole, respectively (Leslie 2004).

One method in which certain by-catch species may be targeted is by fishing ground (Erstadt 2002). Four different fishing areas with divergent fish catches have been identified on the south coast (Erstadt 2002). One area, the Blues Bank, is reported to contain a large number of marketable by-catch species (e.g., horse mackerel, panga, squid, and monkfish) and the proportion of by-catch found in the catch in this area is typically high, around 50% of the total catch (Erstadt 2002). Contrary to this, the Chalk Line (an offshore area) typically results in by-catch rates of approximately 15% of the total catch (Erstadt 2002).

b) EXISTING REGULATORY CONTROLS

The present quota system applicable to the target species of hake and sole arose from the Long Term Rights Allocation Management Process of 2006 ("LTRAMP") (DEAT 2005a). The LTRAMP process assigned an IQ in the form of a "base percentage" for each of hake and sole for the years 2006 through 2015 to 17 different "rights holders," the entities to whom the right to engage in commercial fishing activity was granted by the government. The base percentages are applied to an annually-set total allowable catch for the quota species (hake and sole) (P. Sims, personal communication).

The existing IQs may be transferred among fishery participants permanently or temporarily (within-season). While the MLRA allows for a permanent transfer of rights subject to ministerial approval, in practice such transferability is administratively burdensome and difficult to achieve (DEA 2009; Diemont 2013). Thus, quotas are seldom permanently transferred among participants in the fishery (P. Sims, personal communication). Within-season sharing of quota for target species, however, does occur periodically throughout the fishing year, facilitated by the "effort control model"(P. Sims, personal communication). The effort control model, managed by the Chief Directorate Offshore Resource Management within DAFF, allows for clusters of rights holders to share allocations of hake and sole quota within a given fishing season (P. Sims, personal communication). Data over the study period regarding the effort control model annual clusters, i.e., the cluster landings and composition, were not available for analysis.

There are no IQs for species other than hake or sole in the inshore trawl fishery. While there are not individual quotas for the by-catch species (Attwood et al. 2011), the Department has repeatedly stated its intention to regulate by-catch and "strongly condemns" the deliberate targeting of by-catch species (DAFF 2010, Section 7.17). It specifically states an intention to institute a per-trip limit requiring that the target species of hake, horse mackerel, and sole constitute 50% by weight of the catch (DAFF 2010, Section C.3.8).

The Department also identifies three regulatory mechanisms addressing kingklip, monkfish and silver kob that may constrain the fishing of these species (DAFF 2010, Section B.12 & C.3.3-3.8). First, there are "precautionary catch limits" or "PCLs" set for kingklip (3500 tons) and monkfish (7000 tons) (DAFF 2010, Section C.3.5 & 3.6). These are fishery-wide, precautionary, limits applicable to both the inshore and offshore hake-directed trawl fisheries and the hake line-fishery. A related provision is a "by-catch reserve" for horse mackerel that sets a precautionary limit across the trawl fisheries, presently at 12,500 tons (DAFF 2010, Section B.9.5).

Fishers are not assigned individual catch limits from these PCLs and by-catch reserves, and it is not clear what action, if any, will be taken if these precautionary limits are exceeded (Attwood 2012). The fishing industry has agreed on apportionment of these limits between the inshore and offshore sectors, such that the inshore sector has a limit of 200 tons each of kingklip and silver kob and a limit of 2500 tons for horse mackerel (P. Sims, personal communication). The apportionment of the monkfish PCL is not settled as the offshore sector seeks an allocation of 60 tons to the inshore sector and the inshore sector seeks a greater allocation (P. Sims, personal communication). Across the two sectors combined, the monkfish PCL has not been exceeded since the PCL was added as a permit condition in approximately 2008 (P. Sims, personal communication). If the monkfish PCL allotted to the inshore sector were 60 tons, then it would have been exceeded once since the year 2008. The inshore sector has not exceeded either the kingklip or monkfish PCL allotted to it since the conditions came into force in approximately 2008 (P. Sims, personal communication).

Second, in each rights holder's fishing permit, provisions limit the annual catch of kingklip and monkfish to less than the average catch over the reference period 1998 to 2002 (DAFF 2010, Section B.12.6). For silver kob, the catch must be less than 80% of the average catch over the reference period. In the instance that a rights holder is found to approach or have exceeded the applicable reference period catch, the Department has the right to limit the rights holder from fishing and to take additional action, such as assign observers at the rights holder's cost (DAFF 2010, B.12.7 & 12.8).

The permit does not identify, however, what the reference period averages were for a given rights holder, complicating monitoring and enforcement. Another complication is that there are some existing rights holders that did not operate during some or all of the years in the reference period (P. Sims, personal communication) and it is unclear what limits, if any, should be applicable to these rights holders.

Third, there is a “move-on” rule concerning silver kob. Vessels are required to move to an area at least 5 nautical miles from its current fishing position if the silver kob catch on any trawl exceeds 20% by weight of the sole-catch (if the vessel is sole-directed) or 2% by weight of the hake catch (if the vessel is hake-directed) (DAFF 2010, B.12.9). The Permit does not provide guidance on how to determine whether a vessel is hake- or sole-directed and does not indicate how this condition is monitored or enforced (DAFF 2010). As a practical matter, sole vessels are typically smaller and target the sole grounds closer to shore; the hake-directed vessels generally fish the deeper grounds where hake is more abundant (P. Sims, personal communication).

Finally, there are generally applicable measures that may reduce by-catch. One is the “ring fencing” of the trawl footprint or, in other words, confining the trawl lanes to those areas historically used by the industry (Attwood et al. 2011). Another is the prohibition on trawling in three marine protected areas (De Hoop, Tsitsikamma and Bird Island) and a series of bays within the inshore trawl grounds, designed to limit access to fish nurseries and areas of high diversity (DAFF 2010, Section B.6). There are additionally limitations on gear and effort, such as minimum mesh sizes and limits on sea days for certain vessels (DAFF 2010, Section B.9.3). The minimum mesh sizes for hake- and sole-directed trawlers differ, with the minimum sole mesh size at 75 mm and the minimum hake mesh size at 90 mm (DAFF 2010).

CHAPTER 2: ASSESSING THE SUITABILITY OF AN INDIVIDUAL TRANSFERABLE QUOTA SYSTEM TO MANAGE THE INSHORE TRAWL FISHERY

I. INTRODUCTION

Individual transferable quota ("ITQ") systems have been used successfully in trawl fisheries to manage the exploitation of by-catch and enhance the long-term sustainability of fish stocks (Branch & Hilborn 2008). The purpose of this study is to consider whether an ITQ system may be an appropriate regulatory tool to manage the exploitation of by-catch in the South Africa inshore trawl fishery.

As noted in Chapter 1, a key challenge to ITQ management of mixed-species fisheries is catch-quota balancing (Copes 1986). It is well known, however, that fish populations are structured in space and time, and that in most fisheries there is some ability to target and/or avoid certain species (Branch 2006; Sanchirico et al. 2006; Walmsley et al. 2007; Branch & Hilborn 2008; Fairweather et al. 2010). This is acknowledged by members of the South Africa demersal trawl industry, recognizing that "fishing behaviours and strategy" can increase the catch proportion of various species and that some by-catch species are subject to "semi-targeting" (South African Deep Sea Trawling Industry Association 2010).

In this study, data on catch landed – by species (kg) per fishing trip – were analyzed to establish whether patterns in the composition of fish landed could support a trade in catches among participants in the fishery. If the composition of by-catch species is unpredictable, a market-based trading system focused on a limited number of species, like an ITQ system, would likely not be effective. Similarly, if catch patterns are inconsistent over time, it would be difficult to provide long-term allocations and the long-term interests that are credited with much of the success of the programmes. On the other hand, institution of a new ITQ regulatory regime could create incentives to alter fishing behaviour and may produce the desired catch predictability (Grafton et al. 2005).

Secondary objectives of this study, if consistent patterns in by-catch landings are found, are (i) to consider appropriate bases upon which to conduct an initial allocation of precautionary upper catch limits ("PUCLs") for selected by-catch species in a pilot ITQ programme and (ii) to assess whether selective discarding of quota species and high-grading of hake may be problematic in the fishery. Allocations based on historical catch levels appear to be the predominant method for making initial allocations (Armstrong 2007). ITQ programmes in New Zealand (Armstrong 2007), Iceland (Arnason 1993), Nova Scotia (Dupont & Grafton 2001), and British Colombia (in part) (Dewees 1998), were based on historical catch levels of fishery participants.

The investigation into patterns of by-catch landings in the fishery are approached from two perspectives: by trawling vessels and by rights holders. While there is overlap within these two categories, namely, some rights holders own trawling vessels, it is not complete: Some trawling vessels are owned by non-rights holders and some rights holders do not have trawling vessels.

Among trawling vessels, there is a known distinction between hake- and sole-targeting vessels. In addition, the fishing grounds on which hake and sole predominate are often distinguishable, each with its own species assemblages (Japp et al. 1994). Thus, the volumes and proportion of by-catch species landed are anticipated to differ among hake- and sole-directed vessels.

Within the two groups of hake and sole-directed vessels, variation in species composition may be due to differences in fishing behaviour, influenced by the preferences of the vessel's consumer market, the skipper's experience, and the vessel's preferred fishing grounds. In the inshore trawl fishery, several prominent groupings of vessels exist – vessels shared under joint ownership – that may exploit particular market niches and, therefore, distinguish themselves by the species composition landed. By way of example, large corporate conglomerates that operate in a vertically-integrated style – from fishing, to processing, to packaging – are likely to have specific species and grades of species that better suit their market, whereas smaller operators that cater to a local, fresh fish market would do well with a broad array of species and sizes (Walmsley 2004).

Catch composition (both species diversity and relative proportions) may vary by rights holder for similar reasons as identified for the vessels: rights holders target different markets and, thus, are likely to prefer different species compositions. The 17 rights holders within the fishery vary substantially by the size of their hake and sole quotas. While there is a degree of "inevitable" by-catch associated with trawling for hake and sole (Leslie 2004), targeting of economically valuable by-catch species could be a business decision selected by small and large quota holders alike. Small quota holders, however, are limited in their ability to derive economic benefits from the target species and, thus, may routinely target by-catch species as an economic strategy to counter-balance the small quota (Erstadt 2002; Walmsley 2004). Such a strategy might be revealed in landings data in the way of a consistently above-average proportion of by-catch by certain vessels or rights holders.

The hypotheses examined in this study are the following:

(i) The catch composition of annual landings varies among vessels.

(ii) The catch composition of annual landings varies among rights holders.

(iii) The proportion of landed by-catch is related to the size of quota allocated to the rights holder.

(iv) The proportion of hake landed across the core trawlers varies in a consistent pattern by quarter.

II. Methods

a) Data

i) Landings Data

Vessels within the inshore trawl fishery are active throughout the year. Vessels typically conduct fishing trips over the course of five to seven days with multiple trawl drags during that time. Upon return, each vessel is required to land and have their catches weighed in the presence of a DAFF Fisheries Control Officer and an independent fisheries monitor (DAFF 2010, Section B.11.1-2).

The monitor records the date of trip return and records the weight in kilograms of (at least) the following thirteen nominal taxa: shallow-water cape hake (*Merluccius capensis*); Agulhas sole (*Austroglossus pectoralis*), horse mackerel (*Trachurus trachurus*), panga (*Pterogymnus Ianiarius*), skates (several species within the genus *Raja*), gurnard (two species within the genus *Chelidonichthys*), silver kob (*Argyrosomus inodorus*), chokka squid (*Loligo vulgaris*), white stumpnose (*Rhadbosargus globiceps*), kingklip (*Genypterus capensis*), carpenter (*Argyrozona argyrozona*), monkfish (*Lophius vomerinus*) and sharks (species within the class *Chondrichthyes*), and an "other species" category. The skipper of the vessel also completes a "Demersal Log Book" with information on the fishing effort (number of sea days and drags per trip) and incorporates the landed weights of the catch. The landed weights and Demersal Log Book are provided to DAFF, who compiles and records the information electronically. This system has been in operation for more than two decades and was in effect throughout the study period (P. Sims, personal communication).

For this study, the landings data described above were obtained from DAFF for a five-year period commencing January 1, 2007 through December 31, 2011 (the "study period"), which represents five fishing seasons. This five-year period was selected chiefly for two reasons. First, a study aim is to consider a reasonable basis upon which to allocate preliminary upper catch limits ("PUCLs") to individual participants for selected by-catch species to complement the existing allocations of hake and sole. In the long-term rights allocation process for the quota species (hake and sole), which occurred in 2006, quotas were assigned in part based on historical fishing performance, i.e., whether applicants who previously held fishing rights "effectively harvested" their allocation (DEAT 2005b). Applicants who did not harvest fish during a given season may be excluded (DEAT 2005b) and applicants lacking "good reason" for over- or under-catching hake or sole by more than 10% of the allocations over the prior four-year "medium-term" allocations period that was allocated in 2001 (Diemont 2013) would be penalised (DEAT 2005a). Thus, a PUCL allocation for by-catch species considering the historical performance of fishery participants would be in keeping with historical precedent in the fishery (Leslie 2004).

Second, the particular five-year period selected, commencing in 2007 and terminating in 2011, reflects fishing patterns from current participants in the fishery. Fisheries regulations have undergone substantial reformation since the passage of the Marine Living Resources Act of 1998 (the "MLRA") (Van Sittert et al. 2006; Diemont 2013). Following passage of the MLRA, several initiatives to diversify fisheries participants occurred, resulting in new rights allocations processes (DEAT 2005b). The number of participants in the inshore trawl fishery have since fluctuated, with an initial increase followed by a substantial consolidation (DEAT 2005a; DAFF 2012). Thus, a more recent data set from which the existing participants were actively engaged was sought.

