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The potential for new *Nephrops* trawl designs to positively effect North Sea stocks of cod, haddock and whiting

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Abstract

Within commercial fisheries, particularly mixed fisheries, both target and non-target species are often discarded. Discarding represents a potentially significant loss to the productivity of fish stocks; it can have damaging ecological consequences, and is a potential cause of the failure of recovery plans. The *Nephrops* fishery in the North Sea is classified as a mixed fishery. *Nephrops* trawls are constructed with smaller meshes than trawls used to target whitefish; consequently, the bycatch of juvenile fish can be substantial. Several new *Nephrops* trawl designs have been tested in the North Sea. The data from these trials are used to investigate the potential impact of their implementation on cod, haddock and whiting stocks in the North Sea (including the Kattegat and Skagerrak).

The model examines five trawl designs, and also the scenarios of a cessation of discarding in all North Sea fisheries and in just the *Nephrops* fishery. The model is deterministic, and evaluates the relative differences between scenarios assuming all other variables remain constant. If discarding of cod, haddock and whiting in the North Sea fisheries were eliminated, stocks would increase by 41%, 14% and 29%, respectively, within 10 years. Eliminating discarding in the *Nephrops* fishery alone would increase stocks by 2%, 1% and 13%, respectively, reflecting the relative proportion of catches of these species in the *Nephrops* fishery. For cod and haddock, the introduction of the *Nephrops* trawl with a grid with a square-mesh codend was the only scenario in which a notable increase in stock number was observed. This trawl design facilitates the escape of fish of all ages/sizes from the trawl, effectively making the *Nephrops* fishery a single-species fishery. For whiting, stock numbers and landings increased under all scenarios, but forecasted landings were lower than if current discard patterns continued in all except the no-discards scenario. The dependency of the results on the validity of the assumptions and on the accuracy of the input data is discussed.
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Keywords: Discard; Stock; North Sea; *Nephrops*; Trawl; Cod; Haddock; Whiting

1. Introduction

Within commercial fisheries, both target and non-target species are often discarded dead because they are either surplus to quota or fall foul of bycatch restrictions, are below the minimum landing sizes or are rejected in favour of more valuable fish. The catching and subsequent discarding of fish, particularly within mixed fisheries, represents a potentially significant loss to the productivity of fish stocks and is a potential cause of the failure of recovery plans (Kell et al., 2007). The unnecessary capture of a large number of marine organisms can also have damaging ecological consequences. Therefore, the minimisation of catches and hence discarding of non-target species and undersized fish is an important management objective.

In the North Sea, the main commercial gadoid species are cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*). The estimated percentage of the total catch discarded in 2004 was 21% for cod, 25% for haddock and 82% for whiting (data from the Scientific, Technical and Economic Committee for Fisheries (STECF); this estimate and all following references to the North Sea also include the Skagerrak and the Kattegat). The need for a reduction of all discards is acknowledged but managers have focused on North Sea cod because it is particularly at risk. Also, the stock is currently outside safe biological limits (Fig. 1) and the current scientific advice for it in order to achieve recovery is for zero catches (but see Horwood et al., 2006; ICES, 2006).

Recent research has been conducted to develop more selective trawls in the North Sea mixed fisheries (e.g. Recovery,

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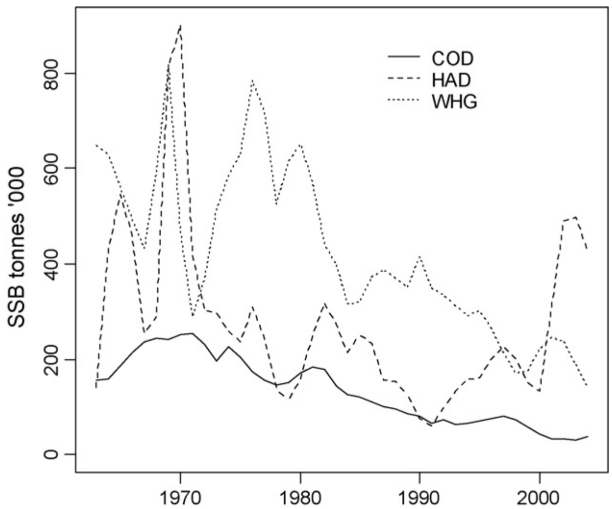

Fig. 1. Output from replicated ICES assessments for North Sea cod, haddock and whiting, illustrating trends in spawning stock biomass.

