# TECHNICAL REPORT

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

Prepared for
WWF South Africa
and the
Responsible Fisheries Alliance
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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

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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

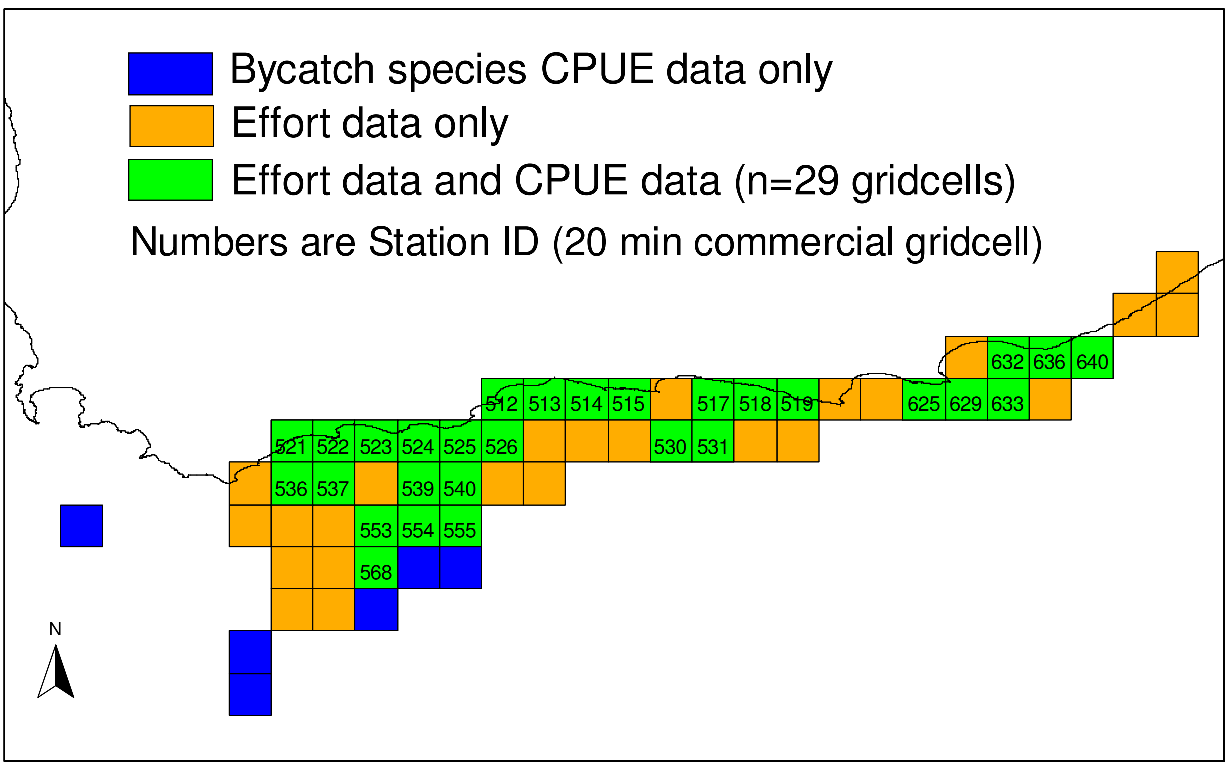


Fig. 1. Gridcells for which data were available for bycatch species CPUE, and trawl effort (hours), for the South African inshore trawl industry.