The landings data received from DAFF provided data on each trip, including the vessel and affiliated company owner, the rights holder(s) for whom landed fish were allocated, information on fishing effort (number of sea days and/or drags), and the landed weight in kilograms for the fourteen species categories described above. To protect the business information of industry participants, their names were replaced by an alphanumeric system. Specifically, vessel names were coded T1 to T34 and rights holders and vessel owners were coded C1 to C30.

ii) Allocation Data

DAFF provided allocation data for the 17 Long Term Rights Allocation Management Process (LTRAMP) rights holders over the study period. Specifically, for each year of the study period, each right holder's base percentage of hake and sole, along with its annual quota (in tons) for the two quota species, was provided.

iii) Market data

A Product Price Index was received from the industry that provides the relative market pricing of 25 species (with multiple grades for several fish) and a “mixed” species pricing. The prices provided are relative to a medium-sized grade of hake (P. Sims, personal communication). The pricing per grades of hake, in conjunction with data on hake landings per quarter, were used to determine whether high-grading of hake may likely have occurred in the fishery over the study period.

b) Analysis

i) Data Preparation

Of the 14 nominal species categories for which landings data were obtained, five, namely, hake, sole, panga, horse mackerel, and monkfish (in part), had weights reported for different subcategories. The subcategories are predominantly grades of fish based on size. Hake contained 11 grades of fish and a “nominal weight” category. The nominal weight category is not a separate grade of hake but rather an estimate of the total catch landed. A factor is multiplied to the total weight landed, depending upon the grade caught, to approximate the weight of whole fish prior to the on-vessel cleaning and gutting. The “nominal weight” category was not used in this analysis. The total weight of hake was compiled by aggregating the weights for each of the 11 grades of hake landed per trip resulting in one combined value of total weight for hake landed per trip.

Similarly, sole contains four grades of fish landed and a “nominal weight” category, panga contains four grades, horse mackerel has three grades, and, monkfish contained two grades, for the year 2011. As with hake, a total weight for each of these species was compiled by aggregating the landed catch per trip for each of the grades.

The landings data also contain an “other species” category consisting of the weight of species landed in addition to those that fell within the 13 species categories. These data were not used in this study.

ii) Variation by vessel

(1) Vessel clusters by species composition

A total of 34 vessels operated during the five-year study period with varying frequency; as noted, a substantial consolidation occurred during the study period. To analyze catch patterns that are more likely to prevail in the future and thus be relevant to a future ITQ programme, a core trawlers subset of the 34 vessels was created. This subset consists of 19 vessels that operated in at least 2010 and 2011; 16 of the vessels operated in all five years of the study period. The basis for including the three vessels that operated in 2010 and 2011 but not all prior years was to include all vessels that are most likely to operate in the future.

The DAFF trip data were aggregated by year for each trawler. The weights of each taxon were standardized by the total catch landed per sample (Clarke & Gorley 2006). To explore clusters of similar species composition in the samples, a dendrogram using group linkages and a multidimensional scaling (MDS) plot were used based on a Bray-Curtis similarity matrix in PRIMER (version 6.1.5; Clarke & Gorley 2006). A group factor was created guided by the clusters formed at the 80% similarity level in the dendrogram. Thereafter, a SIMPER analysis was employed to explore the species composition driving the observed clusters.

The same similarity matrix based on standardized data was used in Analysis of Similarity (ANOSIM) tests (Clarke & Warwick 2001), to explore whether the factors of trawler and year, may have influenced the catch composition of the samples.

(2) Relationships between landings of quota species and proportion of by-catch

Linear models were used to identify whether a significant relationship, if any, existed between the annual proportion of by-catch and the quota species landed. The trawlers were divided into sole-directed and hake-directed trawlers, as identified by the cluster analysis. Within these groupings, samples with fewer than 50 tons landed of the respective quota species were excluded to eliminate samples with a marginal fishing effort. The "by-catch" category was calculated as a sum of the 11 nominal by-catch species categories (i.e., all species with denominated weights except hake and sole); the "other species" category was excluded. The models were applied using R programming language (R Development Core Team, 2009) in RStudio (version 0.97.309, 2012).

iii) Variation by rights holder

(1) Rights holders clusters by species composition

The DAFF trip data were aggregated by year for each rights holder over the study period. As with the vessels, the species for each taxon were standardized by total catch landed per sample record and then subjected to a Bray-Curtis similarity analysis. To explore clusters of similar species composition in the samples, a dendrogram and MDS plot were used based on a Bray-Curtis similarity matrix in Primer (Clarke & Gorley 2006). A SIMPER analysis was performed exploring the species composition within the clusters and ANOSIM tests were used to explore whether the factors of rights holder and year may influence the catch composition of the samples (Clarke & Warwick 2001).

(2) Analysis of rights holders by quota allocations

Linear models were used to identify whether a significant relationship existed between the proportion of by-catch landed and quota size of hake or sole (as identified by the LTRAMP base percentage allocations). Separate models were used for the hake and sole quotas, respectively.

iv) Selective discarding and market influence

Whether selective discarding of hake and sole landings may have occurred was assessed by separately examining patterns of quota species landings by quarter. First, landings of each quota species were aggregated per quarter (January 1 through March 31; April 1 through June 30; July 1 through September 30; and October 1 through December 31). The landings were standardized by the total catch landed per quarter. An Analysis of Variance (ANOVA) was performed to explore relationships between the proportion of hake and sole landed, respectively, out of the total landings and the quarter in which the catch was landed. The ANOVAs were conducted both across all trawlers (combining catches for all trawlers) and then individually on each trawler.

A second analysis was conducted to further explore the effect of market prices on the 11 landed grades of hake, which vary in size from "mince" to "Extra Large." The industry Product Price Index provided four different relative prices associated with six different grades of hake. The 11 landed grades were sorted to match the six industry grades in conformity with the way in which the industry conducts the matching (P. Sims, personal communication). The six grades were then consolidated into four categories as proxies for the four different relative prices. Thus, sample records consisted of the sums by weight of hake for each of the four price categories per trawler by quarter. These landings were then standardized by the total hake landed per quarter. One-way ANOSIM tests were performed for three factors on each data set: trawler, year, and quarter.

III. Results

a) *Industry Profile*

During the study period, 3717 trawl trips were recorded by a total fleet of up to 34 vessels, affiliated with 18 company owners and 17 rights holders (or combinations thereof) in the South Africa inshore trawl fishery. The total landed catch was approximately 39,983 tons over the study period (Appendix 1).

The data reflect substantial consolidation of fishing capacity in the years 2008 and 2009 (Figure 1). There were 32 vessels operating at the start of the study period in 2007. By 2010, there were 19 vessels operating. The number of companies (vessel owners) operating similarly consolidated (Figure 1). The number of rights holders rebounded from a low in 2009 of 13 to a total of 17 in 2011 (Figure 1).

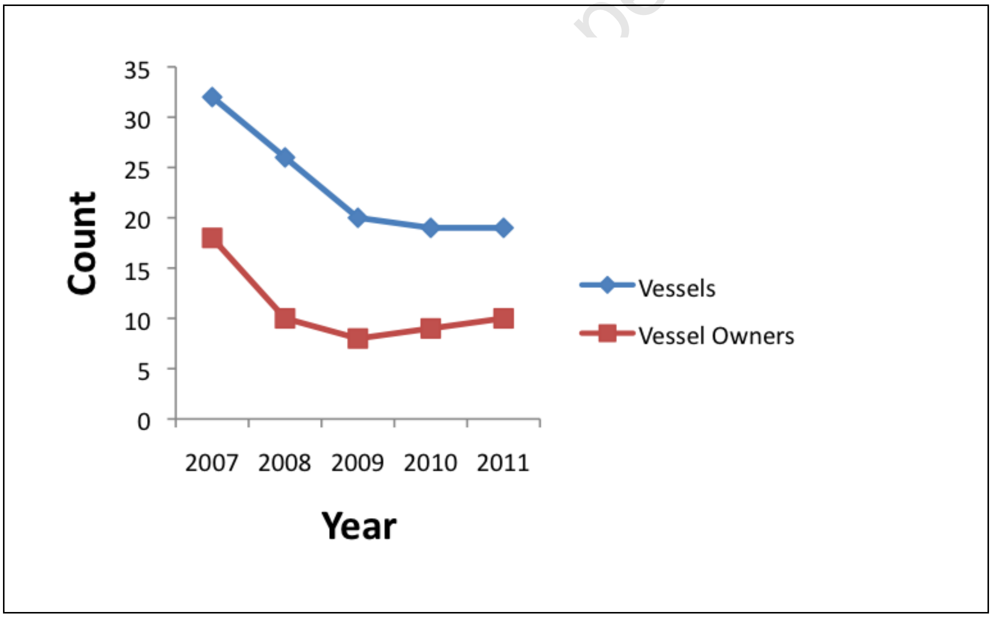

Figure 1. Number of vessels and vessel owners in the South African inshore trawl fishery over the five-year study period.

While the number of operating vessels declined over the study period, the weight of all fish landed increased, suggesting that the fleet may have been over-capitalized or the remaining fleet became more efficient (Figure 1; Appendix 1). Comparing 2011 to 2007, the catch of all species combined increased by 4.1% (approximately 316.3 tons) (Figure 2). This increase was not evenly spread among landed species, however. Certain species experienced substantial increases in landed volumes whereas others declined (Figure 2). These increases appear to be independent of the TACs for the quota species. The sole TAC was the same in both 2007 and 2011 and the hake TAC was actually lower in 2011 than in 2007.

Hake experienced the least change, with a 1% increase in catch (Figure 2). Collectively, the by-catch species experienced a greater change, at 8%, compared to the quota species (hake and sole), combined at 3%. Other species with substantial increases in catch were carpenter, white stumpnose, and silver kob with increases of approximately 580%, 89%, and 75%, respectively, from 2007 to 2011 (Figure 2). Substantial decreases in landed catch from 2007 to 2011 were recorded for shark, skate, and squid, with decreases of approximately 39%, 19% and 13%, respectively (Figure 2).

Over the study period, the 17 rights holders utilized on average 75.6 (± 35.5% SD) of their hake quota and 41.4 (± 40.3% SD) of their sole quota per year (Figure 3). Hake landed catch was greater than an individual right holder's hake quota 21 times and less than quota 51 times, and landed sole catch was greater than an individual right holder's sole quota 7 times and less than quota 65 times. Department personnel explained that quotas were not exceeded on the cluster level, in which several rights holders are managed collectively through the effort control model and, thus, no non-compliance events for quota overages occurred during the study period (P. Sims, personal communication).

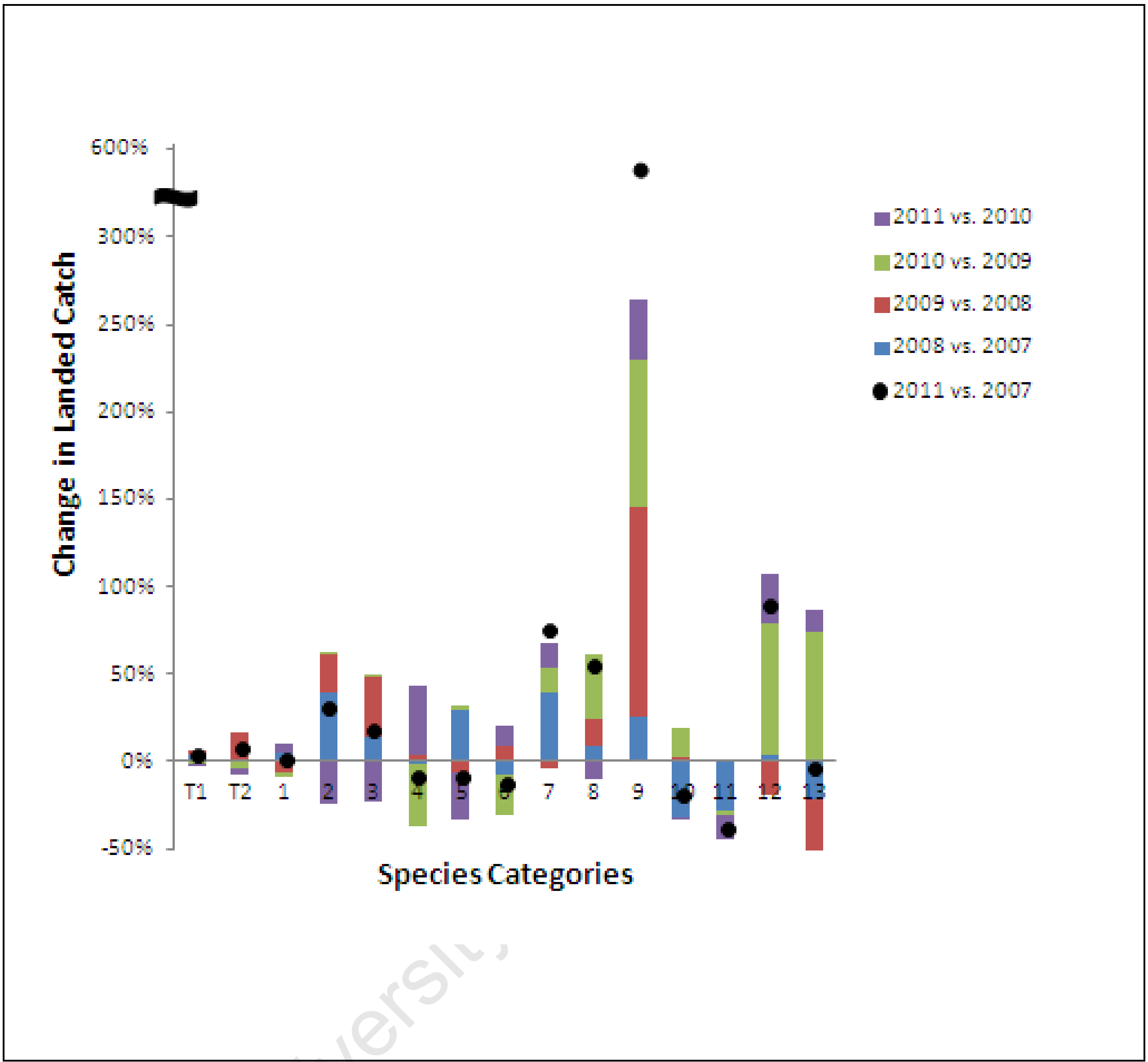

Figure 2. Stacked bar chart showing the percentage change in landed catch over five different time periods for the following species categories: T1 = total catch of all species, T2 = total by-catch, 1 = hake, 2 = sole, 3 = panga, 4 = horse mackerel, 5 = kingklip, 6 = squid, 7 = silver kob, 8 = gurnard, 9 = carpenter, 10 = skate, 11 = shark, 12 = white stumpnose, and 13 = monk fish. Note that the comparison between 2011 and 2007 is indicated by a circular symbol.

