Potential bycatch mitigation measures in the south coast inshore trawl fishery

Discussion document

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Introduction

The south coast inshore trawl fishery is South Africa's oldest trawl fishery. The fishery is concentrated on muddy and sandy bottoms shallower than 110 m around Cape Infanta, Mossel Bay and Port Elizabeth, and to the south in a shallow area of the Agulhas Bank called the 'Blues'. The trawlers originally targeted east coast sole *Austroglossus pectoralis*, and later effort was also directed towards shallow-water hake *Merluccius capensis*.

Given the recent attention on the worldwide failure of fisheries, it is remarkable that catches of east coast sole have remained stable over the course of a century (Fairweather and Glazer 2010). A possible reason for this persistence is the large area of untrawlable rough ground on the wide Agulhas Bank (Japp 1994). However, the fishery does incur a substantial bycatch, amounting to approximately 38% of the total catch by mass, and at least 140 species (Attwood et al 2010). Only two species are controlled by quota in the inshore fishery, namely shallow water hake and the east coast sole. Total landed volumes of silver kob are capped at an historical level, and a move-on-rule is also applied to limit catches of this species.

Concerns over the consequences of bycatch and dumping by sole trawlers along South Africa's south coast were discussed as early as 1931 (Marchand 1933). It was noted then that the sole grounds off Cape Infanta were inhabited by silver kob and young of other species in great quantity. The capture of young sole *Austroglossus pectoralis* was also considered as a possible cause of the perceived decline in productivity on the sole grounds. The mesh size investigations of that period resulted in a recommendation to limit the mesh size to 3 inches (75 mm), which remains the regulation for sole-directed trawlers until today. The current mesh-size for hake trawlers is 90 mm.

An important consideration for the management of the inshore trawl fishery is the extent to which the industry depends on by-catch species. The top twenty species in the pre-discard catches by mass are all marketable species (Table 1), with the possible exception of *Squalus* spp, which, although marketed elsewhere, has no demand in South Africa (Attwood *et al.* 2010). That much of the by-catch is utilised is a positive feature of the fishery, in contrast to many other trawl fisheries which have high discard rates. The industry prefers the term *joint-product* instead of by-catch, with the implication that many of the non-target species make a useful contribution to the profitability of the fishery (Walmsley *et al.* 2007, SADSTIA 2010). Indeed, for fishermen with small hake quotas, the bycatch species play a relatively more important role in the profitibility of their business.

Concerns with regard to the bycatch species is primarily the lack of monitoring and the lack of an effective mechanism to retrain catches of species that are not quota-restricted. There is specific concern over the rates of bycatch of silver kob and the small size at which it is caught, and the indirect effect of the trawl catches on the linefishery which for which silver kob is a primary target in the Still Bay area.

The purpose of this document is to outline a number of possible mechanisms to reduce the extent of bycatch. Broadly speaking this can be achieved in two ways. In the first, it should be possible to extend the management of this fishery to explicitly include species other than shallow-water hake and east coast sole. The view expressed by Davies *et al.* (2009) is that any catch which is unused or unmanaged qualifies as bycatch. By specifically managing more species, the pool of bycatch species is reduced. The second approach is to reduce the catches of unmanaged species relative to the nominal target species. I discuss the possible mechanisms under these headings, providing evidence in support of or against the feasibility of each. Walsmley *et al.* (2006) listed a number of possible mechanisms to reduce bycatch, including alterations to mesh size, closure of certain areas, enforced observer coverage, individual transferable quotas, and fixed bycatch-proportion limits. I discuss these and other potential solutions in the light of the second phase of the observer programme and the most recent changes in the fishery.

This document serves to promote a dialogue between the managers Department of Agriculture Forestry and Fisheries (DAFF), the industry (SECIFA and SADSTIA), and the conservation interests to improve the sustainability of the fishery.

Data sources

The inshore trawl fishery has benefited from numerous surveys and experiments. This report draws on the data sources listed below.

I. Historical survey data are available from 1897 to 1904 and again from 1920 to 1938. These data have yet to be analysed by contemporary scientists, but Marchand (1934) reports on detailed experiments conducted throughout the inshore trawl grounds.
II. Small mesh survey (Wallace *et al.* 1984). A benthic trawl survey was conducted from the R.V. Thomas B. Davie. The primary purpose of this survey was to assess the extent to which estuarine associated species utilize the inshore marine environment as a nursery area. In total, 123 trawls were conducted during four seasons in 1980. Depths ranged from 5 to 97 m.
III. Japan/South Africa joint trawling survey (Hatanaka *et al.* 1983 and Uozumi *et al.* 1984 and 1985).
IV. Observer data (Walmsley *et al.* 2007). A pilot observer programme, implemented from 1995 to 2000, delivered data from 615 trawls from the south coast, amounting to an observer-coverage of 0.3%. These data were used to estimate the bycatch (discards and retained) in the inshore and offshore trawl fisheries.
V. Observer data 2003 to 2006 (Attwood *et al.* 2010). The observer programme continued in late 2002, but with greater coverage (3.5%) and greater representation of areas.
VI. South coast trawl surveys. DAFF conduct two trawl surveys per annum. Data from the years 1986 to 2010 were used to compare with historical survey records and the observer records. In total, 2969 survey trawls were recorded.

Managing a broader spectrum of species

Background

It is the opinion of the author that only two species are explicitly managed in the inshore trawl fishery, namely shallow-water hake and east coast sole, notwithstanding some recent measures that have been taken to restrict the harvest of a few other species. It should be noted that deep water hake and chokka squid are also managed, but that it is unlikely that the records of deep water hake in the inshore catches are accurately ascribed to that species, and that the controls on chokka squid are applied in the squid-directed fishery and not in the trawl fishery. At the very least, the management of a fishery will entail (1) a set of objectives, (2) a set of indicators which can be used to measure the degree to which objectives are satisfied and (3) a mechanism that can be used to adjust the fishery to improve the likelihood of satisfying objectives. Although objectives may change of over time, it is the set of indicators and the adjustment mechanism which require regular, usually annual, attention. Recently abundance trends in most non-target species have been inferred from regressions of survey CPUE over the period 1985 to 2008. Although a rather crude form of assessment, this work could for the basis of more rigourous analyses on species where negative trends are apparent.

Shallow-water hake and deepwater hake have been separated since 1977 in terms of a model based on the changing proportion of each species with depth (Rademeyer *et al.* 2008a), although the species are still not counted separately in catch records. The inshore trawlers catch almost exclusively the shallow-water hake. The model that is used to provide the baseline assessment of the two hake resources is fitted to GLM-standardised CPUE time series. This time series does not include CPUE records from the inshore trawl ground, but only data from the offshore fleet which accounts for the vast majority (85%) of hake catches. On the basis of this assessment, a TAC is recommended, 6% of which is allocated to the inshore fishery (Rademeyer *et al.* 2008b). Whereas the omission of CPUE records from the inshore ground can be justified in terms of data quality and the small contribution of this area to total hake catches, it is important to recognize that the fortunes of the inshore fleet are inextricably tied to the performance of the offshore fleet and the measured abundance of hake species on the deeper Agulhas Bank only.

East coast sole, although a target for some vessels in the inshore fleet, is considerably less abundant than hake, and less widely distributed. It ranks eighth on the list of pre-discard landings for the combination of sole- and hake-directed vessels. East coast sole is not caught by any another fleet or fishery. The TAC for this fishery has been fixed at 872 tons since 1991. Recently these targets have not been attained for economic reasons. There is no indication in the abundances index that this population of fish has diminished below the level corresponding to maximum sustainable yield (MSYL) as a result of harvesting.

It is important to understand the manner in which TACs are allocated to the inshore fleet, as this remains the primary regulatory mechanism on the inshore ground, affecting all species. The general concern in multi-species fisheries is the inequality of the productive capacity of the constituent species in the catch. As is the case in the inshore trawl, the target species is often the dominant catch, which attests to its superior competitive ability. Other species with less surplus production are not likely to withstand the same rate of effort that is applied to optimally harvest the target species (Sparre and Venema 1998). This is an unavoidable conundrum. It is not possible to manage every species at maximum sustainable yield (MSY). Some will be over-exploited, and may be reduced to unsafe levels, as a consequence of managing for optimal benefit from the resource. An attempt to prevent over-exploitation of every species will result in a total harvest that is only about 10 % of the multi-species optimum (Branch and Hilborn 2008).

In the case of the inshore trawl fishery, the uncertainty of the effects of fishing mortality on non-target species is exacerbated by the fact that the effort applied by the inshore fleet is determined not on the abundance of the target species on the inshore ground, but rather on the abundance of the target species on adjacent grounds. It should be clear that the various species that associate with the grounds frequented by shallow-water hake (skates, panga, gurnard, white stumpnose etc) are very poorly managed, if at all. This situation is somewhat surprising, given the statement by the industry that many of these species represent an important economic resource, which it could not easily forgo.

Which species should be managed?

Given that approximately 140 species are caught by inshore trawlers, it is quite impractical to attempt managing all of these. The difficulty was highlighted by Heales *et al.* (2007) who calculated the numbers of prawn trawl observations required to detect declines of given magnitudes among species in different abundance classes. They show that the number of trawl surveys that is economically feasible will not be able to provide sufficient statistical power to detect small changes in the majority of bycatch species. As an example, an analysis of catch per unit effort in 50 trawls in an area for three years could detect declines of 100% in 72–81% of taxa, declines of 50% in 34–43% of taxa, and declines of 20% in only 20–34% of taxa. After 5 years, the power to detect declines of 50% had increased to cover 43–72% of taxa, and declines of 20% to 34–43% of taxa. Although similar trends may apply to the inshore fishery, the analysis of survey CPUE trends mentioned above, covers more than 20 years, which implies there is a reasonable level of power in the survey data for most species.

Table 1 . Average estimated annual catch taken by inshore trawlers in the years 2003 to 2006. The top 20 species are listed. Plurals indicate an assemblage of species, usually at the generic level. Data taken from Attwood *et al.* (2010). It is likely that much of the deep-water hake total was mis-classified and should be lumped with shallow-water hake.