Necessity). Knowledge of the consequences of such technical measures is required to help identify solutions with the most potential benefit to fish stocks, to allow evaluation of our current technical ability to reduce discards, and to permit a comparative analysis of various management strategies.

Computer simulation has been used to evaluate management strategies for North Sea gadoids (Kell et al., 2007, www.flr-project.org). With the exception of e.g. Kunzlik (2003), there are few published works on the potential impact of introducing innovative gear designs on North Sea fish stocks. The present study aims first to determine the utility of eliminating discards of selected North Sea fish stocks (i.e. assuming that discarded fish are no longer caught), and second to assess the potential benefits of using new trawl designs in North Sea *Nephrops* fisheries, based upon ICES estimates of stock status (ICES, 2006).

Nephrops trawls are constructed with smaller meshes (80–90 mm) than trawls used to target whitefish; consequently, the bycatch of juvenile fish can be substantial. Most *Nephrops* fisheries in the North Sea are classified as mixed fisheries. Some fish bycatch is marketable and forms an important component of the landings; the rest is undersized and discarded dead. Several new *Nephrops* trawl designs have been tested in the North Sea. The data from these trials are used to investigate the potential impact on commercial fish stocks of their implementation. The model used is deterministic, and evaluates the relative differences expected between gear designs while assuming all other variables are constant across scenarios, rather than trying to predict absolute changes in stocks.

2. Method

Computer simulations were made using FLR (Kell et al., 2007, www.flr-project.org). FLR is an open source framework for management strategy evaluation that provides a common environment for implementing and linking a variety of fishery, biological, and economic models. FLR includes tools used by ICES working groups to conduct assessments, evaluate alternative management options and for data exploitation. An important reason for use of open source is that the code is freely available, allowing scientists to check and to validate the implementation of methods, computations carried out, and assumptions made.

Table 1
Input parameters for the forecast model

	Cod	Haddock	Whiting
Age range	1–7+	0–7+	1–8+
Fbar age range	2–4	2–4	2–4
Years for mean selection pattern	2001–2004	2001–2004	2001–2004
Years for mean weights at age	2001–2004	2001–2004	2001–2004
Years for mean portioning landings and discards	2001–2004	2001–2004	2001–2004
Years for mean recruitment	2000–2004	1994–2004	1990–2004
F-Multiplier	1	1	1

The FLR model allows the total catch weight to be fixed in forecast years. A series of short-term forecasts was run for each species for one future year (2005), each with an incrementally increasing catch constraint (1–100,000 tonnes). The parameters for North Sea cod, haddock and whiting were those estimated by ICES up to and including 2004 (ICES, 2006)(Fig. 1 and Table 1). From each forecast run, the F-at-age and catch-at-age data were extracted. These data were combined to generate a F-catch-at-age relationship for the forecast year for each species. Therefore, with a given change in catch numbers-at-age, the short-term forecast (STF) could be run with the corresponding *F*-value, interpolated from the catch-*F* relationship.

Catch number estimates for 2005 using new trawl designs were derived from catch comparison trials. Data from the trials of five experimental *Nephrops* trawls were investigated (Table 2). Catch numbers of cod, haddock and whiting at length were summed across all tows for the experimental and standard trawls for each trial. Numbers at length were converted to age using an age-length key generated from the English 2005 North Sea groundfish survey.

The proportional difference in catch numbers-at-age between the control (Table 2) and experimental trawl was multiplied by the estimated total number of fish caught at age in all North Sea *Nephrops* fisheries in 2005.

Partial catches of North Sea cod, haddock and whiting from *Nephrops* vessels in 2005 were taken from a composite database (STECF database for Scottish and Danish vessels and from national sampling programmes for English and Swedish vessels). These were considered the best available data, although no data for whiting and discard data for haddock or cod were available for Danish vessels.