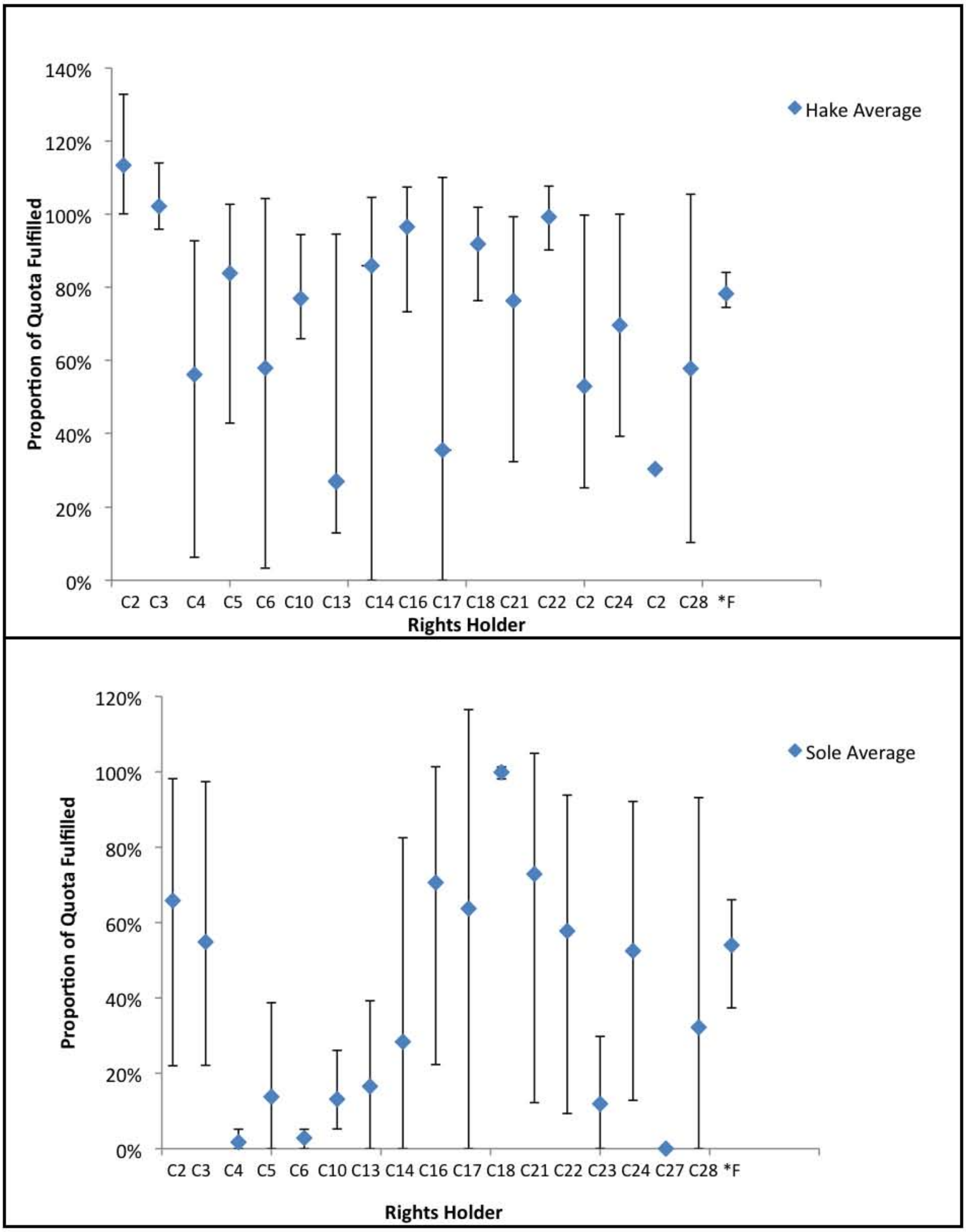

Figure 3. Percentage of (a) hake quota and (b) sole quota fulfilled by rights holder annually, averaged over the study period, with error bars representing the minimum and maximum (annual) values. The fleet-wide average of all rights holders is represented by *F.

b) Patterns of species distribution

i) Variation by vessel

The core trawlers conducted 3279 trips out of the 3717 trip records (i.e., 88%) received for the study period, resulting in 90 samples when aggregated by year. Catch composition differed significantly among the trawlers over the study period (ANOSIM; Global R = 0.708, p = .001). Thus, the first hypothesis that catch composition of annual landings varies among vessels is accepted. Species composition did not significantly differ, however, by the year in which the catch was landed (Global R = -0.013, significance = 0.712).

(1) Vessel clusters by species composition

A cluster analysis identified 12 different separate groupings of annual species composition by trawler using an 80% similarity threshold. Six of the dendrogram groupings contained only one or two samples each and were excluded from further grouping (these groups landed 2,148 tons or 5.4% of the total landings over the study period). The six remaining groupings were assembled into five clusters, identified as groups *a* through *e*. Two of the six groupings were combined into group *e* following a SIMPER analysis that identified the groupings as having catch compositions more than 80% similar.

Groups *a* through *e* landed in total approximately 34,736 tons, representing approximately 86.9% of the total landings harvested over the study period. Groups *a* through *e* can be separated into two different categories dependent upon the amount of sole landed: A SIMPER analysis revealed that the defining species for group *a* was sole, averaging 33.62% (± 5.39 SD) of group *a*'s total catch, as compared to a range of sole proportions of 0.65% (± 0.96 SD) to 7.41% (± 4.37 SD) across the remaining groups. Vessels within group *a* are hereafter referred to as "sole-directed."

The sole-directed group *a* landed approximately 4,140 tons over the study period, representing approximately 10.4% of the total landings over the study period. The average catches for group *a* are similarly proportioned among sole (33.62% ± 5.39 SD), hake (27.73% ± 5.21 SD), and by-catch (25.96% ± 3.97 SD) (Figure 4; Table 1). The three top by-catch species by landed weight for group *a* are skate, silver kob and gurnard (Table 1; Appendix 3).

Groups *b* through *e* are distinguished primarily by the amount of hake and by-catch landed and will hereafter be referred to as the "hake-directed" groups (Figure 4;Table 1). The proportion of by-catch landed appears to vary inversely to the proportion of hake landings (Figure 4). On one end of the spectrum, group *b* landed the most hake (75.58% ± 3.78 SD) and least by-catch (16.84% ± 3.19 SD); on the other end is group *e*, which landed the least hake (34.56% ± 5.23 SD) and the most by-catch (58.88% ± 6.5 SD) (Figure 4;Table 1).

Group *b* landed approximately 10,576 tons over the study period, representing approximately 26.5% of the total landings. The group *b* fishing strategy is centred around hake (Figure 4). The two dominant by-catch species are panga and squid, followed by horse mackerel and skates (Table 1; Appendix 3).

Group *c* landed approximately 9,050 tons over the study period, representing approximately 22.6% of the total catch. The group *c* strategy is predominately hake (60.04% ± 5.07 SD) but with a substantial proportion of by-catch (31.48% ± 5.09 SD) (Figure 4). The three top by-catch species were panga, horse mackerel, and squid (Table 1; Appendix 3).

Group *d* landed approximately 4,361 tons over the study period, representing approximately 10.9% of the total catch. The group *d* fishing strategy is evenly split between hake (42.64% ± 5.02 SD) and by-catch (42.71% ± 4.62 SD), with 7.41% ± 4.37 SD of the catch represented by sole (Figure 4). The three top by-catch species were panga, horse mackerel and gurnard (Table 1; Appendix 3).

Group *e* landed approximately 6,608 tons over the study period, representing approximately 16.5% of the total catch. The group *e* fishing strategy is primarily by-catch (58.88% ± 6.5 SD) with hake coming in second (34.56% ± 5.23 SD) (Figure 4). Group *e* samples landed substantial amounts of panga (32.31% ± 5.32 SD), followed by horse mackerel (15.11% ± 9.32 SD) and squid (4.33% ± 1.41 SD) (Table 1; Appendix 3).

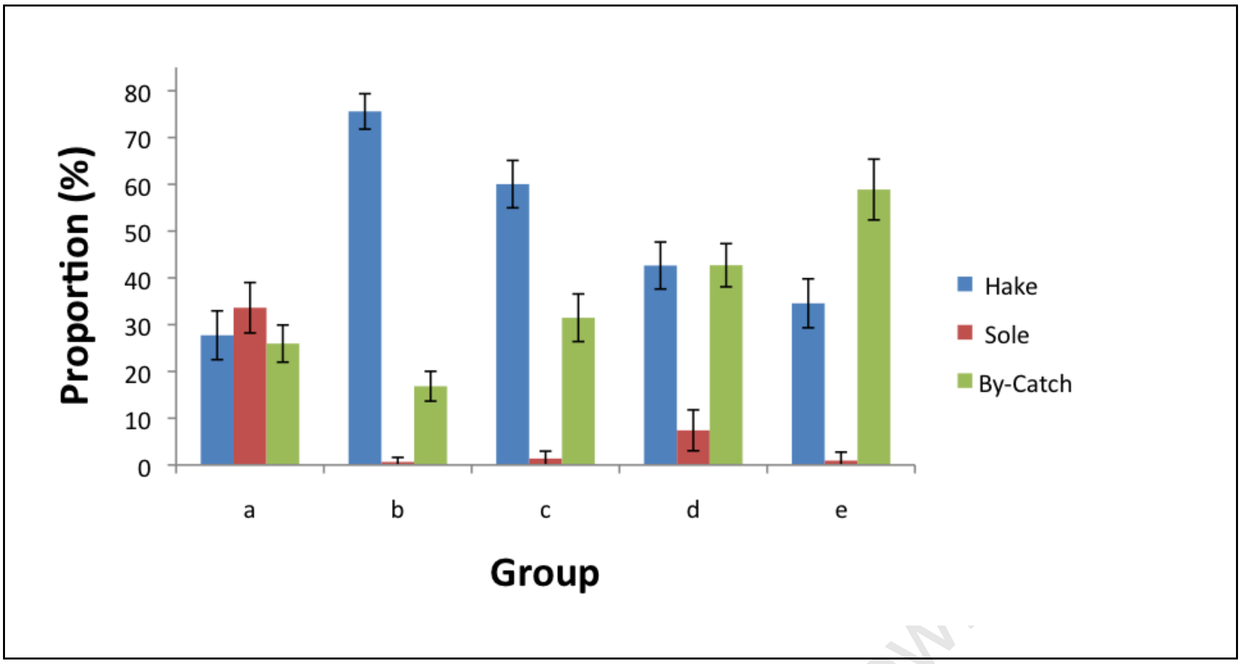

Figure 4. Average proportion of hake, sole, and by-catch (total) landed by each of the five core trawler groups over the study period. Error bars represent the standard deviation.

Table 1. Average proportion and coefficient of variance of the 14 nominal species categories and by-catch (summed) landed by Groups *a* through *e*, based upon annual landings per core trawler.

	Group a	CV	Group b	CV	Group c	CV	Group d	CV	Group e	CV
Hake	27.73	18.79	75.58	5.00	60.04	8.44	42.64	11.78	34.56	15.13
Sole	33.62	16.04	0.65	147.69	1.38	114.11	7.41	58.94	0.94	194.55
Panga	1.36	83.21	5.23	28.45	13.31	27.59	19	21.55	32.31	16.47
Horse Mackerel	0.21	143.12	1.77	55.19	6.27	70.40	5.85	45.34	15.11	61.66
Kingklip	0.28	37.60	0.6	78.12	1.37	82.81	1.13	50.06	0.61	63.58
Squid	2.28	38.22	4.41	28.97	3.31	32.86	3.24	20.47	4.33	32.49
Silver kob	5.72	32.31	0.48	72.96	0.92	68.25	2.56	48.99	0.67	106.44
Gurnard	4.54	60.78	1.39	31.30	2.29	58.36	4.37	24.86	2.55	51.41
Carpenter	0.19	104.46	0.09	96.45	0.33	112.76	0.51	79.10	0.74	83.21
Skate	7.49	37.17	1.78	41.81	1.04	76.06	2.49	60.68	0.85	69.28
Shark	2.6	29.21	0.4	56.25	1.03	96.83	2.71	55.55	0.59	102.28
White Stumpnose	1.27	25.89	0.24	95.59	0.39	94.38	0.62	58.52	0.68	43.29
Monkfish	0.01	181.45	0.43	106.90	1.21	101.67	0.23	141.06	0.43	51.98
Other species	12.7	14.72	6.93	32.90	7.1	40.42	7.25	37.79	5.62	25.98
By-Catch (total)	25.96	15.29	16.84	18.92	31.48	16.17	42.71	10.81	58.88	11.04

Table 2. Average proportions of the 14 species categories landed by hake- and sole-directed trawlers over the study period. The coefficient of variance (CV) per species category is also listed.