Species	Average annual catch (kg)	%	Cumulative %
Shallow water hake	9653757	55.37	55.4
Horse mackerel	1345028	7.71	63.1
Panga	1050173	6.02	69.1
Skates	833321	4.78	73.9
Gurnards	824164	4.73	78.6
East coast sole	504049	2.89	81.5
St Joseph	503551	2.89	84.4
Deep-water hake	427844	2.45	86.9
Dogsharks	409203	2.35	89.2
Silver kob	294264	1.69	90.9
Chokka squid	283206	1.62	92.5
White stumpnose	230517	1.32	93.8
Kingklip	216156	1.24	95.1
Carpenter	107176	0.61	95.7
Monk	86891	0.50	96.2
Geelbek	83984	0.48	96.7
Houndsharks	82249	0.47	97.1
Snoek	56909	0.33	97.5
Ribbonfish	44138	0.25	97.7

The list of bycatch show that 20 species make up approximately 98% of the total catch by mass. All except one is marketed. Would it be possible to attempt management of these 20, bearing in mind that several are targeted by other fisheries, e.g. squid and linefish? To answer this we need to consider objectives, monitoring and catch regulation, of which the last is likely to be the most problematic.

Objectives

MSY is not a possible objective for each individual species, although a multi-species MSY (MMSY) approach may be practical. This reference point is based on a model that combines the production of each population and represents a level of effort for which the combined harvest is at a maximum. Several types of models can be used to calculate MMSY and the corresponding effort. This approach will still disadvantage species which have relatively low carrying capacity as the analysis will be weighted in favour of abundant species, leaving the potential problem that some populations will be over-exploited.

Whereas it might be desirable to manage for MMSY, a second objective, acting concurrently might stipulate minimum thresholds for each individual species. Candidate reference points might include $B_{current}/B_{MSY} > 0.2$ or $F_{current}/F_{MSY} < 1.5$. The purpose of these thresholds is to act as limit reference points, preventing the collapse of any one species. The recent paper on data poor management procedures by Helena Geromont and Doug Butterworth (unpublished, UCT report) shows how species with limited data can be assessed. Their work has only just begun, but it offers some optimism for bycatch management.

Monitoring

The monitoring method will need to correspond to the objectives. Following the suggestions above, total pre-discard catch and (relative) abundance or age-structure will need to be monitored per species.

An observer programme is the only reliable means to obtain pre-discard catches. Walsmley *et al.* (2007) and Attwood *et al.* (2010) argued that this programme (now it its third phase) will need to continue. Both of these studies have made recommendations for its continued implementation, much of which has been adopted. A critical feature of the observer programme is the extent of coverage and the representation of vessels and areas. Several vessels have eluded observers, ostensibly because their small size presents accommodation difficulties. This problem will need to be revisited.

The observer coverage increased from 0.7% to 3.5 % from the first to the second phase, but even the latter figures are rather low and have resulted in wide confidence intervals in total catches. These intervals are too wide to detect even strong changes in interannual catch or CPUE. Consideration should be given to increasing the coverage. Where the extent of high-grading and discarding is severe it may be advisable to increase coverage to 100% (Branch 2006, Branch and Hilborn 2008). Presently, discarding does not seem to be a severe problem in the inshore fishery (Walmsley *et al.* 2006, Attwood *et al.* 2010), although if catch limits are placed on individual species this situation may change.

Survey data present another useful data source, but one which has been poorly utilized in respect of non-target species in the inshore trawl fishery. CPUE can provide a useful index of abundance, some recent examples have been provided by Leslie (2008) and Fairweather *et al.* (2010) for the inshore trawl fishery. CPUE and size structure data can be used to track changes in abundance or fishing mortality in relation to accepted objectives for each species.

Monitoring of species catches, abundance and mortality does not seem to provide a practical or economic impediment to the expansion of management to include the top 20 species. Much of the data is already being collected, and the observer programme has continued, although its coverage may need to be increased.

Catch allocation and control

The real difficulty in multi-species management lies in the regulation of catches of individual species, in a fishery which operates on a very diverse and productive continental shelf. Whichever system is imposed it could strongly influence the fishers behaviour in respect of areas, targeting and high-grading (Alverson *et al.* 1996). The present system (quotas on two target species only) might be seen to encourage discarding of nominal target species if *de facto* targeting of other species can more than cover trip expenses.

Alternative scenarios include a system in which quotas are allocated per species. These quotas may simply be a fixed proportion of the target species, but as Walsmley *et al.* (2007) have reported, this is not favoured by the smaller companies which rely proportionately more on non-target species. The next step is a full ITQ system, in which quotas can be transferred between rights holders. ITQ or ITQ-like fisheries outperform other forms of management in the pursuit of sustainability (Costello 2008). Branch and Hilborn (2008) describe how the ITQ system has fared in the mixed trawl fishery of British Columbia, when combined with 100% observer coverage. Fishers have quotas for every species, and may trade these quotas with others, allowing for over fishing of some quotas and under-fishing of others, through a system of trading and roll-overs. Each fisherman has the ability to adjust the mixture of species in the catch by targeting certain areas at certain times, and using their knowledge of the grounds to maximize individual opportunities in a flexible but controlled framework. ITQ systems by themselves do not overcome discarding problems, hence the need for 100% coverage in British Columbia, but they do give fishers a share in each resource when quotas are imposed. It is this share which encourages compliance and resource husbandry (Alverson *et al.* 1996).

A potential problem in the application of a full multi-species ITQ system in the South African context is that the introduction of new targets and the setting of quotas for species previously unregulated may, by law, necessitate the calling for applications for new rights, and such rights will not automatically accrue to existing rights holders in the demersal fishery. This possibility may destabilize the fishery and may result in an elevation of effort directed at what was previously regarded as bycatch. It might be better to consider bycatch allowances, rather than recognize new targets.

Presently precautionary catch limits have been set for three species caught by the inshore trawlers, namely silver kob, kingklip and monk. These limits could be used effectively, but must apply to pre-discard catches, and will therefore require high observer coverage. It remains to be seen how the skippers will respond if these limits are exhausted before the quotas of nominal species.

Another option is a shift to an effort-controlled system. The input controlled fisheries are in some ways simpler, obviating the need to reconcile catches with quotas, which can be an arduous task in a diverse multi-species fishery. Catch will still need to be recorded and total allowable catches will still need to be set, and translated into an overall effort allocation. This conversion can provide some difficulties, especially where catchability is influenced by environmental conditions and technological advances. The advantage of effort control is surely its simplicity and lack of incentive to high-grade, but the control over individual species will be poor, and will almost certainly need to be linked to other input controls.

Presently the bulk of the trawl fishery in South Africa (inshore and offshore) is limited in terms of hake quotas and a sea-days limit. The latter is calculated on the basis of the quota size and the power of the vessel. The intention of this effort restriction is to limit the extent of targeting of by-catch species. It could be argued that the combination of a quota and effort limit is the next best option to a full ITQ system. The system has not been evaluated in South Africa, and it is unclear how the presently calculated sea-day limits relate to mortality of non-target species. Presumably the sea-day limits do not restrict the ability of fishers to catch the quota species, although this amount of effort may be more than some species can sustain. Despite this uncertainty, we presently have a system which could constrain the extent to which fishers can target unregulated species if applied correctly.

Reduction of the volume of bycatch by input controls and gear restrictions

The most direct method of reducing total bycatch is simply an overall reduction in effort (Alverson *et al.* 1996). As this will impact of total landings and revenue, other mechanisms need to be explored first. These include gear modifications and area and time closures.

Area and time closures

Marine protected areas have been declared in the coastal zone (within 3 nautical miles of the coast) largely for the protection of coastal biodiversity and the management of recreational and small-scale fisheries (Attwood *et al.* 1997). The application of marine protection areas offshore in South Africa is still untested, but it is the aim of the South Africa's National Biodiversity Institute to establish such areas for the conservation of offshore biodiversity, consistent with international and national policy guidelines (Sink and Attwood 2008). Fisheries management is one of the potential applications of such areas. The closure of fishing grounds, either permanently or temporarily is not new, but has long been regarded as a possible mechanism to regulate the impact of fisheries. Hilborn *et al.* (2002) list the potential applications in fisheries and the situations in which such regulations are more likely to be effective. They cite reduction of collateral damage as one such application, with reference to habitat damage and bycatch. However, they also caution that effort displacement may cause undesirable consequences elsewhere.

I investigated the potential of area closures as a means to decrease the overall quantity of bycatch in the inshore trawl fishery. A report by Lombard *et al.* (2010) is included as an appendix to this document, detailing the methods and results of this investigation. An abbreviated version is provided below.

The rationale behind the search for potential areas for closure is that the fish species composition varies across the inshore trawl ground and that the ratio of target species to bycatch species is consistently greater in some areas than others. This assumption was supported by the most recent observer data. Attwood *et al.* (2010) identified several areas of similarity with respect to species assemblages in catches. Lombard *et al.* (2010) used catch per unit effort data averaged per 20' x 20' grid-block across the four years as a surrogate for species abundance. These data were used in a decision support software tool, Marxan (Possingham *et al.* 2000) to identify areas that achieve quantitative targets for bycatch reduction while minimizing the cost to the industry. Marxan uses an objective function to identify the best set of areas for closure, or a number of possible sets that will meet the objectives. The objective function does not explicitly consider effort displacement, so this component is handled separately, once the best set(s) has(ve) been identified.

The objective function that was used to define the search required selection of areas that represented 20% for all 27 species (as measured by CPUE) while selecting grid-blocks for closure with the lowest recorded trawl effort. Trawl effort was used a surrogate for revenue, instead of the catch of target species, as it was assumed that revenue is made from bycatch species as well. The rationale was that the industry would be less willing to forgo heavily-trawled than lightly-trawled areas. No attempt was made to clump the solutions, i.e. to choose grid-blocks that are adjacent. Although this may have presented a solution that is easier to manage, it generally comes at the cost of having to select more grid-blocks to achieve the objective.

Sufficient data were available for only 29 grid-blocks out of a total of 48, but these contained the vast majority of trawl tracks. The remaining grid-blocks were therefore of little significance for the planning exercise. Seven grid-blocks were selected for the most efficient solution. These included 553 (Blues), 513 (Mossel Bay), 515 (Knysna), 629 (South of Algoa Bay), 632 (Bird Island) and 640 (Port Alfred). The cost amounted to a 10% loss of trawl tracks, i.e., the areas selected contained 10% of the trawling effort.