Regulations for the mandatory use of trawls containing a grid with square-mesh codend (SMC) were introduced in Sweden for vessels working inshore in 2004. Only catches made by Swedish vessels not using the grid with SMC were included in the analysis, to avoid overestimating reductions in catches. This assumed

Table 2
Nephrops trawl gear designs and trial information

Trawl design	Description of main features	Trial location	Hauls	Reference
Control trawl (to which all trawls were compared)	80 mm diamond-mesh codend, square-mesh panel (87 mm mesh) at 12–15 m from codline	–	–	–
(1) Dyneema panel	One square-mesh panel (95 mm mesh) constructed of high strength knotless thin twine at 12–15 m from codline	Farn Deeps	10	(Revill et al., 2007)
(2) Grid with square-mesh codend	Swedish grid, with bar spacing 35 mm combined with 70 mm square-mesh codend	Farn Deeps	10	(Catchpole et al., 2006)
(3) Double square-mesh panel	Two PPE square-mesh panels (∼85 mm mesh) at 12–15 m and 20–23 m from codline	Farn Deeps	10	(Revill et al., 2007)
(4) Cutaway trawl	Headline lowered and set back	Farn Deeps	24	(Revill et al., 2006)
(5) 100 mm diamond codend	100 mm diamond-mesh codend	Farn Deeps	10	2005 (unpubl.)

that those using the grid with SMC in 2004 did so for the duration of the forecast period.

The proportion of the total catch by weight in the North Sea attributed to *Nephrops* vessels was derived from the STECF database. *Nephrops* vessels accounted for 12% of cod catches, 13% of haddock catches and 46% of whiting catches by weight in the North Sea in 2005. The partial catches derived from the composite database were applied to these proportions to give the catch numbers-at-age attributed to *Nephrops* trawlers in the ICES catch data file.

For each age, the relative difference in catches from the trials multiplied by the catch number attributed to *Nephrops* vessels provided a number caught had the experimental gear been used in 2005. Using the *F*-catch relationships, generated with the catch constraint function, *F*-values corresponding to the estimated catch numbers when using the new gears were then used to run a 10-year catch forecast.

2.1. Scenarios

Scenario 1: A baseline stock projection was run for each of North Sea cod, haddock and whiting, against which seven scenarios corresponding to different possibilities for discard mitigation were compared. All scenarios were run for 10 years. Input values for parameters are given in Table 1.

Scenario 2: A complete cessation of discarding in all North Sea fisheries. *F*-values corresponded to the number in the catch minus discards (i.e. a hypothetical scenario of perfect knife-edged selection).

Scenario 3: A total cessation of discarding in all North Sea *Nephrops* fisheries.

Scenarios 4–8: The impact of introducing four new *Nephrops* trawls; Dyneema panel (4), grid with SMC (5), two square-mesh panels (6), cutaway (7) and a 100 mm codend (8). The trials for all selected gear designs were performed on the Farn Deeps *Nephrops* fishery. There were 24 comparative tows for the cutaway trawl, and 10 for al the other designs. All trials were conducted between 2004 and 2006.

2.2. Model assumptions

The model made the following assumptions:

1. Constant distribution and level of fishing effort. The effects of effort restrictions, quotas and closed areas on catching patterns remained constant during the forecast period.
2. There was no change in selection patterns in the other fisheries during the forecast period.
3. In scenarios 4–8, all North Sea *Nephrops* trawlers used the new gear designs.
4. Recruitment was constant.
5. The impact of discard reduction on the stocks of each species was assumed to be independent of other species.
6. The biological characteristics of natural mortality, mass and maturity-at-age remained constant in the projection.
7. The proportion of the catch landed and discarded at each age was constant.
8. Catch comparison trials provided representative changes in selection pattern with the introduction of the new designs.
9. Using a sum of all tows in each trial assumed equal variance between trials. Standard deviations in the lengths of fish caught during each tow were tested using ANOVA. Variance was equal for all except the trial of the grid with the square-mesh codend (for which there was less variance between tows).

Equations used in the forecast assessment are shown in the Appendix.