	Hake-Directed		Sole-Directed	
	Proportion (%)	CV (%)	Proportion (%)	CV (%)
Hake	58.01	26.29	25.77	31.36
Sole	2.69	162.87	35.54	22.72
Panga	13.04	70.48	1.3	84.97
Horse Mackerel	6.56	116.09	0.2	148.65
Squid	3.56	38.63	2.48	52.55
Gurnard	2.48	62.31	4.45	59.41
Kingklip	1.02	106.42	0.28	38.52
Skate	1.63	79.10	7.14	40.85
Monkfish	0.87	227.03	0.03	281.40
Silver kob	1.24	109.34	6.09	38.83
Shark	1.08	113.85	2.81	38.72
White Stumpnose	0.45	84.12	1.19	35.46
Carpenter	0.32	119.13	0.18	106.70
Other species	7.05	37.30	12.57	15.17
Quota species	60.7	23.12	61.31	5.29
By-catch	32.25	44.49	26.13	14.66
Other Catch	39.3	35.71	38.69	8.38

(2) Trawler participation by group over time & group consistency over time

There is a clear demarcation of the 19 core trawlers into 5 sole-directed trawlers and 14 hake-directed trawlers that was consistent over the study period. Five trawlers had catch compositions that clustered them into group *a*. Over the study period, these five trawlers were exclusively within group *a* or within an omitted group that was within the same left fork of dendrogram branching as group *a* (Table 3; Appendix 2), with one exception for one year. These left-fork dendrogram groups are collectively more than 60% similar to one another and less than 40% similar to the remaining groups (the right fork of the dendrogram). As detailed above, the reason for this large intra-similarity of the left-fork dendrogram groups and inter-dissimilarity among the remaining groups is the proportion of sole landed.

Of the 19 trawlers, 7 showed consistent catch compositions that grouped them in the same cluster for all five years of the study period (Table 3). Nine trawlers fell within two groups and three grouped into three or more clusters during the study period (Table 3).

The similarity of samples within each group was high, ranging from 83.28% to 93.70% (Table 3). At the vessel level, the similarity of samples ranged from 74.08% to 95.65% (Table 3).

Table 3. The number of years each core trawler was represented in a particular group (including the omitted groups, "groups x") during the study period, along with the average similarity (%) of samples within each group. Separately, the average similarity (%) per trawler is also provided.

Trawler	Group a	Group b	Group c	Group d	Group e	Groups x	Similarity (%)
Avg. Similarity (%)	85.89	93.70	86.54	85.65	83.28	--	--
T1			5				89.52
T17	5						87.98
T19	5						90.83
T20		5					94.23
T30					5		87.22
T31		5					95.65
T32		5					95.16
T4						2	76.82
T12			3			2	80.5
T14	3					1	77.17
T15		3	2				90.91
T16				3	2		81.05
T25	3					1	74.08
T27			1	4			81.81
T28			3	2			84.51
T33	4					1	78.54
T10		1	2			2	77.84
T6		1	2	2			82.58
T9		1	2	2			80.38

(3) RELATIONSHIPS BETWEEN PROPORTIONS OF LANDED QUOTA SPECIES AND BY-CATCH

The average proportion of by-catch landed across trawlers over the study period varied from a minimum of 14.1% to a maximum of 60.9%, with the median at 28.9% (Figure 5). The five sole-directed core trawlers had a less variable range of by-catch proportions (22.7% to 28.9%) than the hake-directed trawlers (Figure 5).

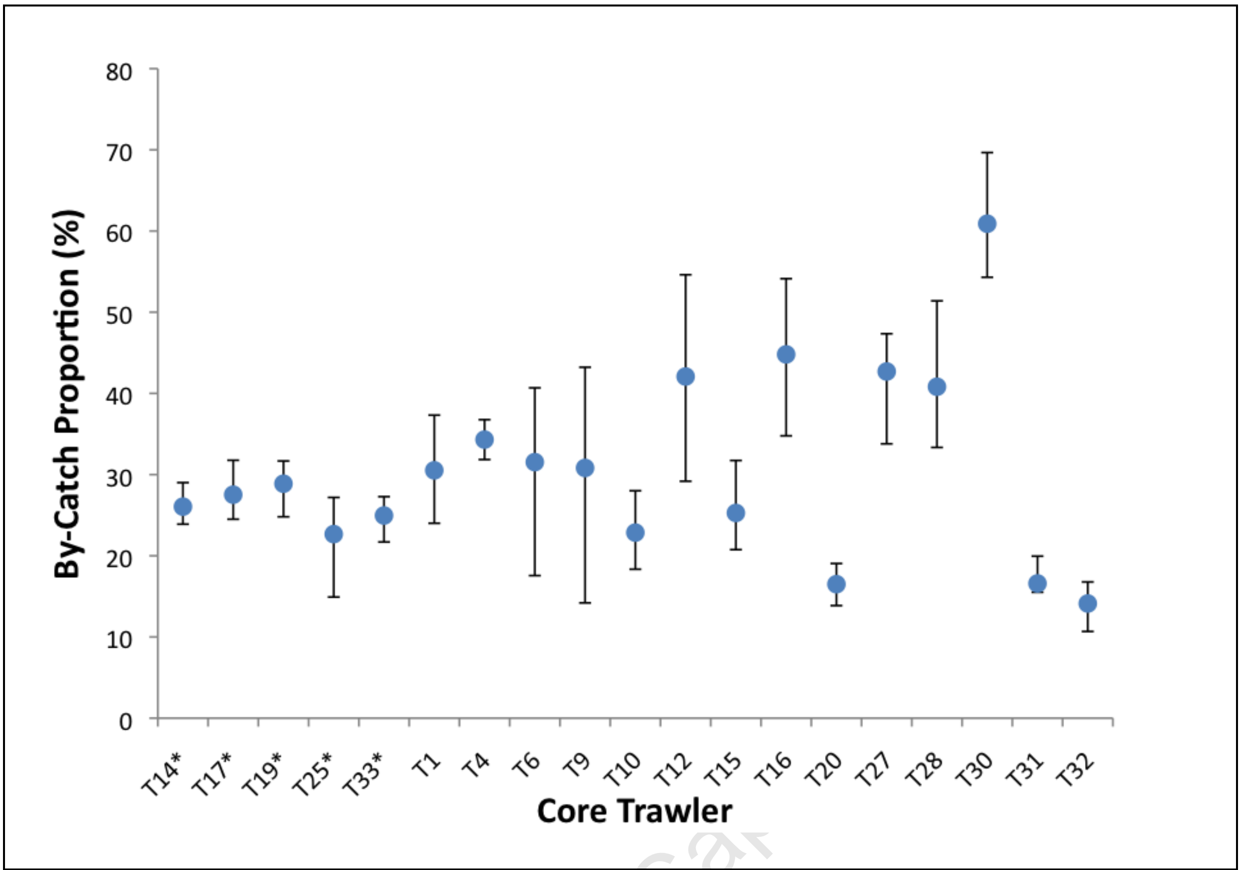

Figure 5. Proportion of annual by-catch landed by trawlers averaged over the study period. Errors bars represent the range of annual values. The "*" on five x-axis labels identifies the trawler as a sole-directed vessel.

There were 67 annual samples for the hake-directed trawlers and 23 annual samples for the sole-directed trawlers. The proportion of by-catch landed by the hake-directed trawlers varied (negatively) with the amount of hake landed, although only a small proportion of the variation is explained by this relationship ($F_{1,68}$ = 7.49, p=.0079, Adjusted R^2 = 0.086) (Figure 6). The proportion of by-catch landed by the sole-directed core trawlers was similarly negatively related to the amount of sole landed ($F_{1,15}$ =6.27, p=0.024, Adjusted R^2 = 0.25) (Figure 6).

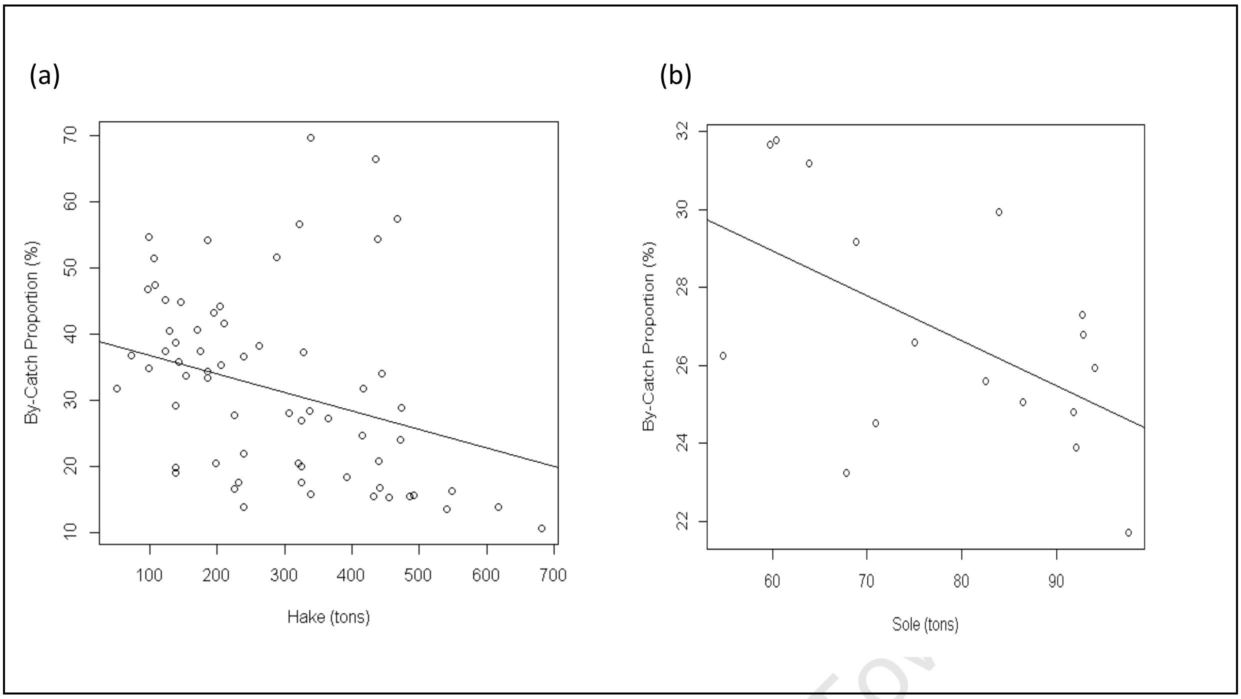

Figure 6. Proportion of by-catch landed annually versus (a) hake landings within the hake-directed groups (groups *b-e*) and (b) sole landings within the sole-directed group (group *a*). Slope of linear fit taken from significant linear models reported in the text. Note that samples with hake or sole catches of less than 50 tons have been omitted (see Methods).

ii) VARIATION BY RIGHTS HOLDER

(1) RIGHTS HOLDER CLUSTERS BY CATCH COMPOSITION

The landings data identified 23 rights holders, including the 17 with LTRAMP quota allocations. Five of the six additional non-LTRAMP entities were combinations of existing LTRAMP rights holders for whom the landings were not apportioned by trip or an offshore entity that was given limited authorization to fish inshore during the study period. The records for these five entities were excluded, consisting of 247.6 tons or approximately 0.6%, of the landed biomass. The remaining entity merged with an existing rights holder and, thus, its catches were merged with the existing LTRAMP rights holder.

A total of 72 annual sample records were analyzed for the 17 rights holders. Catch composition differed significantly among the rights holders during the study period (ANOSIM; Global R = 0.421, significance = 0.001), but did not differ significantly among years (ANOSIM; Global R = 0.015, significance = 0.25). The second hypothesis, therefore, that catch composition of annual landings varies among rights holders is accepted.

A cluster analysis identified 14 catch composition groups at an 80% similarity threshold (Appendix 4). Those clusters which contained three or fewer samples were excluded from further analysis. The 16 samples omitted in this way represented 2008.3 tons of catch or approximately 5.0% of the total landings over the study period.

The remaining four clusters – named groups *f*, *i*, *j* and *l* – landed in total 37,524.9 tons (approximately 93.5%) of the landed biomass over the period. The clusters varied substantially by total weight landed (between 1,768.23 tons and 15,707.74 tons). Each group contained samples for each year of the study period except that group *i* did not contain samples for the year 2008.

A SIMPER analysis of the species proportions showed that the groups are primarily distinguished by the proportion of by-catch landed, in descending order from group *f* – with over 50% of the catch represented by by-catch – to group *l*, with approximately 7% by-catch (Figure 7). The composition of by-catch differed notably (Table 5; Appendix 5). Group *f* had a large proportion of by-catch (Figure 7) predominantly composed of panga and horse mackerel (Table 5; Appendix 5). Group *i* is distinguished by its relatively low biomass landings (approximately 4% of total landings) and its substantial proportion of kingklip (2.84 ± 1.09%)(Table 5; Appendix 5). Group *j* has notable proportions of sole (7.12 ± 2.78%) and panga (11.67 ± 2.16%). Landings in group *f* were dominated by hake (76.72 ± 2.82%); and the small by-catch proportion was dominated by panga (4.51 ± 0.67%) and squid (3.87 ± 0.37%).

The similarity of samples within each of the four groups ranged from 84.56% to 87.82% (Table 5), with an average similarity across groups of 85.76 (± 1.42%). Within rights holders, the similarity of samples ranged from a low of 32.54% to a high of 95.94% (Table 5).