**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

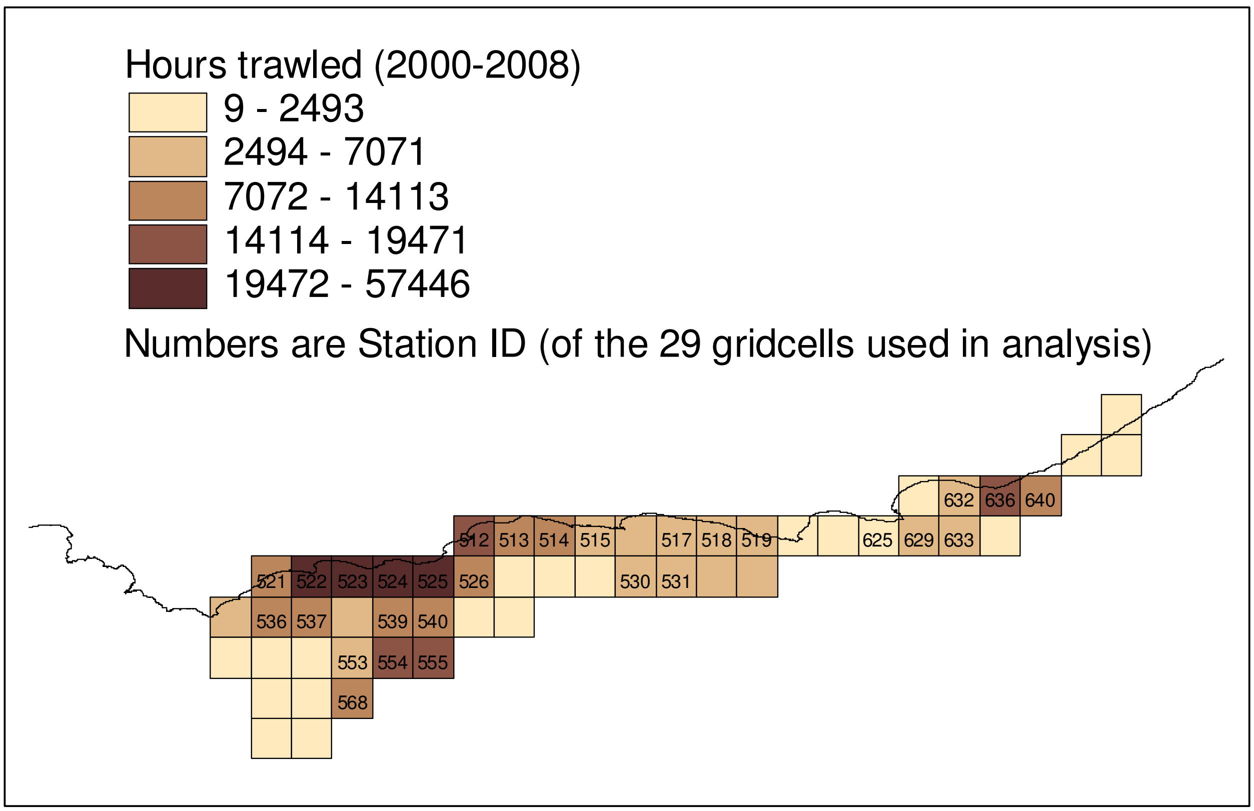


Fig. 2. Trawl effort (hours) for the South African inshore trawl industry. Station Ids are shown for only the 29 gridcells used in analysis (See Fig. 1).

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: [blue] the four irreplaceable gridcells (chosen by every solution); [blue] + [pink] the seven gridcells of the most efficient solution; [green] 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** |