3. Results

Hereafter, the terms *increases* and *reductions* refer to percentage changes for the various scenarios when compared with the baseline projections. This is because future recruitment is difficult to predict, so the baseline is used to show the relative benefit of introducing the new gears. Forecast changes in stock and landings are shown in Fig. 2 and Table 3.

3.1. Cod

In the absence of discarding in all North Sea fisheries, cod stock numbers increased substantially by 41% and landings by

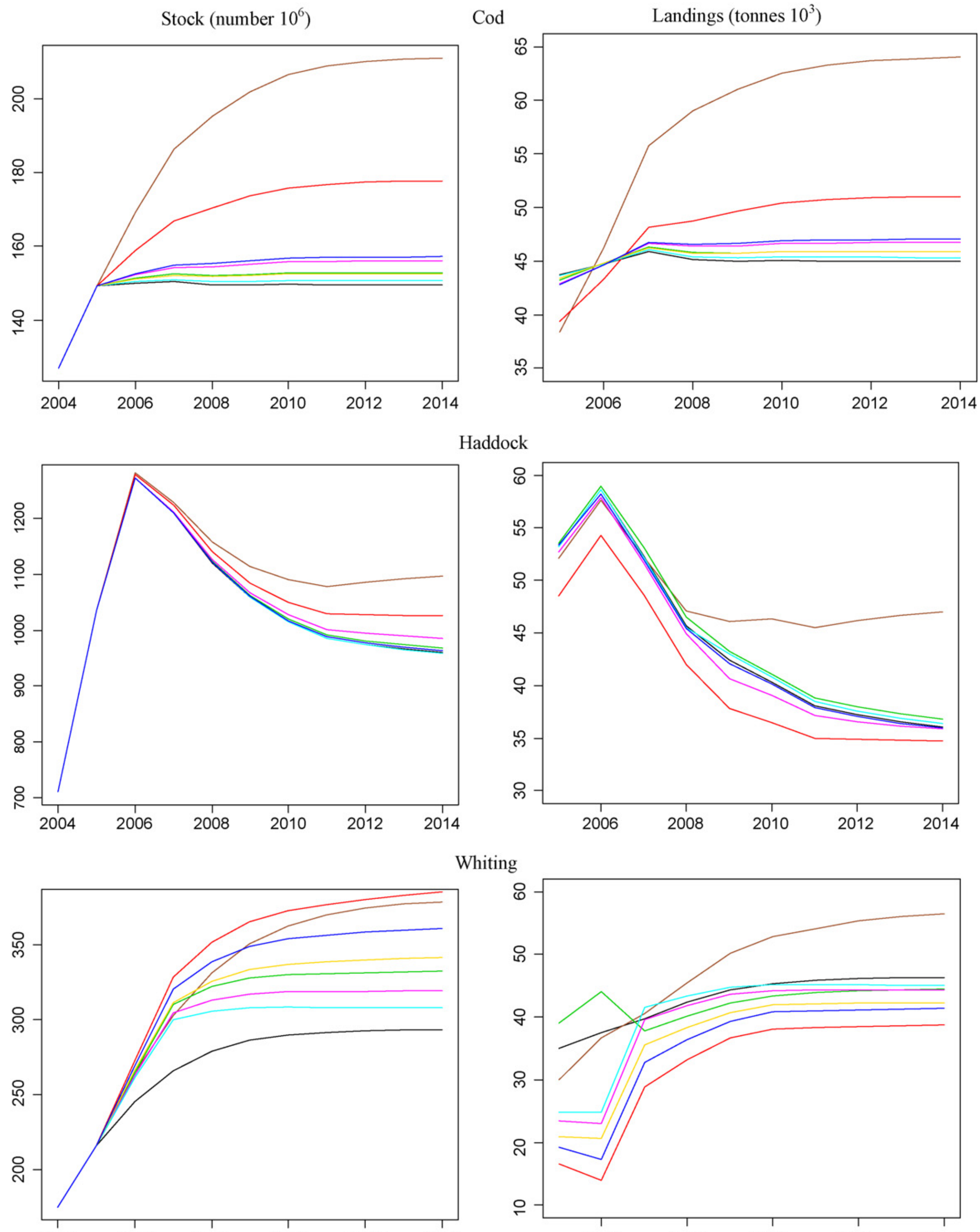

Fig. 2. Model output for forecast stock (number 10^6) and landings (weight) of North Sea cod, haddock and whiting comparing the baseline run (black) with the scenarios of no discarding in any fishery (brown), no discarding in *Nephrops* fisheries (green) and the following trawl designs in *Nephrops* fisheries: Dyneema SMP (pink), grid and SMC (red), two SMPs (turquoise), Cutaway trawl (yellow) and 100 mm codend (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

42% after 10 years. All other scenarios except for the introduction of the grid with SMC design showed little deviation from the baseline forecast. For the first 2–3 years of the forecast, the scenarios with a cessation of discarding in all fisheries and the introduction of the grid with SMC resulted in a reduction in landings relative to the other scenarios.

3.2. Haddock

The overall trend of declining stock number and landings is a consequence of the 1999-year class, which was considerably larger than in other recent years, and the assumption that recruitment during the forecast period would be equal to the

Table 3
Percentage change in North Sea stock (numbers) and landings (weight) forecast after 10 years relative to the baseline runs under the scenarios of discard reductions and the introduction of new *Nephrops* trawl designs

Scenario	Cod		Haddock		Whiting	
	Stock	Landings	Stock	Landings	Stock	Landings
No discards	41	42	14	30	29	22
No discards from *Nephops* fishery	2	2	1	2	13	−4
Dyneema SMP	4	4	3	−1	9	−4
Grid with SMC	19	13	7	−4	31	−16
Two SMP panels	1	1	0	1	5	−3
Cutaway trawl	2	2	–		16	−9
100 mm codend	5	5	1	0	23	−11

mean of the last 10 years. The scenario of a cessation in discards in all fisheries increased in stock numbers by 14% and landings by 30%. The grid with SMC demonstrated a 7% increase in stock, but a 4% decrease in landings. All other trawl designs and the scenario of a complete cessation of discard in the *Nephrops* fisheries showed little deviation from the baseline.