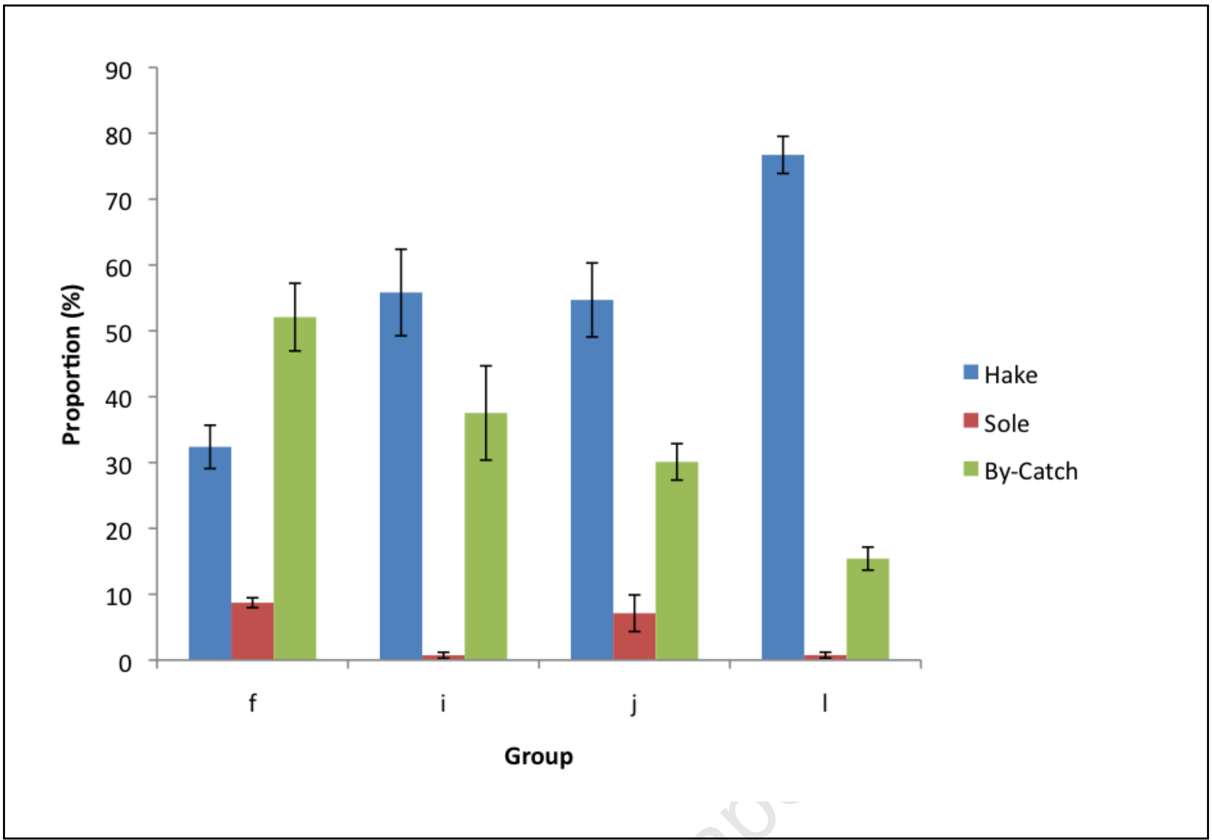

Figure 7. Average proportion of hake, sole, and by-catch landed by the four rights holder groups over the study period. Errors bars show the standard deviation.

Table 4. Average proportion (%) and coefficient of variance (CV, %) of the 14 nominal species categories and by-catch (total) for Groups *f*, *i*, *j* and *l*, based upon annual landings per rights holder.

	f		i		j		l	
	Proportion (%)	CV (%)	Proportion (%)	CV (%)	Proportion (%)	CV (%)	Proportion (%)	CV (%)
Hake	32.38	10.16	55.82	11.76	54.69	10.27	76.72	3.68
Sole	8.72	8.58	0.73	63.07	7.12	39.04	0.77	57.41
Panga	23.8	20.97	12.74	40.33	11.67	18.52	4.51	14.93
Horse Mackerel	13.23	28.04	15.25	19.79	3.69	24.09	1.85	23.35
Kingklip	0.49	38.19	2.84	38.47	0.93	39.58	0.56	55.95
Squid	4.04	24.96	1.89	29.97	3.65	18.50	3.87	9.42
Silver kob	1.76	22.13	0.86	46.19	2.07	28.58	0.49	57.99
Gurnard	3.36	22.29	1.47	43.89	2.79	28.60	1.29	20.04
Carpenter	0.6	71.83	0.09	82.58	0.31	83.82	0.09	66.35
Skate	2.55	35.87	0.42	105.45	2.19	18.94	1.79	26.84
Shark	1.13	59.66	0.56	57.18	1.43	19.14	0.4	64.83
White Stumpnose	0.85	19.35	0.16	94.92	0.52	52.10	0.25	80.85
Monkfish	0.3	31.07	1.25	47.20	0.86	58.56	0.32	69.24
Other species	6.81	24.09	5.92	24.65	8.08	7.42	7.1	21.697
By-Catch	52.09	9.86	37.53	19.08	30.11	9.19	7.1	21.69

(2) RIGHTS HOLDER PARTICIPATION BY GROUP OVER TIME

The compositions of rights holders showed some consistency over time, in that the majority of rights holders clustered within one or two groups throughout the study period (Table 5).

Table 5. The number of years each rights holder was represented in a particular cluster of similar catch compositions (including the omitted groups, as groups x), along with the average similarity (%) of samples within each group. The average similarity (%) within rights holders is also provided.

Rights Holder	Group f	Group i	Group j	Group l	Groups x	Similarity (%)
Avg. Similarity (%)	85.31	85.36	84.56	87.82	--	--
C2			5			80.85
C3			3	2		78.84
C4		2		1	2	74.36
C5		3			2	77.66
C6					3	59.97
C10				5		95.94
C13				2	2	32.54
C14			3	2		75.64
C16			5			88.33
C17		1			3	41.66
C18	5					88.34
C21	2		1		2	72.93
C22		1	4			86.3
C23			3	2		81.25
C24				1	1	68.56
C27					1	n/a
C28			1	2		75.34

(3) ANALYSIS OF RIGHTS HOLDERS BY QUOTA ALLOCATIONS

The hake base percentage allocations for the 17 rights holders ranged between 0.65% and 34.05%. The average allocation was 5.88% (± 8.84 SD) and the median was 2.48%. The sole base percentage allocations ranged between 0.93% and 31.60%. The average allocation was 5.88% (± 8.16 SD) and the median was 2.47%.

A weak negative relationship was identified between the proportion of by-catch landed annually by rights holders and their hake quota (base percentage) ($F_{1,69}$ = 6.49, p=0.013, Adjusted R^2 = 0.073; Figure 8). The proportion of by-catch was not found to vary significantly by the size of sole quota ($F_{1,69}$ = 0.219, p=0.642, Adjusted R^2 = -0.0113). One sample contained zero by-catch and was excluded from analysis because it represented a once-off trade in quota species among two rights holders. The third hypothesis, therefore, that the proportion of landed by-catch is related to the size of quota allocated to the rights holder is rejected in regards to the sole quota. The hypothesis is also rejected in regards to the hake quota even though a significant relationship was identified because the relationship explains a small proportion of the variation, as depicted in Figure 8 (Adjusted R^2 = 0.073).

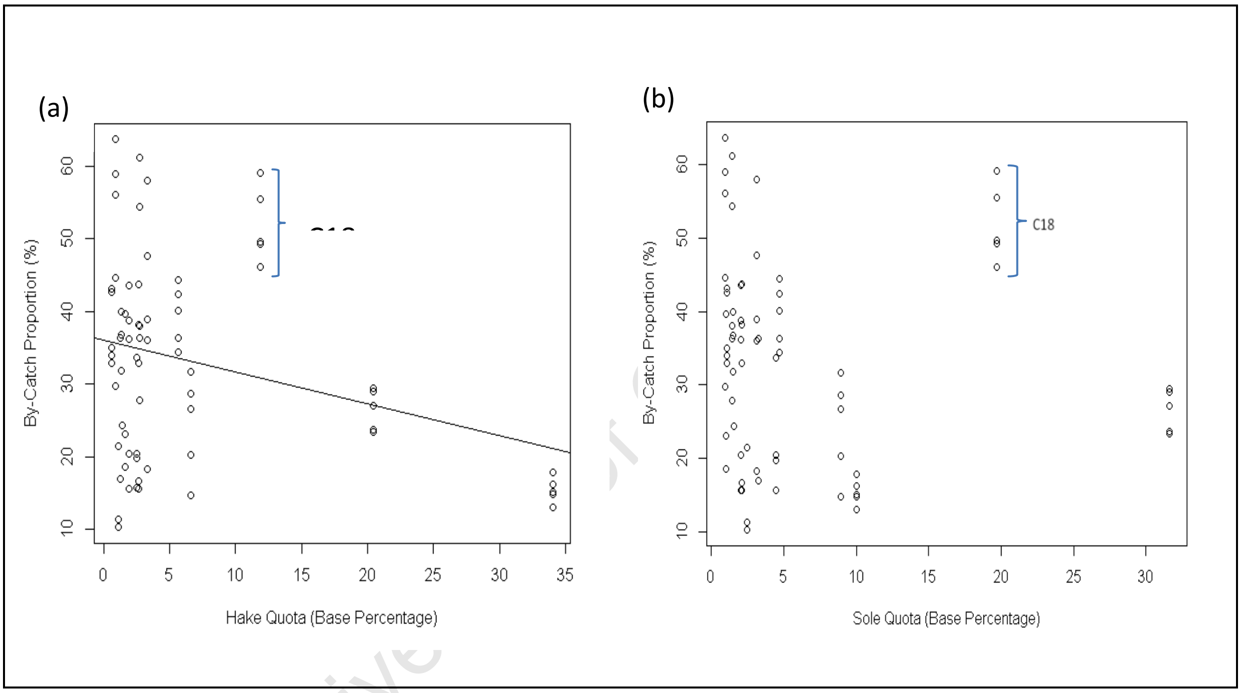

Figure 8. Proportion of by-catch landed annually by rights holder versus (a) hake quota (base percentage) and (b) sole quota (base percentage). Slope of linear fit taken from significant linear models reported in text.

iii) Selective discarding and market influence

There were 21 quarterly samples omitted as the trawler with whom the omitted samples were associated did not conduct trips in each quarter of that year, resulting in a total of 312 samples analyzed. All samples for trawler T4 were omitted because T4 did not fish in each quarter of at least one year, resulting in a total of 18 trawlers analyzed. A relationship was found between the proportion of hake landed and the quarter of landing across the 18 core trawlers combined ($F_{3,308}$=

6.117, p=.00047) (Figure 9), but not between the proportion of sole landed and quarter of landing ($F_{3,308}$= 0.096, p=.962). The fourth hypothesis that the proportion of hake landed across the core trawlers varies in a consistent pattern by quarter is, therefore, accepted.

At the individual trawler level, a significant relationship was found for ten trawlers between the proportion of hake landed and the quarter of landing (Appendix 6) but not for the remaining eight core trawlers analyzed. The ten significant trawlers can be split into a group of three trawlers (Figure 10) that show an increase in Q2 followed by a downward trend to Q4; a group of five trawlers in a "u" shaped curve with higher catches in the first and fourth quarters; and two remaining trawlers that generally follow a downward trend. There was one significant relationship found between trawler T6 for its proportion of sole landed and the quarter of landing ($F_{3,16}$= 3.55, p=.034).

There were no significant differences found in the catch composition of the four hake market grades among the core trawlers by quarter (Global R = -0.005, significance = 0.92) (Appendix 7). The catch composition of the four hake market grades did differ significantly by trawler, however (Global R = 0.62, significance = 0.001) and also differed by year (Global R = 0.037, significance = 0.001).

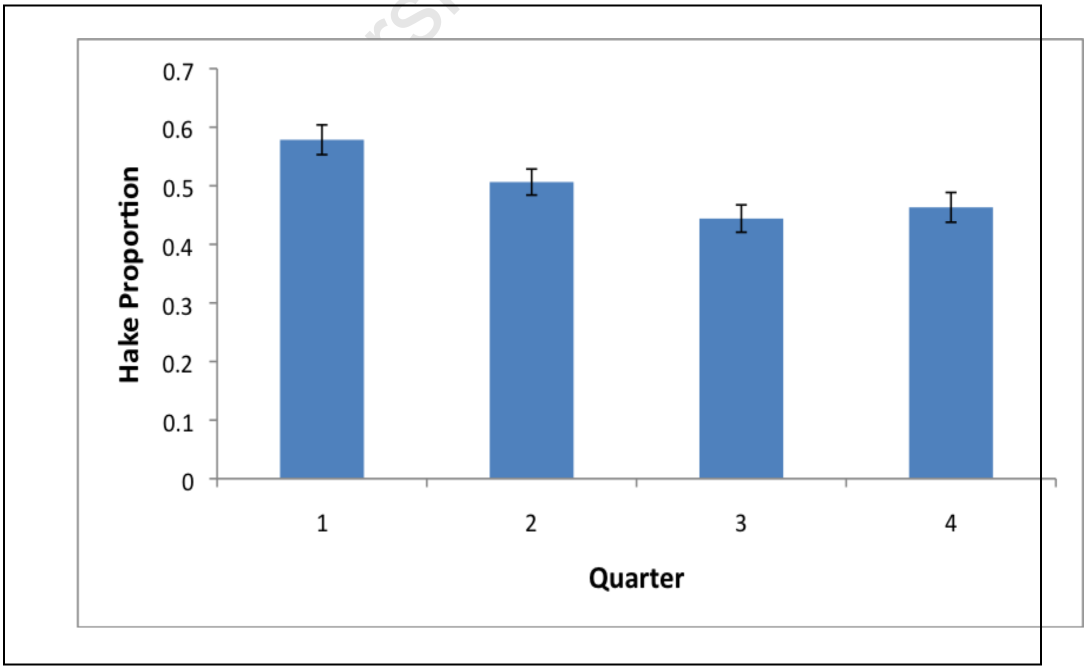

Figure 9. Average proportion of hake landed by the core trawlers, out of the total landed catch, per quarter. Error bars represent the standard error.