The greatest concern with implementing this solution is the possibility that trawlers which are displaced to other areas will potentially catch more bycatch, and so nullify the objective. Another model was developed to assess the impact of displacement on each of 27 bycatch species, called the effort displacement model.

Model description:

The programme selects a set of grid-cells (j) for closure, such that the total catch of species i is reduced by an amount of at least (T_i).

$$\sum_j E_j b_{ij} x_j \geq T_i \quad , \qquad \text{equation 1}$$

where E_j is the effort applied in grid-block j, b_{ij} is the average cpue of species i in grid-block j, x_j is a binary variable (1 for a closed area, 0 otherwise) and T_i is a target specified for species i. Catches in the remaining areas after displacement will be

$$\sum_j E_j b_{ij} |1 - x_j| \left(\frac{\sum E_j x_j}{\sum E_j |1 - x_j|} \right) = C_i \, , \qquad \text{equation 2}$$

where C_i is the increase in catch of species i in the remaining (fished) areas.

To evaluate the effect of displacement, the value of T_i is compared to C_i. If C_i exceeds T_i then the catch of species i will be increased the selection of grid-blocks.

The set of x_j values was supplied by the Marxan model. I used the best solution in the effort displacement model (Appendix figure 3), which projects a decrease in catch of every species and a total reduction in bycatch of just over 600 tons (Figure 1). This result confirms that the Marxan solution would not disadvantage any species because of the displacement of effort. Fifty-thousand random selections with a mean of 6 grid-block closures (there are a total of ~14 million possible unique selections of five grid-blocks) were also tested to see if the Marxan solution could be improved upon. Of these selections only 36% reduced overall bycatch (Figure 1). None achieved reductions in every species, yet the total bycatch reduction achieved by the best Marxan solution could be exceeded by 40%, by dropping this condition.

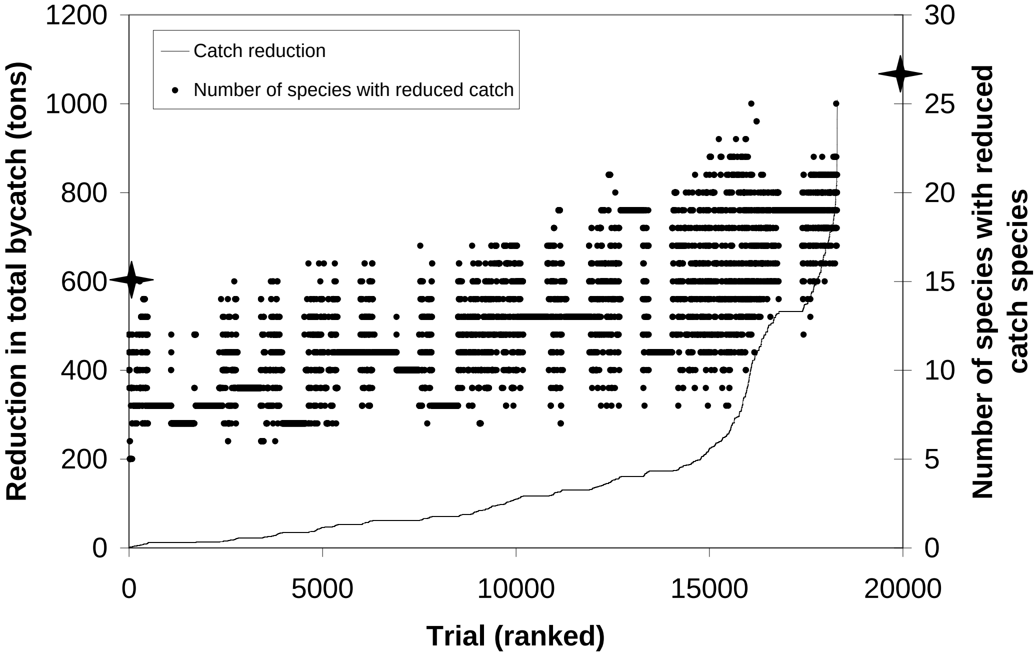


Figure 1. The results of 50 000 random trials of the effort displacement model. Those 18302 trials that resulted in net reduction in bycatch are displayed. The total number of species which displayed

bycatch reductions is plotted on the second y axis, and is limited to a maximum of 27. The stars indicate separately the solution of the best Marxan model, on each axis.

The effort displacement model results suggest that a random allocation of areas for closure will not achieve the desired objectives, and that in most cases it will provide a solution worse than the baseline (existing) case. It is also interesting to note that the objective function used in Marxan, which tries to find the areas with the highest bycatch species abundance and lowest catch found the rare solution(s) in which all bycatch species showed a net-reduction in the catch. The reason is that the effort which is displaced is kept to a minimum, and the areas to which it is displaced have relatively lower bycatch abundance.

The fact that areas selected are widely separated reflects the need to protect the full diversity. Figure 2 shows the trawl track super-imposed on the 'best solution', from which it is clear why certain grid-blocks were selected. Marxan searched using average CPUE and not total catch, while selecting for grid-blocks with the lowest effort. Grid-block 553, for example, is representative of the 'Blues', but is only partially trawled, presumably as the north-western part of the grid-block is rough ground. Likewise the remaining inshore blocks contain relatively low effort, yet represented sole grounds (Algoa Bay region and Mossel Bay), and the cold water intrusion off Tsitsikamma. The lack of a grid-block selected off the Infanta to Still Bay coast reflects the intensity of trawling there, and the fact that similar species assemblage is found in the Algoa Bay region (Attwood *et al.* 2010).

Another explanation for the selection of lightly trawled areas is that they represent marginal habitat for target species, and as a result contain a higher biomass of non-target species. Grid-block 553 incorporates much untrawlable ground, and probably harbours an assemblage of species associated with hard ground.

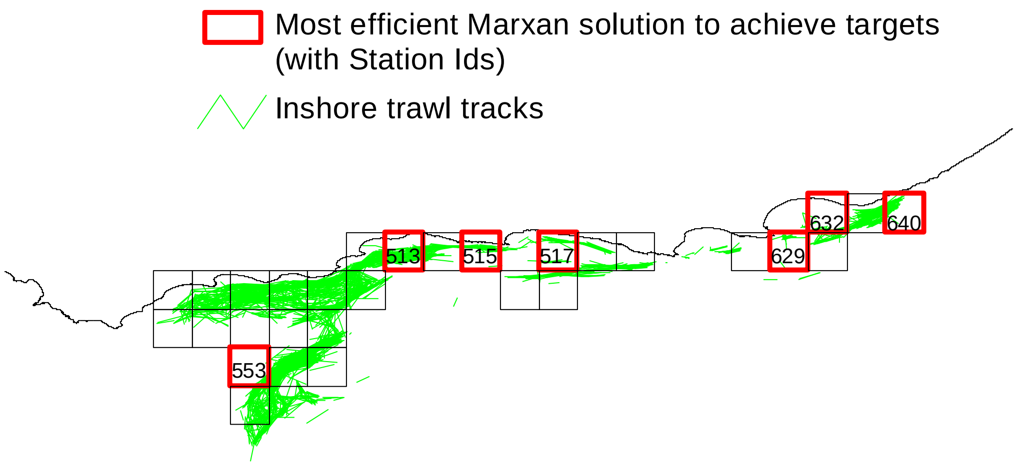


Figure 2. The best solution that achieves the target of representing 20% of the abundance of 27 bycatch species while minimizing the loss of fishing ground. Red blocks represented grid-blocks selected for closure. Green represents the trawl tracks recorded from 2000 to 2008.

The effort displacement model shows that the best solution will reduce bycatch by only 600 tons per annum, which is only about 10% of the total annual bycatch estimated from 2003 to 2006. The selection by Marxan for 20% was compromised by the fact that each grid-block did not contain an equal amount of trawl effort. If a greater reduction is required then a larger proportion of the trawl tracks will need to be included in the final set. Each selection will also need to be tested for the effort displacement effect.

The models show that the danger of effort displacement is not a concern if the Marxan solution is used, and therefore that it may not be necessary to reduce effort to the extent that it matches the reduced availability of trawl ground. A number of modeling studies have recommended effort reduction as a means to overcome the displacement problem (Guénette *et al.* 2000, Hilborn *et al.* 2006), but none of these have reckoned with the plasticity provided by spatial variation in species composition across the ground.

Are the selected grid-blocks a practical set for closure? It might not be practical to close the entire grid-blocks, where selections entirely block trawl tracks. The Marxan solution needs to be treated with some flexibility. Closure would not have to follow grid-block shapes, or even be limited to the grid-block selected, but would need to be located in that region to be representative. Shapes should be selected to interfere with trawling as little as possible, and may need to be aligned with the tracks.

An advantage of opting for closed areas is that it may coincide with the recommendations emerging from the broader Protected Area Expansion Strategy. As there will be pressure to declare marine protected areas in the offshore environment, it would preferable to ensure that these will not disadvantage the industry, and that it will promote the protection of unregulated species after effort displacement.

The existing closed areas include all shallow bays, as defined by a series of straight lines joining prominent Capes. The rationale for this closure was to protect nurserys of fish such as shallow-water hake (Badenhorst and Smale 1991) and silver kob (Smale and Badenhorst 1991). The concept time-area closures have been suggested for the Infanta region as a possible means to protect silver kob (SADSTIA 2010). To assess this idea, we need to examine the seasonal trends in silver kob and other species.

Seasonal closures

Placing a moratorium on trawling in some months and in some areas may reduce the catch of species that are known to aggregate in those areas. The kingklip box south-west of Port Elizabeth is an example of such a restriction applied to the offshore fishery. In that case the restriction is applied to protect spawning aggregations of kingklip, which, if not protected, would be caught at an unsustainable rate.

Are there aggregations of species on the inshore trawl ground at certain times of the year? Catch per unit effort records from the observer data were averaged by month for each area. The areas used for this analysis were the seven broad areas defined in Attwood *et al.* (2010), redisplayed here in Fig 3.