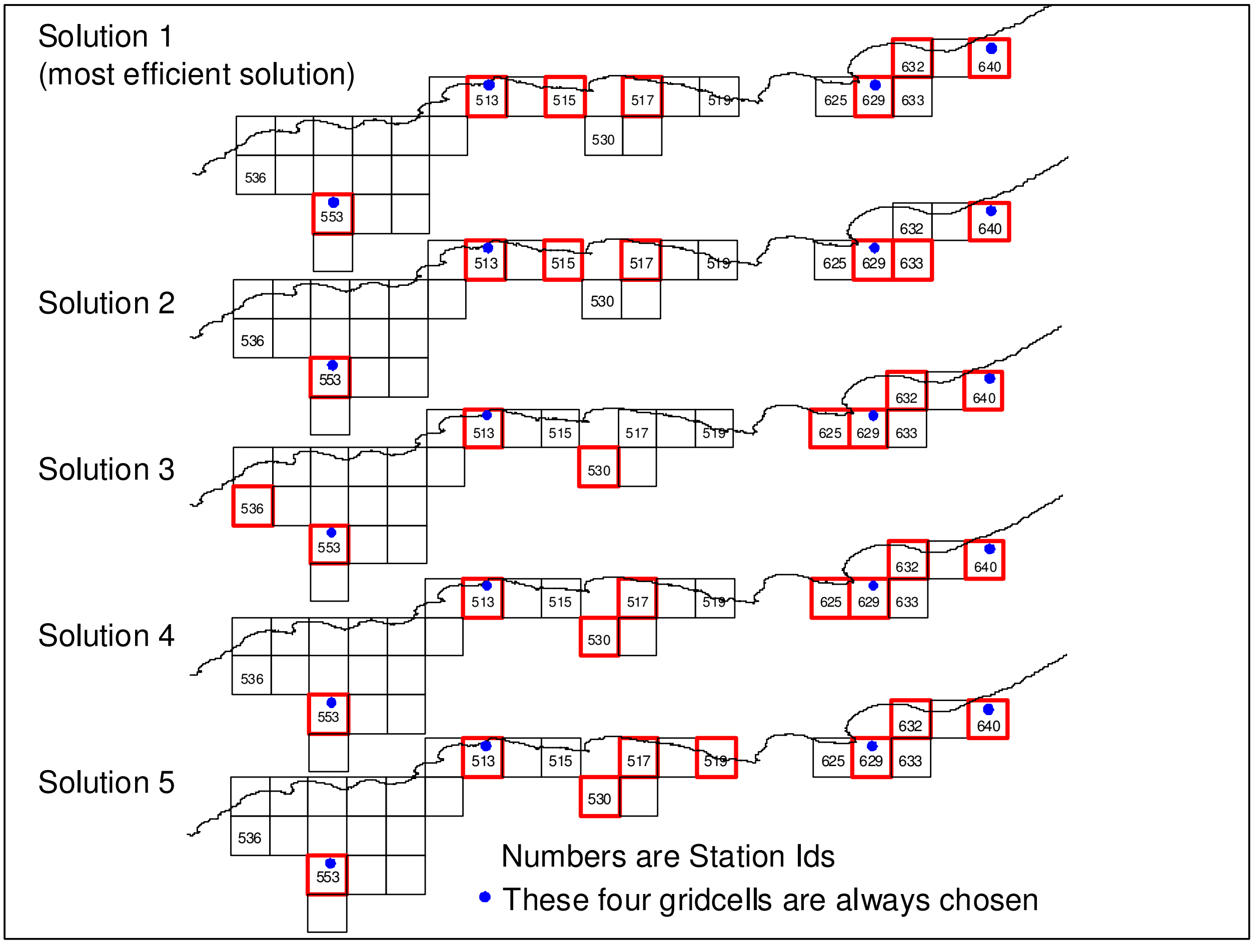


Fig. 3. The five different Marxan solutions (red gridcells) that achieve targets.