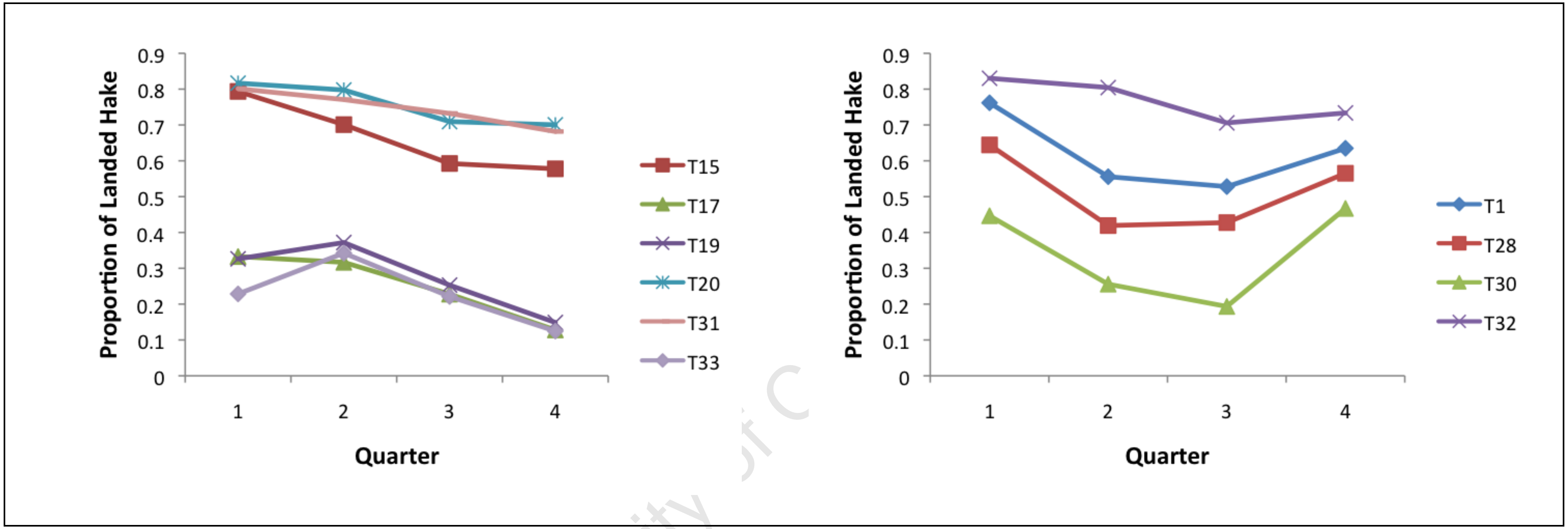

Figure 10. Average hake catch landed per quarter for each of the 10 trawlers whose hake catches varied significantly among quarters (as identified by the ANOVA analysis).

IV. Discussion

The weight of landed catch increased over the course of the study period even though the fishing fleet decreased from 32 to 19 vessels, suggesting that the fleet had been over-capitalized or that the remaining fleet became more efficient or increased effort. During the study period, the increase in by-catch landings substantially outpaced increases in hake but not sole landings. The sole landings increased in each year of the study period as compared to the prior year except for the last year (2011), in which the landings decreased relative to 2010.

This trend is disconcerting because it suggests that the fishery may be increasingly targeting by-catch species. Alternatively, the increased landings could also be explained by increases in the abundance of by-catch species. Comparing the last year in the study period to the first, there were large increases of certain species, e.g., carpenter (580%), white stumpnose (89%), and silver kob (75%), amidst more modest declines of others. Several of the by-catch species that have increased are of conservation concern. In the DAFF 2012 status of marine fisheries, carpenter was listed as "depleted" and silver kob as "heavily depleted" (DAFF 2012).

A comparison with prior analyses of the average landed catch of kingklip and monkfish, two species that have been the focus of management concern (Leslie 2004), suggest an increased proportion of these species is being landed. The average proportion of kingklip landed (expressed as a percentage of landed hake), was found to be 0.79% for the years 1990 to 2001 in the inshore trawl fishery (for selected landings in which horse mackerel did not comprise > 25% and sole did not comprise > 10%; Leslie 2004). Using the same criteria for this study period, the average proportion of kingklip landed was 1.97%, representing an increase of approximately 150% from the prior study. In the same comparison, for monkfish the percentage of landed hake was 0.70% over the period 1990 to 2001 (Leslie 2004), whereas in this study, it was 1.29%, representing an increase of approximately 84%.

Despite these increases, the catch of four by-catch species of concern have remained within the informal precautionary limits provided by the fishing sector. Industry targets for the inshore sector were set for silver kob (200 tons), kingklip (200 tons), monkfish (~60 tons) and horse mackerel (2500 tons) (P. Sims, personal communication). Over the study period, landed catches of silver kob averaged 121 tons (± 24 SD), kingklip averaged 89 tons (± 10 SD), monkfish averaged 50 tons (± 12 SD), and horse mackerel averaged 538 tons (± 89 SD). As noted, there is disagreement between the inshore and offshore sectors regarding what the monkfish target for the inshore sector should be.

While the permit also incorporates reference period averages for kingklip, monkfish, and kob, to which the rights holders should comply, the historical averages were unavailable for comparison.

a) Variation by vessel

Species composition varied significantly by core trawler. A major point of divergence separating the composition of the trawlers' catches was whether the trawler was hake- or sole-directed, as was anticipated. Both hake- and sole-directed vessels landed similar proportions, ~39%, of "other catch" (inclusive of the "other species" category not included in most analyses above), although the variation about this average was far greater for the hake-directed vessels than for sole-directed vessels. This is largely in accord with Attwood et al. (2011), who found a total by-catch proportion of 42% across both hake- and sole-directed catches based on data obtained from an at-sea observer programme over the period 2002 to 2006. The proportion of other catch also falls within the 47% estimate for the hake-directed groups, but is greater than the 22% estimate for the sole-directed groups, for the years 1996 to 2000 reported by Walmsley (2006).

The larger coefficient of variance for by-catch for hake-directed groups (approximately 45%), as compared to the sole-directed groups (approximately 15%), indicates that more by-catch directed fishing may be occurring in the hake-directed groups. The large coefficient of variance reflects that hake-directed fishers employ different fishing strategies: Some land a large proportion of hake whereas others land less hake and more by-catch. This variation could be explained by the natural variability in species composition associated with hake-related habitats compared to sole habitats or differences in mesh size as sole-directed vessels have a smaller required minimum mesh size (75mm) than hake-directed vessels (90 mm; DAFF 2010).

These findings of greater variability in the landings of by-catch species by hake- and sole-directed trawlers are corroborated by the coefficients of variance for by-catch species as reported in Table 2. Seven by-catch species have coefficients of variance of average proportion greater than 100% for the hake-directed groups, as compared to three species for the sole-directed groups. The hake-directed fishers, thus, land different proportions of several by-catch species, indicating that targeting may be occurring. If the by-catch were purely incidental, the coefficients of variance would likely be relatively low. However, some of the variance may be due to different species compositions (and relative proportions) associated with different hake fishing grounds, making it difficult to conclusively determine if by-catch species are being targeted and by how much. DAFF has available geographically-referenced data for each trawl trip but these data were not analyzed in connection with this thesis.

The species composition of by-catch differed substantially among the hake- and sole-directed groups. The three most dominant by-catch species for sole-directed trawlers were skates, silver kob, and gurnard. For the hake-directed trawlers (collectively), the three species were panga, mackerel, and squid. Based on catch composition, the hake-directed trawlers can be further divided into four groups (*b* through *e*), distinguished principally by the amount of hake and by-catch landed.

The relative proportion of by-catch species varied substantially between the hake groups, with different species dominating the proportion of by-catch landed among groups. These landing patterns are fairly consistent over the study period. Year was found not to significantly explain differences in the species composition of core trawlers across the study period; not surprisingly, trawlers showed high fidelity to the five groups across the study period.

According to (Leslie 2004), all hake-directed groups, except for group *b*, would be classified as "targeting" fish other than hake since the average hake proportion of landings is less than 75%. Groups *d* and *e*, in particular, landed a greater proportion of by-catch than hake, which seems to be strong evidence that trawlers are employing a strategy to increase by-catch landings. Such apparent by-catch targeting strategies by certain trawlers are also apparent in the annual proportions of by-catch landed among trawlers, which ranged from 14% to 61% over the study period.

These catch patterns and the mixed-species nature of the community composition within the inshore trawl grounds (Japp et al. 1994), warrant a paradigm shift in perception of the fishery. The inshore trawl grounds represent a mixed-species fishery that should be regulated as such. The industry term "joint product" seems more apt than "by-catch" to describe the mixed catches within the inshore trawl grounds.

i) USING QUOTA-SPECIES CATCH AS THE BASIS FOR A BY-CATCH ALLOCATION

Among both hake- and sole-directed trawlers, the proportion of by-catch landed does not appear to correlate strongly with the amount of hake or sole landed. While there were significant (negative) relationships found between the landings of quota species and proportion of by-catch, they explained a small proportion of the variability in the data (8.6% for hake-directed samples and 24.8% for sole-directed samples).

The results do not strongly support a pro rata allocation of by-catch dependent on the size of the hake or sole landed catch. The data suggest that such a pro rata allocation would be in tension with the status quo in the industry, and, would likely be viewed as inequitable to a substantial number of industry participants. It is recognized that the more accepted a regulatory approach is by fishers, the more likely it is to be complied with (Beddington et al. 2007).

In sum, these results suggest that future regulatory programmes addressing by-catch within the fishery should take into account the distinction between hake- and sole-directed fishing patterns. Further, the results suggest an alternative method of allocating by-catch PUCLs, which may be superior to a pro rata allocation, which is to recognise the different fishing strategies within the fishery (as demonstrated by the five fishing groups, Figure 4) that are driven by groupings of distinct catch compositions. Each group landed a unique proportion of by-catch species, which seems relatively consistent over multiple years. Further analysis is warranted to use these patterns of catch compositions to develop by-catch species allocations in a future by-catch allocation programme.

b) *VARIATION BY RIGHTS HOLDER*

Species composition varied significantly among the landings of different rights holders, with four separate groups being identified based on their catch compositions. These groups landed 93% of the catch over the study period and are representative of the fishery.

The different groupings and the relative proportions of species landed by rights holders within these groups likely reflect different economic strategies employed by the rights holders. Leslie (2004) suggests that a hake-directed catch containing less than 75% hake indicates targeting (at least in part) of a species other than hake. Using that threshold, the only rights-holder group that would be considered solely hake-directed would be group *l*, which caught 26.2% of the total landings during the study. The remaining three groups, representing approximately 67% of the total landings, would be considered to be targeting "joint product" to some degree.

The range in by-catch landed across the four groups highlights the different market strategies undertaken by the rights holders (Figure 7). Rights holders in group *f* landed the most by-catch – substantially larger than their landings of hake or sole – with an average proportion greater than 52%. By contrast, rights holders in group *l* landed on average 7% by-catch. These highly divergent by-catch proportions, on either side of the threshold suggested by Leslie (2004) and the average suggested by Attwood et al. (2011), indicate strategies to maximise (group *f*) and minimize by-catch (group *l*). The other two groups, *i* and *j*, displayed average by-catch proportions of 30 and 38%, respectively.

The same five species – panga, horse mackerel, squid, gurnard, and skates –dominate the by-catch landings across all four groups (except that kingklip replaced skates in group *i*), however, the proportions of these species vary greatly across the groups suggesting that an active market could be established among group participants.

The high similarity of samples within the four groups (on average approximately 85%), together with the fact that the majority of rights holders consistently fell into one or two groups, suggests that the catch compositions are relatively stable over time. In sum, the results underscore the "joint product" nature of by-catch in the fishery and the advisability of including formal regulatory measures incorporating select by-catch species. They also suggest that an initial PUCL allocation by rights holder on the basis of four principal clusters of catch composition could be appropriate. Rights holders could be assigned base allocations of by-catch species in accordance with the groups they have fished. Some further analysis would be needed to effectively accommodate rights holders that participated in more than one group.

i) USING QUOTA-SPECIES CATCH AS THE BASIS FOR A BY-CATCH ALLOCATION

The proportion of by-catch was found to be negatively related to rights holders' allocations of hake but not of sole. The cause of the weak relationship is the substantial variation in the proportion of by-catch landed among small hake quota holders (those with less than 5% of the base percentage allocation). A similar pattern is observed for the sole quota holders with small base percentages. This variability suggests that while it may be that some small quota holders seek to supplement their revenue by targeting by-catch (Walmsley 2004), it is not a strategy shared by all small quota holders.

Conversely, the negative relationship between by-catch proportion and the size of the hake allocation and landings suggest that large quota holders generally rely less on by-catch species. Notably, however, one company (C18), had large quota holdings of both hake and sole but landed a substantial portion of by-catch throughout the study period, ranging from 46 to 60% of its annual catch (Figure 8).

The implication for a future ITQ programme is that a pro rata allocation of by-catch PUCLs based on the size of the hake or sole allocation would be inconsistent with current practice. The variability in proportions of by-catch landings among quota holders would render either a direct pro rata allocation or an inverse pro rata allocation inequitable (based on recent practice) to many participants in the fishery.

c) Selective discarding and market influence

The amount of hake landed varied significantly by quarter across the trawlers. This appears due to elevated landings in the first quarter and smaller landings in the third and fourth quarters. Analysis of the quarterly landing patterns by the ten individual trawler for whom there were significant results, however, revealed three principal patterns. The patterns show opposing trends, which suggests that seasonal hake catchability may not account for all patterns observed. There are several reasons that could account for the differences, such as different trawling grounds, selective discarding by some trawlers, and the weather, among others.