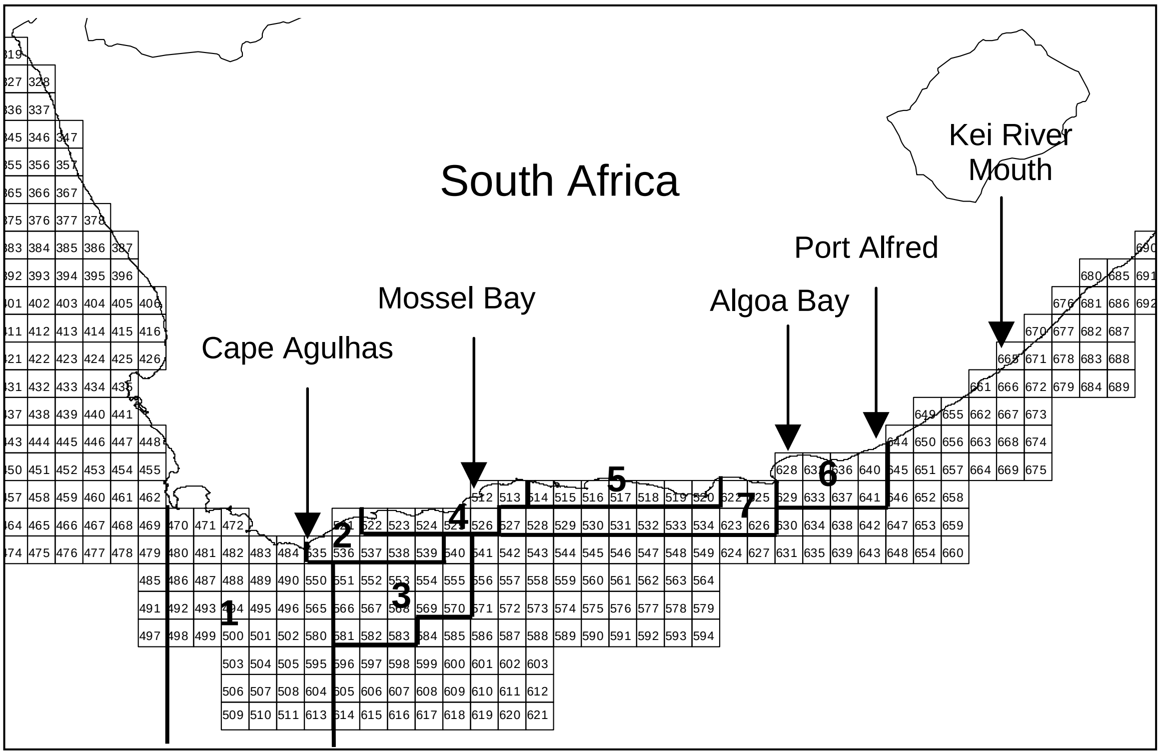


Figure 3. A map showing demersal trawl grid and the seven areas defined on the basis of species composition.

Shallow water hake show no clear seasonal trends in CPUE. Average values are in the region of 180 kg per hour (Figure 4). No trend is evident on individual grounds either.

The same is true of dogfishes which are 9th on the catch list, and for which the average CPUE is about 7 kg per hour. There is no obvious explanation for the consistently low catch in June of dogfishes, and this merits further investigation.

Gurnards, 5th on the catch list, averaged around 13 kg per hour. Catches rates across all areas were highest from August to November, but the variability was too high to confirm any trend. May to July showed unusually low catches rates of gurnard.

In the case of east coast sole, 6th on the catch list, it would appear that January and February trawling yields the worst results, but again no clear agreement with respect the remainder of the year on each of the grounds. It is quite conceivable that that sample sizes were too small to detect clear trends on individual grounds.

Clear seasonal trends were evident in a number of other species despite small sample sizes. The first of these is silver kob, which is tenth on the list. This species, which only averages 4.6 kg per hour, is clearly more available to trawlers in winter on the three major grounds where it is caught. The inshore-offshore migration of this species was first mentioned by Griffiths (1996), who noted higher linefish catches in shallow water in summer.

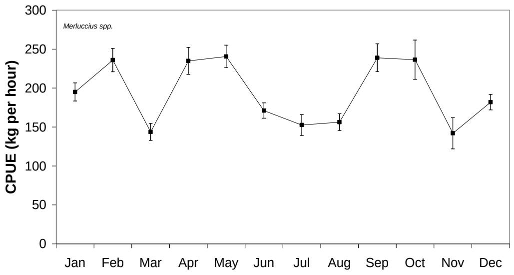
There is some indication of an east-west migration in panga, the third most abundant catch. These fish are abundant off Algoa Bay in winter and abundant off Still Bay in summer. This trend confirms findings by the Japan/South Africa surveys (Uozumi *et al.* 1984) and the surveys analysed by Badenhorst and Smale (1991). The fish seems to spawn predominantly in the east in late winter and to recruit in the west. Average panga sizes increase from west to east.

White stumpnose is fairly low on the catch list (12th) and variances are high, but again there is an indication of higher catch rates in winter and spring. Similar to silver kob, this species spawns offshore in spring, and migrates to shallow water in summer (Griffiths *et al*. 2002).

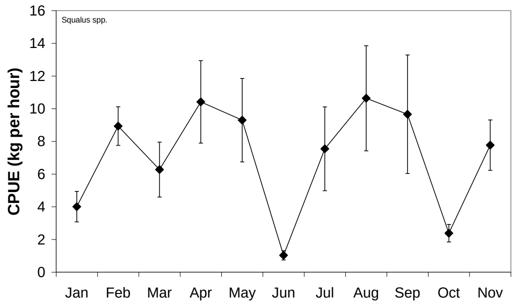
The final species considered are the skates, which is a group of several closely related species. The lumping of species is likely to obscure species-specific trends. Nevertheless, a seasonal trend is evident, again peaking in late winter. The trend for zone 3 (Blues) may in fact be spurious, because of one very large catch taken in July which pushed up the variance. The other two zones (4 and 6) show elevated catch rates in winter (July to September).

The onshore-offshore migration seems to be a pattern followed by several unrelated species. The shallow waters are more productive and warmer in summer. In winter these species seek refuge in the cooler and deeper water, less affected by the seasons, where they build gonads for spawning. For the reduction of bycatch, time-area closures could include zones 2, 4 and 6 during late winter.

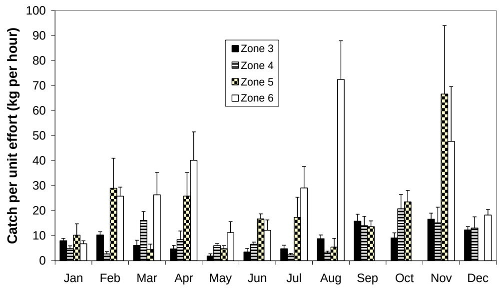
Shallow-water hake



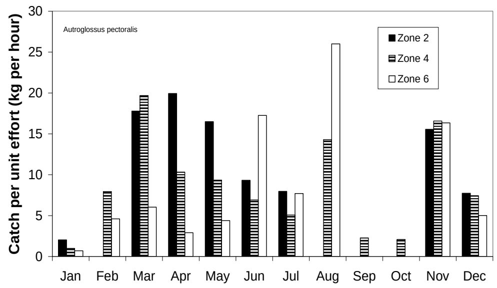
Dogfishes



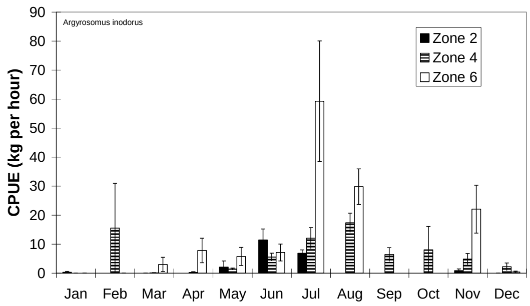
Gurnards



East coast sole



Silver kob



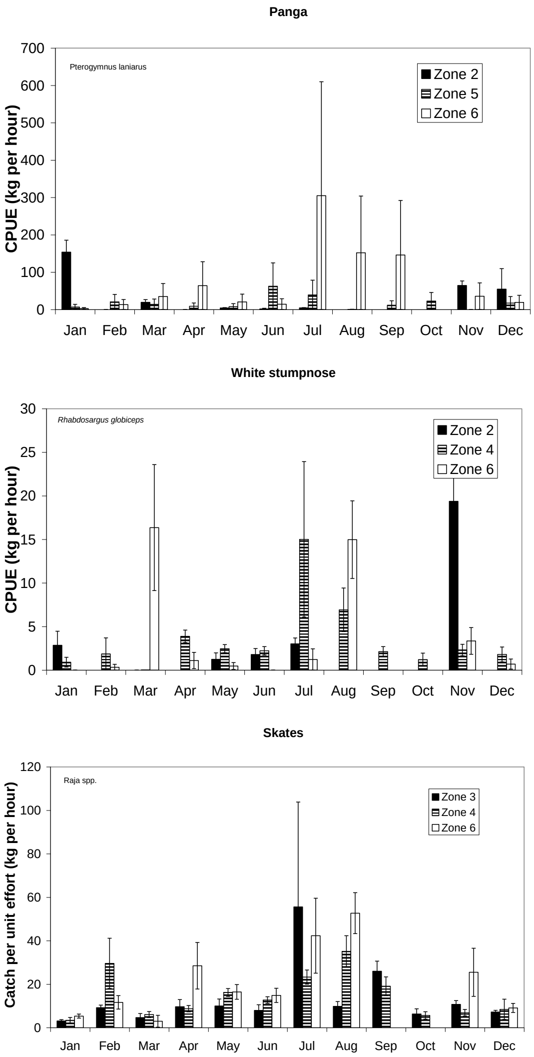


Figure 4. Seasonal trends in the catch per unit effort of species caught by inshore trawlers from 2003 to 2006. Where clear trends are evident, the data are split into the various zones. Data are only shown for zones where the species are commonly caught. The absence of a bar indicates insufficient data (n < 10 trawls). Error bars indicate standard error.