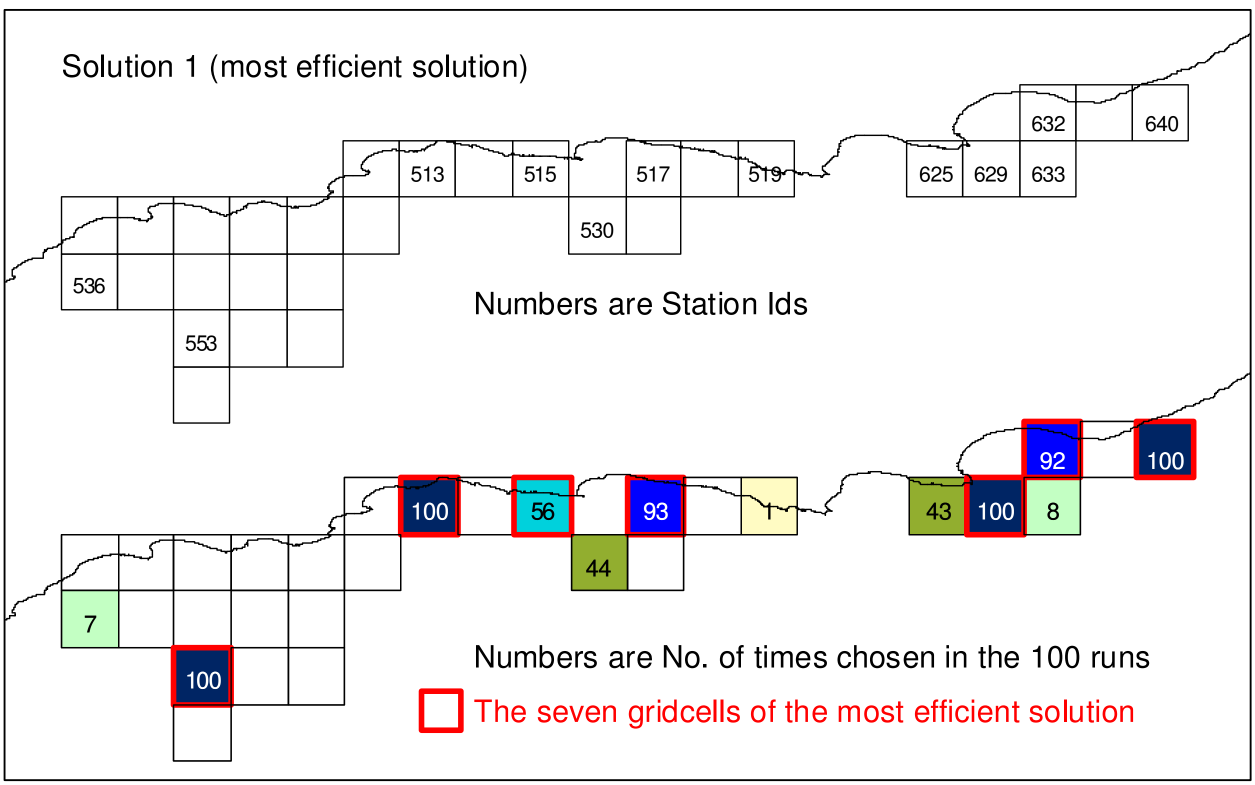


Fig. 4. The most efficient solution that achieves targets (and the No. of times each gridcell is chosen by the 100 runs of Marxan).

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).

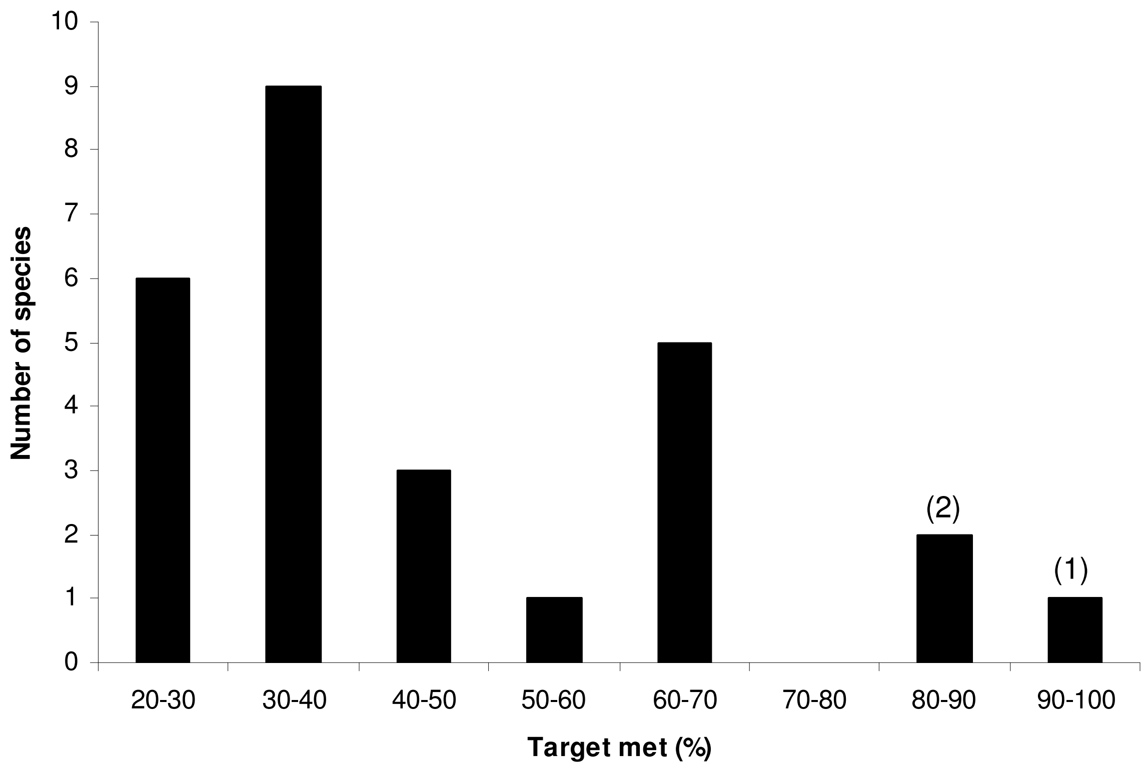


Fig. 5. Targets achieved by the most efficient solution for the 27 bycatch species. Each species requires only a target of 20% reduction in bycatch (CPUE value), but most species receive at least a 30% bycatch reduction.

(1) = Fingerfins

(2) = Sand soldiers and Shysharks

## 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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