Fishing effort also does not appear to explain the trends. The hake landings were standardized by the total landed fish catch per quarter thus accounting for any increases or decreases in effort. The quarterly patterns in hake landings are also not apparently explained by an increase in particular grades of catch by quarter. There was no significant relationship found between the composition of hake grade and the quarter in which it was landed.

Sole landings per quarter were not found to vary significantly across trawlers, although there was a significant result for one trawler. This one exception could be explained by the Type I error rate. With a sample size of 18 trawlers and a 5% significance level, nearly one response (0.9) is anticipated to return with a significant result even though the null hypothesis should be accepted (i.e., likely a false positive) (Quinn & Keough 2002). Thus, there do not seem to be significant patterns of sole landings by quarter.

In sum, there are significant differences in the proportion of hake landed by certain vessels by quarter that are not fully explained by changes in effort or seasonal availability. Analysis of hake market grades per quarter does not indicate that particular grades of hake are being preferred over others. Additional data collection, particularly through at-sea observer data, is recommended to determine whether the patterns observed are caused by selective discarding or some other factors, such as preferred trawl grounds.

CHAPTER 3: STUDY REVIEW

I. Conclusion

The inshore trawl fishery lands substantial catches of by-catch and these landings appear to be increasing over time. The data also suggest an economic reliance on by-catch by the majority of participants in the fishery. This fact need not be negative to the industry, fishery management, or conservation. Rather, it is a reality that regulatory schemes should adapt to and properly manage to keep exploitation within sustainable limits.

This study's investigation of by-catch fishing patterns within the inshore trawl fishery identifies discrete patterns of fishing behaviour by industry participants that are consistent over time. These patterns signal that an ITQ programme may be a suitable approach to sustainably manage the exploitation of high priority by-catch species within the fishery.

A future ITQ programme will need to decide, as a preliminary matter, on which basis to conduct an initial allocation of select by-catch species PUCLs. The analyses conducted here suggest that PUCLs could be assigned on the basis of clusters of fishing strategies either by vessel or by rights holder. It is recommended that discussions with industry occur to identify which basis is the most practical from an implementation and management perspective.

If allocations are made on the basis of vessel, they should distinguish between hake- and sole-directed vessels. These vessels are distinguished both in the proportion and composition of by-catch landed. Further, among the hake-directed vessels, there are subgroups of different fishing strategies with different compositions of by-catch species. The trawlers showed high fidelity to these fishing strategies. Thus, an allocation of by-catch PUCLs on the basis of these fishing patterns would appear to be in keeping with existing practice. This is also in keeping with ITQ allocations worldwide, which are predominantly based on historical fishing records (Armstrong 2007).

PUCL allocations on the basis of hake and sole quota size are not recommended because there does not appear to be a strong relationship between the size of the hake or sole quota and by-catch landings. While as a general matter it appears that larger quota holders rely less on by-catch, this relationship was not strong and there were exceptions. A high proportion of by-catch was found among both small and large quota holders.

An analysis of the DAFF-managed effort control programme is warranted to see if a pilot ITQ programme with by-catch PUCLs could feasibly be added to the existing programme. It appears that under the programme limited in-season trading of quota species is already occurring among fishery participants. Finally, the results suggest that significant patterns of hake landings by quarter exist for some trawlers but there could be several explanations for these patterns although there does not appear to be evidence of high grading of hake across the fishery.

II. FUTURE RESEARCH

There are three issues that should be further examined in conjunction with a pilot ITQ programme: Discard estimates, the "other species" category, and geographical referencing of trawl trips.

First, the data examined in this study consists entirely of "landings" data. In other words, only fish that were kept on board and not discarded at sea were recorded. At sea discards are a substantial feature of commercial fishing throughout the world today (Kelleher 2005; Davies et al. 2009). While estimates have varied widely, global discards are estimated to be between 7.3 million and 39.5 million tons per year in commercial fisheries (Kelleher 2005; Davies et al. 2009). Demersal finfish trawl have accounted for approximately 36% of estimated global fishery discards (Kelleher 2005).

Discards often differ in species composition from the retained catch as there is preferential retention of the more marketable species, and grades of species, in the landed catch (Attwood et al. 2011). Juvenile and small fish, along with unmarketable species, are frequently discarded at sea (Walmsley et al. 2006; Attwood et al. 2011). This has substantial conservation impact because these fish are typically dead upon discard and are not accounted for in the estimates of fishing mortalities based upon the landings data (Gillis et al. 1995b; Walmsley 2004).

As a general matter, however, discarding in the South Africa inshore trawl fishery has not been assumed to be a substantial problem for the quota species as the landed catches have fallen within the confidence intervals of the observer-based estimates (Attwood et al. 2011). Comparison of the observer and landings data suggest that the overall discard rate for the fishery may be around 16.2% (Attwood et al. 2011).

The discard rate may present a substantial concern for future regulation of some of the by-catch species, however. By way of example, landed catches of silver kob were about 67% of the observer estimates from pre-discard catches, suggesting a high rate of selective discarding or underreporting, although this could not be confirmed in light of the wide confidence intervals on the observer estimates (Attwood et al. 2011). This finding is not surprising in light of the documented fact that the inshore trawl grounds contain nursery areas of sensitive fish species, such as silver kob (Nel et al. 2007), likely resulting in the catch of undersized fish.

Future studies are needed to estimate the volume of by-catch discarded so that an accurate picture of the total fishing mortality can be compiled. This is essential to set PUCLs at levels that are appropriate for the sustainability of the fish stocks. For example, future studies may identify a species-specific proportion of likely discards to retained catch, which would enable the setting of PUCLs for those species throughout the fishery at sustainable levels.

Second, for species other than the 13 nominal species, the landings data provided total weight in an "other species" category. On average, there was an annual landed catch of 591 tons (± 62 SD) of "other species" during the study period. These "other species" are likely comprised of marketable species since they were not discarded at sea and were landed. These species may also be of conservation concern. By way of example, Attwood et al. (2011) identified substantial catches in the inshore trawl fishery of St. Joseph and geelbek, which meet both criteria. All species of conservation concern should be identified. Species-specific weights should then be obtained and the analyses here should be updated to incorporate these species.

Third, another issue that could aid understanding of fishing patterns would be to study the geographical-referencing of trawl trips. Species composition within the inshore trawl grounds are known to correlate to specific habitats (Japp et al. 1994; Erstadt 2002; Walmsley 2004; Attwood et al. 2011). This could help further explain the patterns of by-catch composition identified in this study.

III. MANAGEMENT RECOMMENDATIONS AND IMPLEMENTATION CONCERNS

The need for a comprehensive management strategy to sustainably manage by-catch exploitation within the inshore trawl fishery is well recognized (DAFF 2010). The landings data reveal that by-catch may be increasingly targeted by fishery participants and, in any case, is an important part of the fishery. The existing regulatory tools appear inadequate to reduce increases in by-catch landings. Management should identify a limited number of priority by-catch species (i.e., based on landed weight, conservation concern, or some combination of the two). PUCLs for these species should then be established, ideally based on the best available scientific data that considers the actual discard rate for PUCL species.

Following on the need for data on discarding, management should re-institute the observer programme to obtain accurate proportions of discards to landed catch per species. Information on discards will be necessary to develop PUCLs that can sustainably manage the exploitation of by-catch stocks. Successful ITQ programmes adopted elsewhere have 100% observer at-sea coverage to provide accurate estimates of discarding and associate this with substantial improvements in stock assessments and reductions in discarding (Branch et al. 2006).

Once the PUCLs are established, there are several tools that could be used to manage the PUCLs. This study recommends conducting a pilot ITQ programme. As noted above, an ITQ programme to manage the exploitation of by-catch is largely in accord with the policy objectives in the applicable South African regulatory framework. The benefits of ITQ programmes are many, commonly reported benefits include the alignment of individual fisher's interests with the long-term sustainability of the resource, reduction in overfishing and overcapacity, and incentive to retain rather than discard unwanted catch. The ITQ programme should be based around the allocation of PUCLs of select by-catch species to fishery participants that are freely transferable (in-season). This allocation of PUCLs to fishers should be based, at least in part, upon their past fishing performance as identified in this study. The ITQ programme should also allow for some carry forward of quota to cover overages and underages to minimize the incentive to discard.

Two issues that will require attention prior to implementation of a pilot programme are (i) anticipatory steps to discourage "specialists" in particular by-catch species, and (ii) consideration of whom to designate as the regulatory target (i.e., vessel or rights holder).

(i) A trading programme could inadvertently encourage the development of by-catch specialists – fishers who monopolize the trade and catch in particular species – unless protective measures are put in place. Specifically, if unchecked, a participant could become a specialist in a given species (e.g., silver kob) and seek to control the market for this species (or limit the ability of other fishers to fish in an area with high prevalence of the species). These fishers could then be incentivized to overfish this species and discard the non-target species caught. This problem could further be exacerbated if the fishers were limited to certain grounds due to gear configurations (e.g., the vessel cannot reach depths greater than a certain level). In that instance, there would likely be an over-exploitation of the species in particular habitats to which the fishers does have access. This uneven exploitation of the species could jeopardize the sustainability of select populations. Thus, it is recommended that caps on the accumulation of quota be identified prior to a pilot programme.

(ii) The study here identifies fishing patterns based on annual catches at the vessel and rights holder levels. The current allocations of hake and sole are awarded exclusively on the rights holder level. As noted previously, not all rights holders own vessels and vice-versa. Thus, communications with the industry and fisheries management personnel are essential to determine which basis may be more appropriate to manage a PUCL-ITQ system (i.e., the rights holder or vessel level).

Finally, this study identified consistent fishing patterns substantially targeted towards by-catch species. If an ITQ programme is not selected for a pilot programme, a limited intervention focused on select participants that land substantial amounts of by-catch should have a substantial conservation impact.

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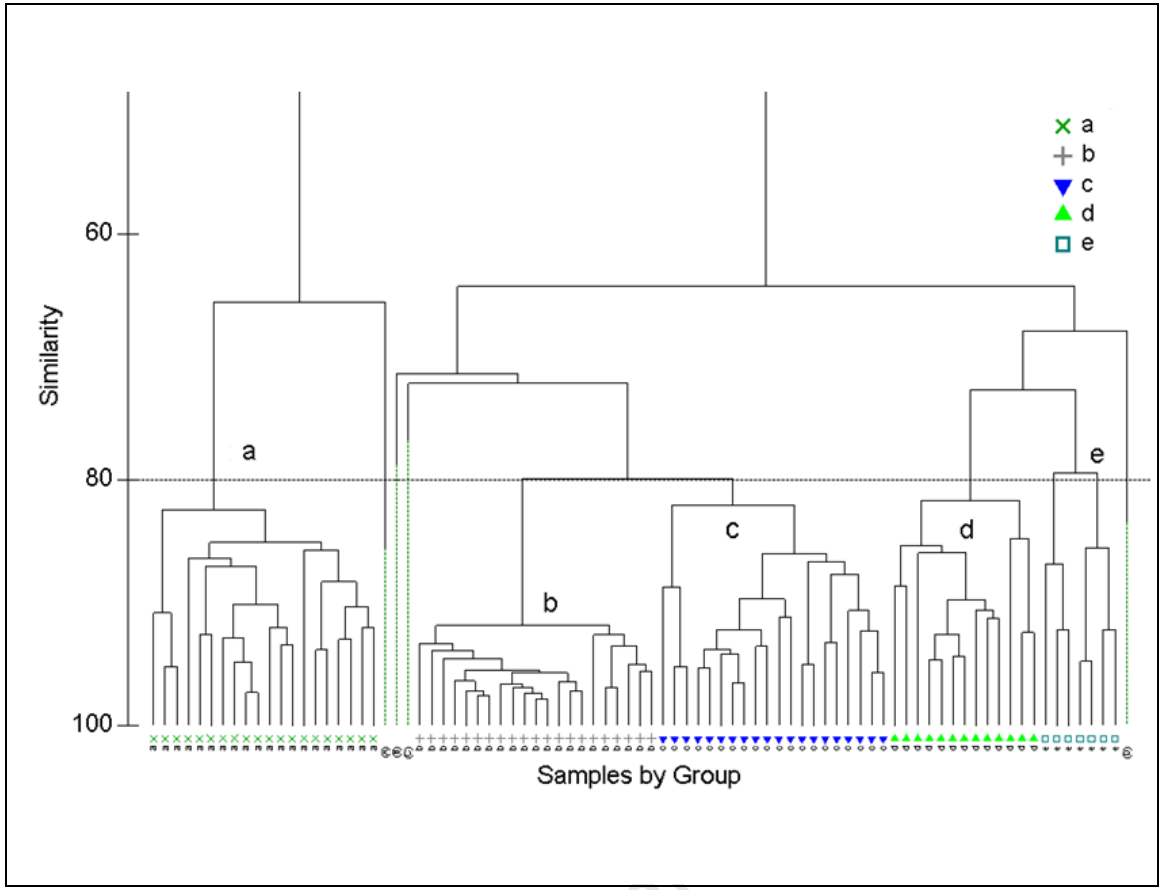
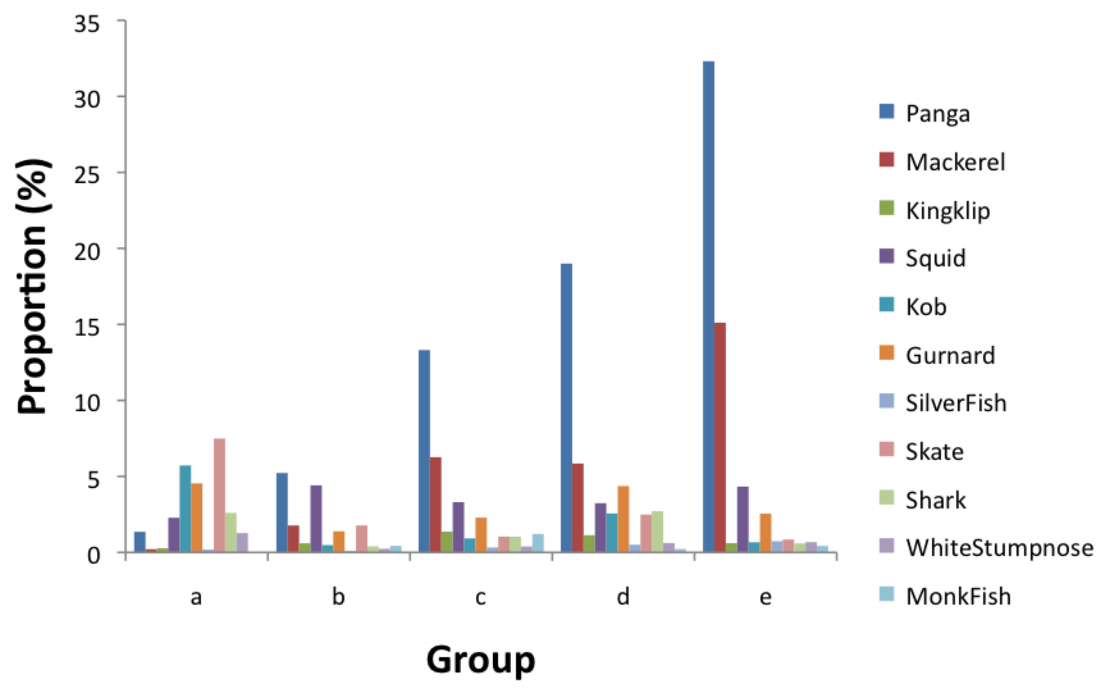
APPENDICES