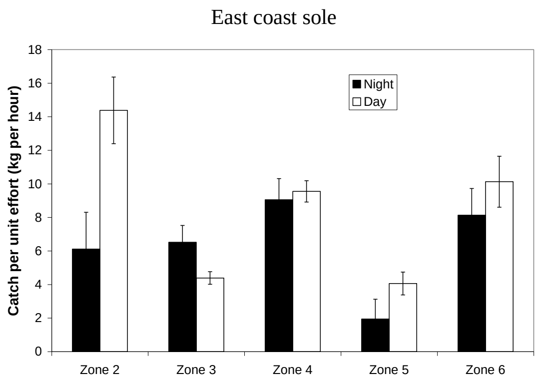
Restrictions on night trawls

The fishery shows a strong diurnal pattern with typically four trawls in daylight hours, and, in approximately one third of voyages, two additional trawls at night. Night trawls are directed at sole. The net-on-bottom time was 2.6 h for day-time trawls and 4.7 h for night-time trawls. This difference is significant. Night trawls accounted for more than 15% of all trawls in grid-blocks 521, 523, 524, 536, 537 and 539 (i.e. zones 2 and 4). Night trawls in zone 6 made up about 8% of all trawls. Elsewhere night trawling was infrequent. Duration of net tow differed significantly between day and night.

Diversity per haul is partly a function of trawl duration. The longer the trawl, the greater diversity of habitat covered (Alverson et al. 1996). Survivorship of incidental bycatch is also reduced by longer tows. For bycatch species such as large sharks and turtles, it would be advisable to keep the tows short, to increase their chances of survival. However, the bycatch in the inshore trawl does not include incidental catches of large mammals, birds or reptiles. The majority of the bycatch are marketable fish and sharks, and there will not be much incentive to return fish. Survivorship of incidental bycatch is not a major concern in this fishery.

There may, however, be a difference in the availability of certain bycatch species to trawls between day and night. If so, restrictions could limit trawls to a particular time of day when a cleaner catch can be expected. Given that night trawls were only a feature on sole grounds, the catches of east coast sole and silver kob were examined in these zone (Fig 5). For neither of these species was there a significant difference between day and night catch per unit effort, except for east coast sole in zone 2, where daytime catches were greater.

Other species were examined comprehensively during the Japan/South Africa joint trawling survey (Hatanaka *et al.* 1980). In these surveys it was found that panga catches did not differ between day and night on the central Agulhas bank, but catches were greater in the daytime on the eastern Agulhas bank. Hake and horse mackerel catches were greater in the day everywhere. These two species migrate off the bottom at night. Investigations into other species were not attempted, as it does not seem there is much merit in a night trawling ban, given the good availability of east coast sole at night and the lack of diurnal differences in catch rates with respect to silver kob and panga.



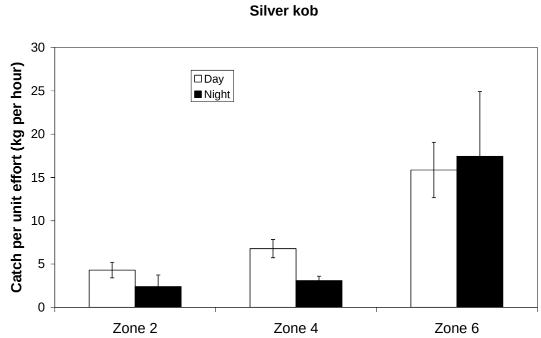


Figure 5. Comparison of catch per unit effort between day and night trawls by zone. The error bar refers to one standard error.

Move-on-rule

The move-on-rule is a mixture of input and output controls currently practiced by trawlers. Trawlers are expected to move at least 5 miles if the catch of silver kob exceeds a certain fraction of the catch in bag. This restriction has not yet been evaluated, either for its effect on silver kob catches nor with respect to the cost of fishing. So far the rule is only applied to silver kob. It would not be practical to apply such a rule to a broad spectrum of species.

Mesh size

Mesh size investigations in the sole-directed fishery were made by (Marchand 1934) using saving gear, panel nets and trouser cod-ends. He used mesh sizes ranging from 2.75 inches to 3.5 inches. The goal of this experiment was to find the best gear for capture of mature soles, while saving immature soles. The 3 inch mesh gave the best compromise on all grounds (Algoa Bay, Plettenberg Bay, Mossel Bay and Cape Infanta). The 3 inch net was found to retain only 35% of undersized sole (< 12-inch), whereas, the 2.75-inch net retained 76% of undersized soles. The larger mesh net (3.5 inch) allowed too large an escape of marketable soles. The 75 mm mesh limit is still used today for sole directed trawlers whereas 90 mm applied to hake-directed trawlers. No experimental results were reported with respect to other species.

Mesh selectivity was tested during the Japan/South Africa joint trawling survey. Three mesh sizes were tested, namely 90, 105 and 120 mm mesh. These gave 50% retention sizes of hake of 26 cm, 31 cm and 39 cm respectively. The corresponding sizes of panga were 18 cm, 23 cm and 23 cm respectively (Hatanaka *et al.* 1983, Ouzumi *et al.* 1983). This survey also recorded the total volume of bycatch, in relation to the catches of hake, squid, horse mackerel and panga. Unfortunately, the results are impossible to interpret because the nets of different sizes were used in widely separated areas. The effect of the mesh size is therefore confounded by geographical effects.

There is probably some merit in revisiting the mesh size debate with regard to bycatch and MMSY. Renewed experiments focussing on other species will be required.

Bycatch excluder devices

Bycatch excluder devices are used mostly to separate the target from incidental bycatch, which are either prevented from entering the net, or ejected from the net during trawling. As discussed earlier with respect to restricting night trawling, the bycatch excluders do not offer a solution to the problems experienced by the inshore trawl fishery. The unmanaged bycatch are mostly fish of the same or similar size to hake, and therefore tricky to separate. The same is not true of the sole-directed fishery, where the big bycatch species, silver kob, is quite different from the target. The amounts of large sharks caught are relatively small, with the exception of skates, smooth-hound sharks and vaalhaai, all of which are marketed in a particular size range. Bycatch excluders are difficult to handle on the small trawlers, may reduce overall catch and are therefore unlikely to find easy acceptance by skippers.

Recommendations

The bycatch of the inshore trawl can, in the first instance, be addressed simply by reclassifying many of commonly caught species from bycatch to targets. This shift will properly reflect the status of the fishery as a mixed trawl fishery, which depends on a variety of species. These multiple targets need to managed, which will entail setting objectives (targets and limit reference points), implementing an effective monitoring and assessment framework, and regulating the fishery to achieve these objectives.

The best method available, based on experience in similar fisheries in British Columbia and New Zealand, is an ITQ system applied to a variety of species. Such a system will allow trading between rights holders and allow for roll-overs of quota, to ensure that the correct mix of species is taken, while minimising the incentive to high-grade and dump fish. The precautionary catch limits applied to silver kob are a step in the right direction, but it is presently unclear how the fishery will react in situations when these limits are reach before hake and sole quotas are exhausted.

Such a system is expensive to implement legally, and it may not be affordable or practical, in which case a second best option would be the sea-day allocation, as is currently used in conjunction with hake and sole quota control. However, this system will need to be adapted to explicitly regulate the capture of bycatch species, and even so would not provide absolute limits on any particular species.

Among the many forms of input controls, there is considerable merit in closed areas. The conservation planning model (Marxan) and the effort displacement model have together identified areas which would represent the full suite of bycatch species, wile at the same time redistribute effort in a manner that will not require a drop in TAC. The areas selected lie at the edge of trawl grounds and in marginal area. Where areas are equivalent in species composition those near Algoa Bay are selected above those off Infanta, reflecting the need to avoid heavily trawled areas and to represent the greater diversity in the east. The Marxan output should be treated as a guide only, and common sense would dictate that an area off Infanta should also be considered, as the potential fishery benefits fall outside the scope of the Marxan software. The model output can be compared with the frozen trawl footprint to find areas of commonality. To have an impact on the bycatch, it is unavoidable that closed areas will have to divert trawlers.

Closed areas can be combined with closed seasons. Although Murawski (2000) argues against this form of management, in the case of the inshore trawl fishery it is clear that a number of coastal species aggregate on the trawl grounds, particularly the sole grounds, in mid to late winter.

The recently introduced move-on rule would seem to be a good restriction, but its effect will need to be examined.

With respect to gear restrictions I have little basis to comment on the effectiveness of mesh size or bycatch excluders without having done experiments testing alternative gear. The early mesh size experiments pertained only to sole. The Japan/South Africa mesh size experiments confound gear type and area, making it impossible to assess the effects of mesh size. Bycatch excluders, although they could be tested are unlikely to exclude fish of a similar size as hake (e.g. silver kob), and will be difficult to use on the small inshore trawlers.

This documents follows from a number of other documents (Japp 1994, Smale and Badenhorst 1996, Walmsley *et al.* 2006 and SADSTIA 2010), each recommending and evaluating options. There seems to be some commonality in respect of the desire to try closed areas and to expand the quota system to other species, and to persist with the observer program.

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Dr. Rob Leslie provided many useful comments on the original version of the report. Peter Sims also provided many useful insights. The work was funded by the Responsible Fisheries Alliance.

Appendix

TECHNICAL REPORT

30 September 2010

USE OF MARXAN TO IDENTIFY POTENTIAL CLOSED AREAS TO REDUCE BYCATCH IN THE SOUTH AFRICAN INSHORE TRAWL FISHERY

Prepared for
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Forward

This document is a technical report with details of a project to identify potential closed areas for bycatch reduction in the South African inshore trawl fishery using systematic conservation planning software (Marxan). It forms part of a more comprehensive project by Attwood *et al.* (2010) in which further analyses are undertaken to measure the impact of displaced fishing effort on overall bycatch.

This draft document delivers on the following contractual obligations:

1. Identification of effective closed areas: complementarity analysis of gridcells
2. Identification of areas where high bycatch (in particular bycatch of undersize fish e.g. kob) and low target species catches occur

Acknowledgement

We thank Dr Samantha Petersen of WWF South Africa for driving this research and for important discussions during the project.