Appendix 1. The catch (in tons in landed format) of each of the 14 species categories, and total by-catch, during the study period.

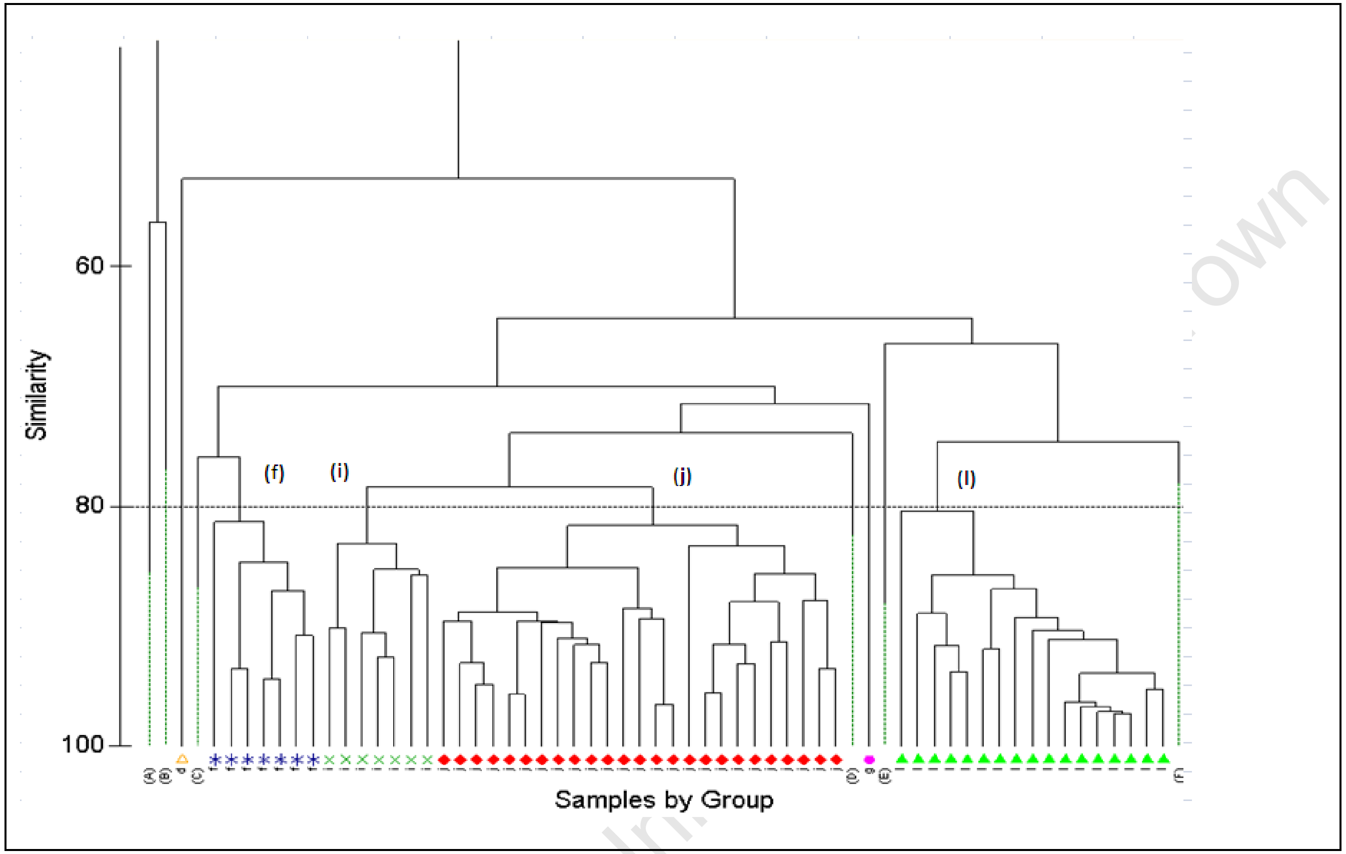
Year	Hake	Sole	Panga	Horse Mackerel	Kingklip	Squid	Silver kob	Gurnard	Carpenter	Skate	Shark	White Stumpnose	Monkfish	Other Species	By-Catch (total)
2007	4340.88	318.03	820.34	590.06	60.54	314.61	86.35	149.01	7.59	207.15	110.69	33.64	61.08	601.49	2441.04
2008	4539.30	443.79	936.56	578.99	78.34	290.78	120.60	161.73	9.52	141.86	79.18	34.72	47.94	509.97	2480.24
2009	4219.31	541.66	1252.27	599.07	73.08	315.00	116.26	186.28	20.95	145.38	80.16	28.14	30.08	580.24	2846.67
2010	4137.76	543.49	1257.19	384.66	75.25	244.26	132.19	256.39	38.61	170.07	78.75	49.64	52.44	682.60	2739.46
2011	4395.86	414.95	968.00	537.31	55.50	273.57	151.21	231.37	51.65	168.14	67.84	63.50	58.83	580.05	2626.91



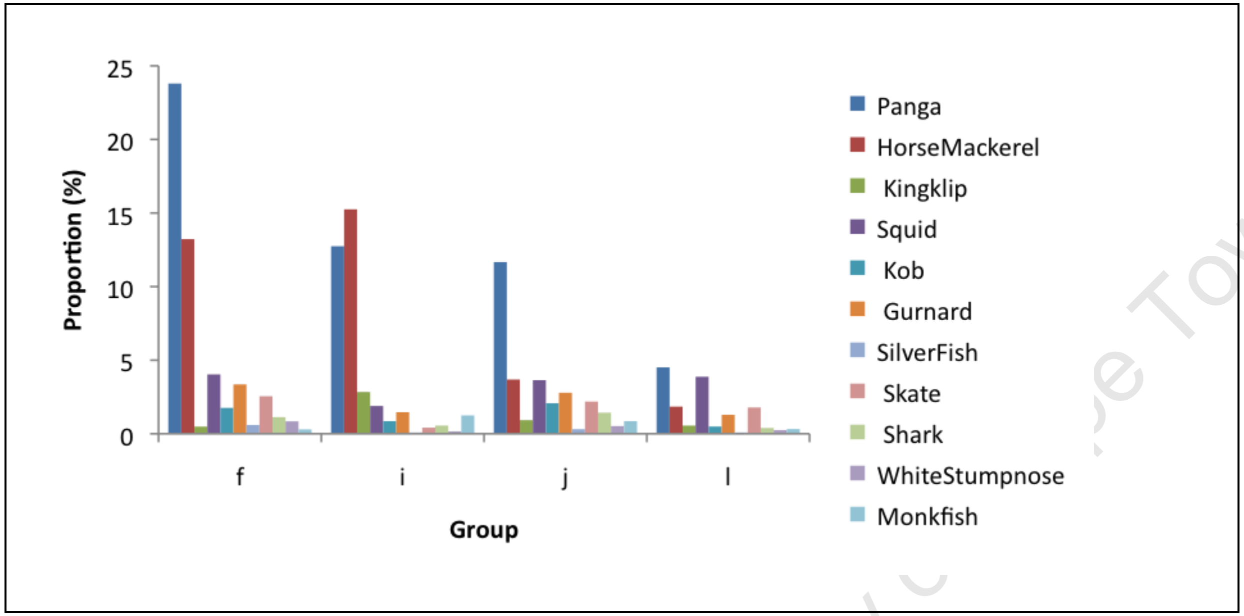
Appendix 2. Dendrogram showing the similarity in catch composition among annual samples of landed catches by core trawler.Three or more samples with greater than 80% similarity are grouped by categories *a* through *e*.



Appendix 3. Average proportions of each of the thirteen nominal by-catch species landed per trawler group during the study period.



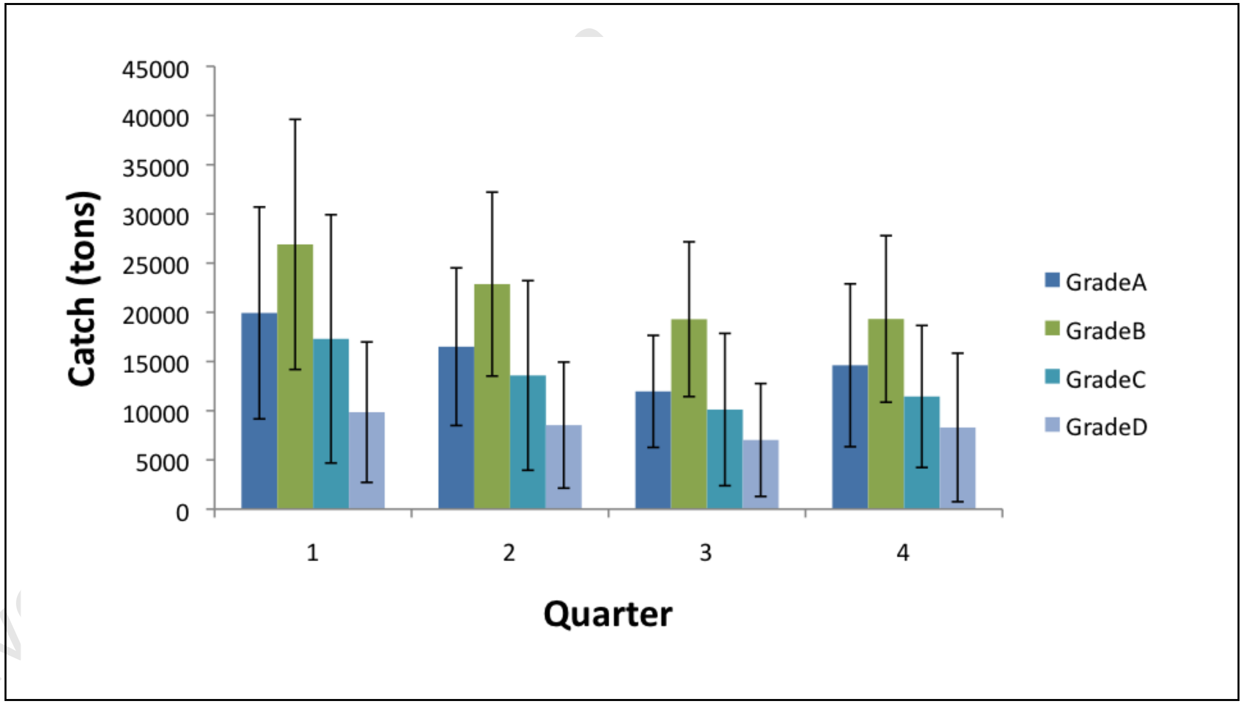
Appendix 4. Dendrogram showing the similarity in catch composition among annual samples of landed catches by core trawler. Samples with greater than 80% similarity are grouped by categories *f*, *i*, *j* and *l*.



Appendix 5. Proportion over the study period of each of the thirteen nominal by-catch species per group based on annual rights holder landed catches over the study period.

Appendix 6. Summary of the significant results of the ANOVA analyses by core trawler comparing the total hake catch landed and quarter of landing.

Vessel	Df	SS	Residual SS	F	p
T1	3,16	0.1647	0.1863	4.72	0.015
T15	3,12	0.12	0.063	7.78	0.0038
T17	3,16	0.13	0.073	9.68	0.0007
T19	3,16	0.14	0.06	12.54	0.00018
T20	3,8	0.032	0.0065	13.19	0.0018
T28	3,16	0.14	0.18	4.37	0.02
T30	3,16	0.28	0.28	5.42	0.009
T31	3,16	0.04	0.043	4.96	0.013
T32	3,16	0.051	0.037	7.34	0.0025
T33	3,12	0.095	0.088	4.35	0.027



Appendix 7. Average hake catch landed by grade per quarter across the core trawlers, with errors bars representing the standard deviation.