Citation: Lombard, A.T., C. Attwood, K. Sink and H. Grantham. 2010. *Use of Marxan to identify potential closed areas to reduce bycatch in the South African inshore trawl fishery.* Technical Report for WWF South Africa and the Responsible Fisheries Alliance. WWF South Africa.

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INTRODUCTION

The objective of this report is to identify potential closed areas to reduce bycatch in the South African inshore trawl fishery, while minimising the impact on the catch of the two target species (shallow-water hake *Merluccius capensis* and east coast sole *Austroglossus pectoralis*). Additional considerations are that bycatch should be reduced within all species in Table 1 (i.e. a complementarity analysis) and that closed areas should preferentially be selected in areas with smaller (young) fish (both bycatch and target species). Spatial planning units are the South African commercial gridcells of 20’ x 20’ (approximately 1130 km^2 at 35^oS), each of which has a unique Station Id.

The document *Bycatch in the South African inshore trawl fishery: observer records from 2003 to 2006* (Attwood and Petersen 2010) provides a detailed background of the fishery and its bycatch concerns.

Given that there are quantifiable trade-offs in an analysis that aims to reduce one variable (bycatch) while simultaneously minimising the impact on another variable (target species catch), and that there are many bycatch species and two target species, the problem is complex. Consequently, we used a decision support software tool, Marxan (Possingham *et al.* 2000), to identify areas that achieve quantitative targets for bycatch, while minimizing the cost to the fishing industry. The same software was used to identify options for spatial and temporal closures for reducing bycatch in the South African pelagic long-line fishery (Grantham *et al.* 2008). Marxan uses an objective function (Game and Grantham 2008, Watts *et al.* 2009) which employs simulated annealing to identify a configuratiuon of planning units (gridcells) that will meet objectives (e.g. reduce bycatch in all species by at least 20%) while simultaneously minimising costs to the fishing industry (e.g. have minimal impact on the total number of hours trawled).

The objective function in Marxan, however, currently does not deal with displaced fishing effort, so in this report we are assuming that any fishing effort falling within potential closed areas will NOT be displaced elsewhere. However, the effect of displaced fishing effort on bycatch cannot be ignored, so we have developed additional software to do the required calculations. These calculations are included in the final report by Attwood *et al.* (2010).

METHODS

1. Bycatch data

Data source	Second phase of the *Offshore Resources Observer Programme*
Data resolution	20 x 20 minute commercial gridcells
Data values	Average CPUE[1] (kg/hr) per species per gridcell (from 2003 to 2006), data available for 79 species (including target species) and 35 gridcells[2]
Data used in analyses	Of the 79 species for which CPUE data existed, only 27 nominal species[3] were used in our analyses (Table 1). Species were excluded if they were (i) target species (i.e. hake or sole), (ii) key offshore bycatch species (e.g. kingklip and monk), (iii) pelagic species (e.g. horse mackerel) or (iv) had a mean CPUE <0.1. In addition, gridcells with <10 trawls were also excluded from analysis. The final data set consisted of 27 species in 29 gridcells (Fig. 1, green cells).

[1] Catch per unit effort
[2] Data provided by Attwood and Petersen (2010)
[3] Species records not identified to genus-species level were lumped into nominal species

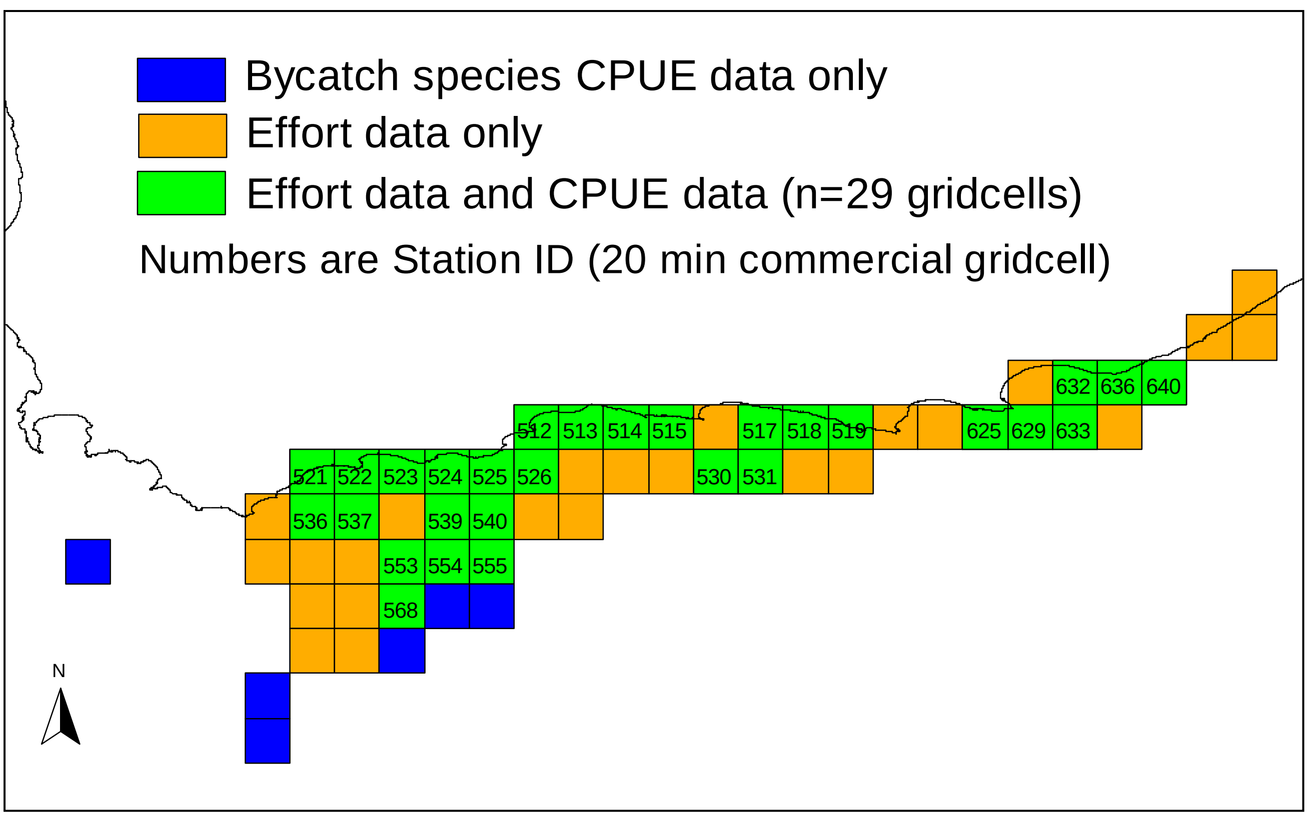

Fig. 1. Gridcells for which data were available for bycatch species CPUE, and trawl effort (hours), for the South African inshore trawl industry.

2. Size structure data

Data source	Second phase of the *Offshore Resources Observer Programme*
Data resolution	20 x 20 minute commercial gridcells
Data values	Mean mass per species per gridcell (from 2003 to 2006)[1] (calculated as the total mass, per species, in the trawl sample, divided by the number of fish of that species in the sample)
Data used in analyses	Data for six species were used: Carpenter, Geelbek, Panga, Silver kob, White stumpnose and shallow-water hake. These species were chosen because of their overlap with other fisheries (notably the demersal long-line fishery and the hake hand-line fishery), which causes conflict, and because of the interest in the discarding of small hake. Data were included in analyses only if the species was found in 10 or more trawls, per gridcell. The final data set consisted of five species (White stumpnose were found in insufficient trawls) in 34 gridcells (these 34 gridcells included all of the 29 gridcells used for the bycatch data, except for gridcell 625, see Fig. 1).

[1] Data provided by Attwood and Petersen (2010)

Data were processed as follows: the mean mass, per gridcell, of the five qualifying species, in the 29 qualifying gridcells, was noted. Each of these values was then scaled from 0-1, per species. The multiplicative inverse of each scaled value was then calculated (so gridcells with smaller fish received bigger numbers). The average value of these multiplicative inverses was then calculated, per gridcell (nodata values were ignored). The final sum of all the averages was 820.33. We set a target of 20% of this value for the Marxan analyses (this forces Marxan to choose cells with small mean masses for the five qualifying species).

3. Fishing effort data

Data source	Commercial catch and effort data for the inshore trawl fishery (MCM[1])
Data resolution	20 x 20 minute commercial gridcells
Data values	Hours spent trawling, from 2000 to 2008. Data available for 53 gridcells (Fig. 2)
Data used in analyses	Only gridcells for which both bycatch data and effort data were available, were used. Since all 29 of the final gridcells from the bycatch data set had effort data, these 29 gridcells were used in all further analyses (Fig. 1, green cells).

[1] Marine and Coastal Management

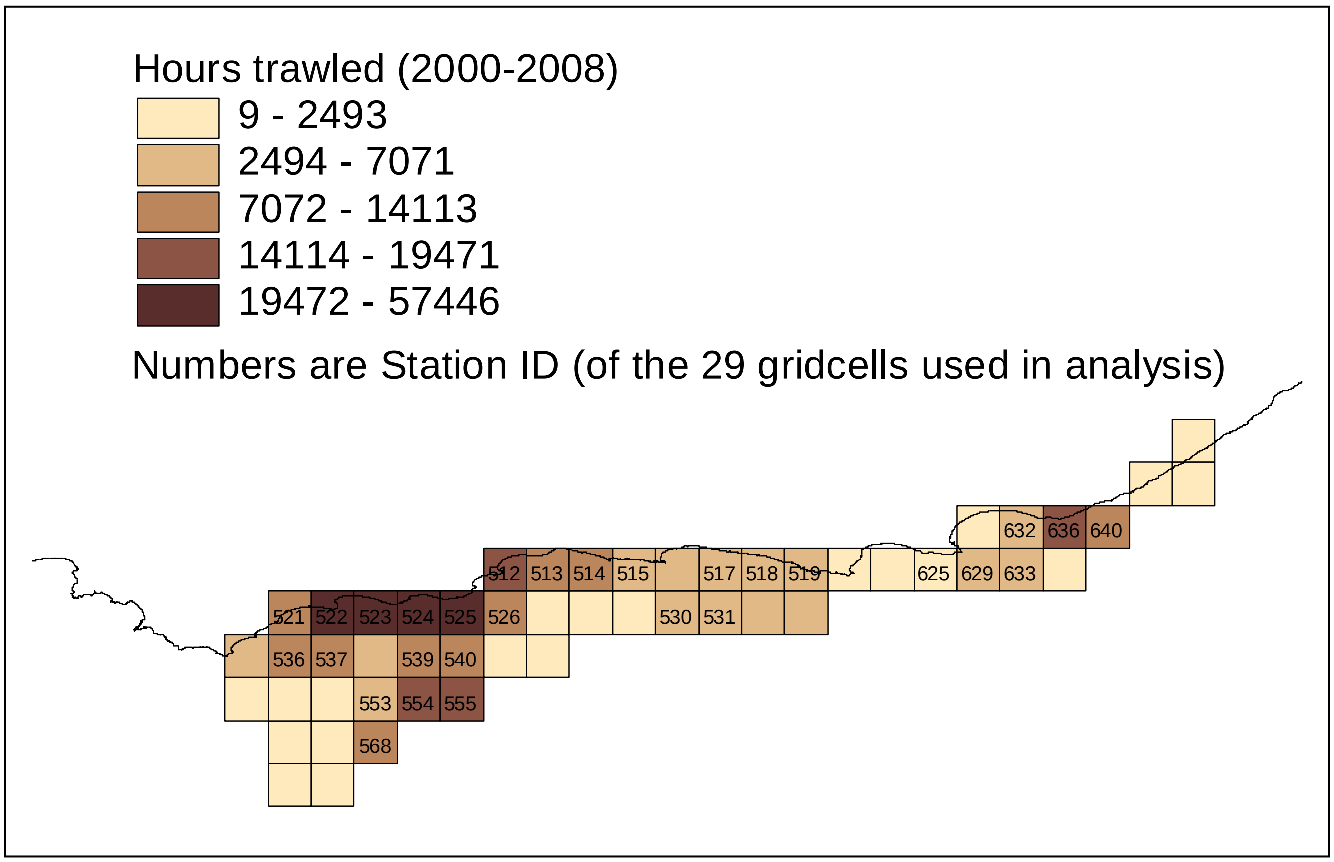

Fig. 2. Trawl effort (hours) for the South African inshore trawl industry. Station Ids are shown for only the 29 gridcells used in analysis (See Fig. 1).

Table 1. Mean CPUE (kg/hr) of the 27 nominal bycatch species considered in this report (where mean CPUE is the mean of all the mean CPUE values per species per gridcell).

	English name	**Genus**	**Species**	**Mean of mean CPUE (kg/hr)**
1	Panga	*Pterogymnus*	*laniarius*	25.357
2	Gurnard unidentified	*Chelidonichthys*	spp	16.199
3	Skate unidentified	*Raja*	spp	11.781
4	Dogshark unidentified	*Squalus*	spp	10.346
5	St Joseph	*Callorhincus*	*capensis*	10.271
6	Chokka squid	*Loligo*	*vulgaris*	4.852
7	Silver kob	*Argyrosomus*	*inodorous*	4.210
8	White stumpnose	*Rhabdosargus*	*globiceps*	2.351
9	Geelbek	*Atractoscion*	*aequidens*	1.867
10	Carpenter	*Argyrozona*	*argyrozona*	1.684
11	Houndshark unidentified	*Mustelus*	spp	1.407
12	White seacatfish	*Galeichthys*	*feliceps*	0.873
13	Cape dory	*Zeus*	*capensis*	0.711
14	Jacopever	*Helicolenus*	*dactylopterus*	0.688
15	Lesser guitarfish	*Rhinobatos*	*annulatus*	0.484
16	Bulray	*Myliobatis*	*aquila*	0.455
17	Horse fish unidentified	*Congiopodus*	spp	0.447
18	Soupfin shark	*Galeorhinus*	*galeus*	0.368
19	Electric ray unidentified	*ORDER TORPEDINIFORMES*		0.271
20	Shyshark unidentified	*FAMILY SCYLIORHINIDAE*		0.212

21	Belman	*Umbrina*	*canariensis*	0.181
22	Roughnose skate	*Cruriraja*	*parcomaculata*	0.176
23	Striped catshark	*Poraderma*	*africanum*	0.170
24	Catshark unidentified	*Halaelurus*	spp	0.166
25	Fingerfin unidentified	*FAMILY CHEILODACTYLIDAE*		0.130
26	Red fish unidentified			0.124
27	Sand soldier	*Pagellus*	*natalansis*	0.103

4. Marxan analyses

Marxan uses an objective function (1) to identify areas (in our case gridcells) that achieve quantitative targets for bycatch, while minimizing cost to the fishing industry (see Possingham *et al.* 2000; Game and Grantham 2008; and Watts *et al.* 2009 for more details). Our bycatch target was to reduce bycatch in all species by at least 20% (using CPUE values), while preferentially selecting gridcells with a small mean mass of four species of bycatch (Carpenter, Geelbek, Panga and Silver kob), and one target species (shallow-water hake) (see section 2. "Size structure data" for target calculation). Our cost target was to minimise the number of trawl hours "lost" to the industry in the chosen gridcells. Our assumption in this analysis is that these hours will not be displaced to other areas. The more comprehensive project (Attwood *et al.* 2010) does not make this assumption – instead it calculates the effect of this displcaed fishing effort on total bycatch.

$$\sum_{PUs} Cost + BLM \sum_{PUs} Boundary + \sum_{ConValue} SPF \times Penalty + CostThresholdPenalty\,(t) \qquad (1)$$

Table 2 lists the variables we used in the Marxan analysis.

Table 2. Variables used for Marxan analysis.

Target for bycatch species	**Target for small fish (of the five qualifying species)**	**Species Penalty Factor**	**Boundary Length Modifier**	**Number of runs**	**Number of iterations**
(at least) 20% reduction in CPUE for all 27 bycatch species	(at least) 20% of the value 820.33	100	1	100	1 000 000

RESULTS

Table 3 shows the results of the Marxan analysis. Of the 100 runs, each of which achieved the specified targets, only five runs were spatially different (Fig. 3). The most efficient solution (solution 1) has the lowest value for the objective function and requires seven gridcells (Table 3 and Fig. 4). Solution 2 is the same as solution 1 except that gridcell 632 is swapped for gridcell 633. Solutions 3-5 each require eight gridcells to achieve targets. Four gridcells are chosen in every solution (513, 553, 629 and 640) (Table 3 and Fig. 3).

Table 3. Marxan results: the four irreplaceable gridcells (chosen by every solution); + the seven gridcells of the most efficient solution; the five gridcells chosen by some of the alternative solutions.

Station Id (gridcell)	Number of times chosen in the 100 runs	Most efficient solution (solution 1)
512	0	
513	**100**	**yes**
514	0	
515	**56**	**yes**
517	**93**	**yes**
518	0	
519	1	
521	0	
522	0	
523	0	
524	0	
525	0	
526	0	
530	44	
531	0	
536	7	
537	0	
539	0	
540	0	
553	**100**	**yes**

554	0	
555	0	
568	0	
625	43	
629	**100**	**yes**
632	**92**	**yes**
633	8	
636	0	
640	**100**	**yes**

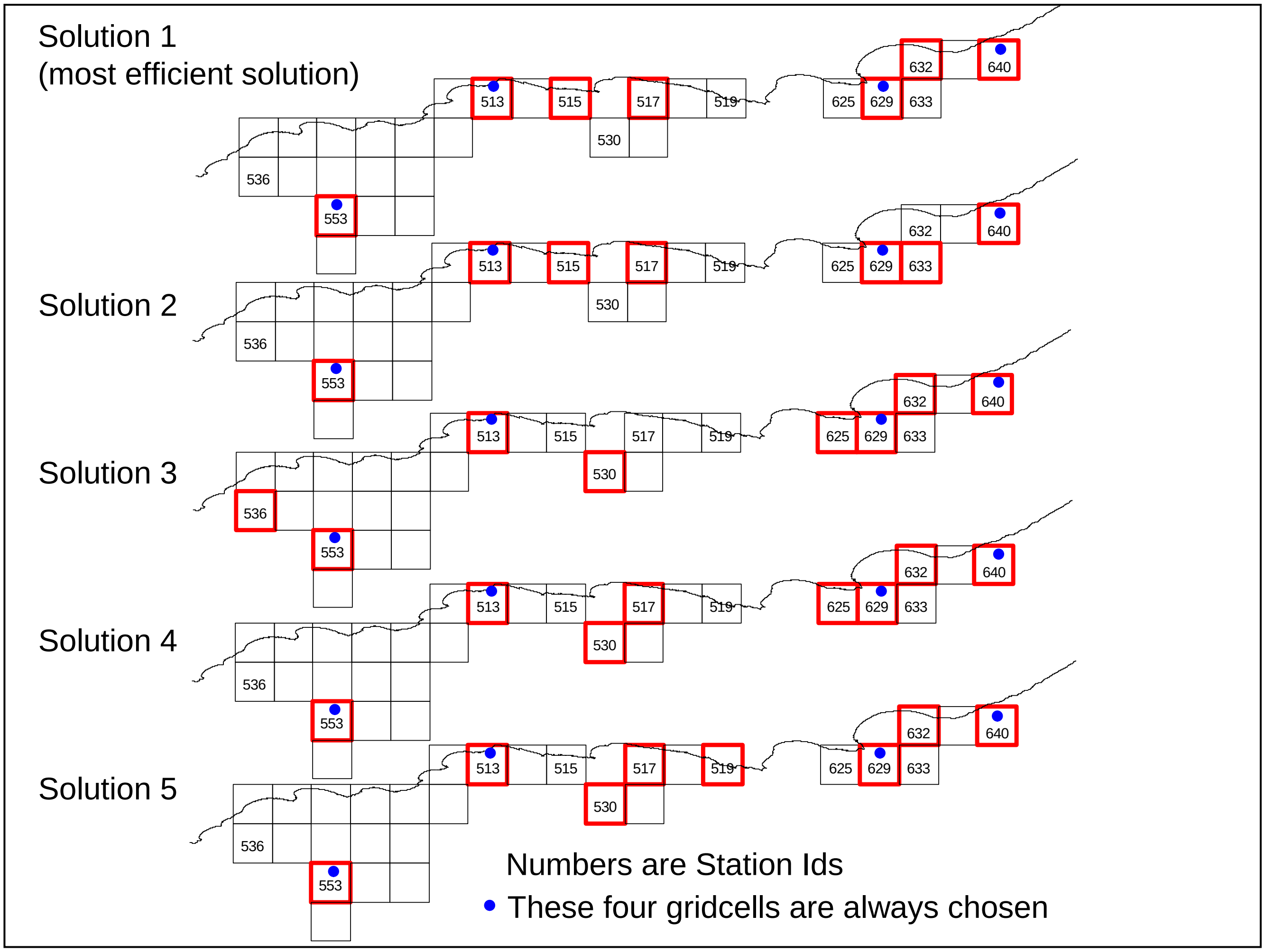

Fig. 3. The five different Marxan solutions (red gridcells) that achieve targets.

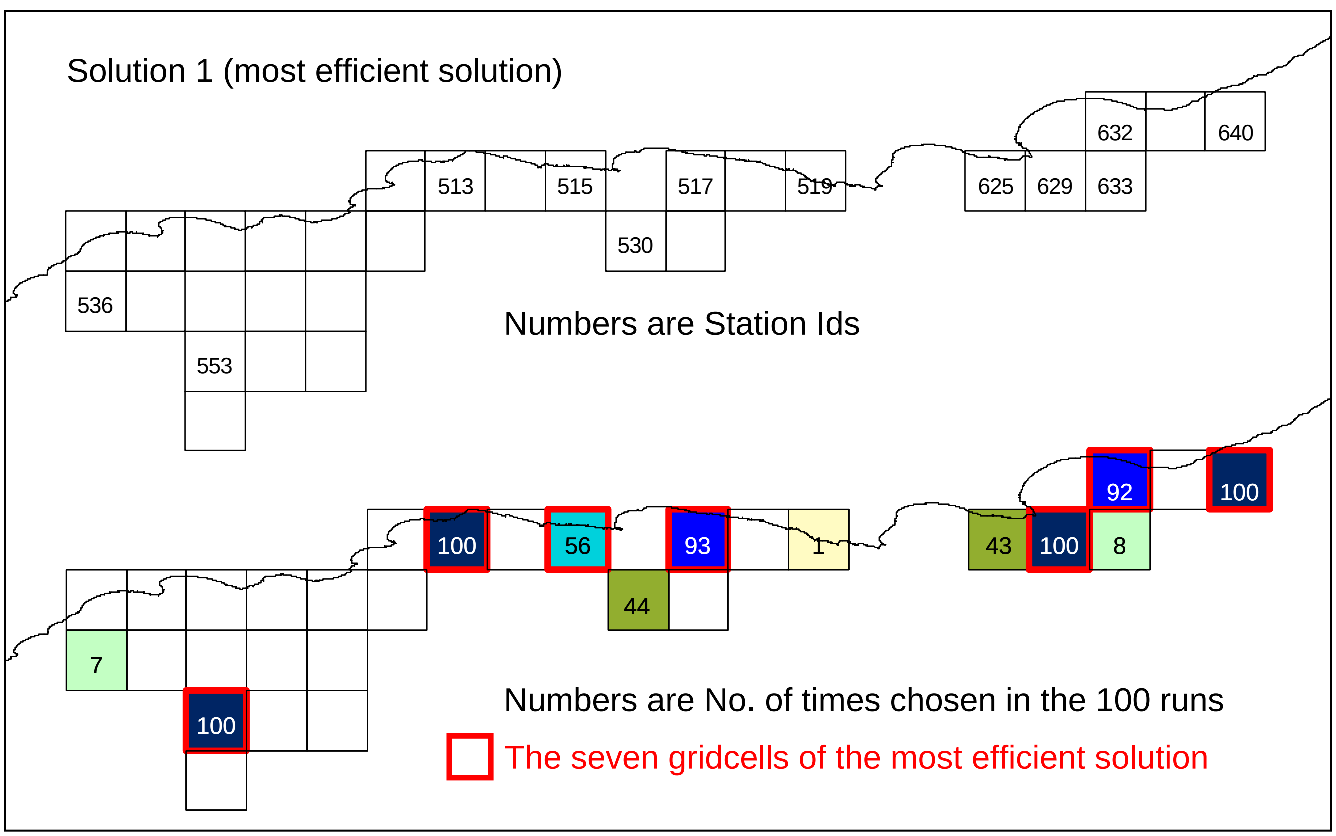

Fig. 4. The most efficient solution that achieves targets (and the No. of times each gridcell is chosen by the 100 runs of Marxan)

Although seven gridcells are required by the most efficient solution to meet all targets (removing any one of these seven gridcells results in at least one bycatch species falling below target), the seven gridcells deliver an over-achievement of targets for many species (this is to be expected because CPUE values of the 27 different species do not follow the same spatial trends). Fig. 5 shows that Fingerfins have their bycatch (CPUE value) reduced by almost 100% (instead of the required 20%), and Sand soldiers and Shysharks both have their bycatch reduced by between 80-90%. 18 species have their bycatch reduced by between 30-70% and six species just meet the 20% minimum target reduction.

The 20% target set for gridcells with a small mean mass of the five selected species is only slightly over-achieved by the most efficient solution (24% is achieved).

The total cost to the fishery in terms of hours is 10% (43 132 hours of a total of 429 122 hours).

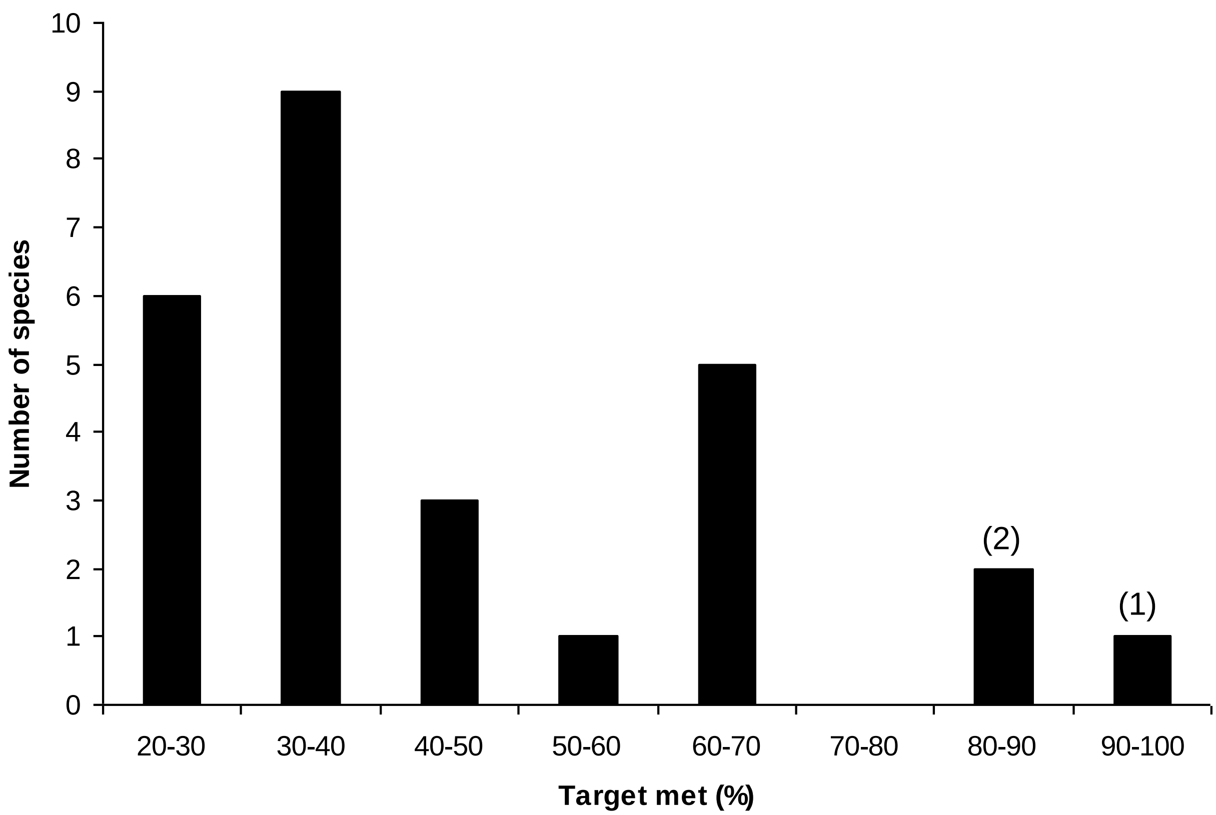

Fig. 5. Targets achieved by the most efficient solution for the 27 bycatch species. Each species requires only a target of 20% reduction in bycatch (CPUE value), but most species receive at least a 30% bycatch reduction.

DISCUSSION

Of the 29 gridcells available for analysis, seven can meet the required targets (Table 3 most efficient solution). In other words, if these seven gridcells are closed to inshore trawling, there could be at least a 20% reduction in the bycatch of all 27 species analysed, with only a 10% cost to the fishery in terms of hours trawled. The seven gridcells are also biased towards areas where many small fish are caught for four bycatch species (Carpenter, Geelbek, Panga and Silver kob) as well as one target species (shallow-water hake).

Although a minimum target of 20% was set for bycatch reduction in all species, the final results of the most efficient solution deliver much higher reductions. Most species achieve at least a 30% bycatch reduction, and three species achieve reductions over 80%: Fingerfins and Sand soldier have very limited distributions (data for only 3 gridcells) and one of these gridcells (640) is selected for the most efficient solution, thus giving vey high bycatch reduction for both of these species, and Shysharks occur more widely but have a very high bycatch in gridcell 513, which is also selected by the most efficient solution.

We acknowledge that the spatial distribution of these seven gridcells may not be practical for trawl closures for a number of reasons (e.g. trawl gear deployment, compliance monitoring, etc.) and the redistribution of effort from these gridcells across the inshore fishery may significantly change the final calculations of bycatch reduction. We thus explore these issues in the more comprehensive project by Attwood *et al.* (2010).

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