3.3. Whiting

With a complete cessation of discarding in all North Sea fisheries, whiting stock numbers increased by 29% after 10 years, similar to the 31% increase with the introduction of the grid with square-mesh codend. Stock numbers also increased substantially under the scenarios of introducing the 100 mm codend and the cutaway trawl. Smaller, but notable increases in stock numbers were apparent with the introduction of the other trawl designs. All scenarios other than a cessation of catching all unwanted whiting resulted in a reduction in landings. The grid with SMC, 100 mm codend and cutaway designs yielded the lowest projected landings.

4. Discussion

If all cod, haddock and whiting discarding in the North Sea fisheries were eliminated, then stocks would increase by 41%, 14% and 29%, respectively, within 10 years relative to the baseline. Eliminating discarding in the *Nephrops* trawl fishery alone would increase stocks by 2%, 1% and 13%, respectively, reflecting the relative proportion of catches of these species in the *Nephrops* fishery.

For cod and haddock, the introduction of the *Nephrops* trawl with a grid with SMC was the only scenario in which a notable increase in stock number was observed. This design facilitates the escape of fish of all ages/sizes from the trawl, effectively making the *Nephrops* fishery a single-species fishery. Applying the change in overall catches expected with the introduction of this design demonstrated a reduction in total catch number across all ages by an estimated 17% for cod and 9% for haddock.

For whiting, stock numbers and landings increased under all scenarios, but forecasted landings were lower than if current discard patterns continued in all except the no-discards scenario. The result was the same when investigating the potential impact of technical measures in the North Sea demersal roundfish fishery in 2002 (Kunzlik, 2003). The expectation is for improved gear selection to lead to short-term losses, followed by medium-term or long-term gains. As individuals that would otherwise have been retained by the fishing gear grow larger they will contribute to increase the stock and yield. However, whiting cannot grow large enough to recover from the short-term losses (Kunzlik, 2003).

For whiting, the introduction of new *Nephrops* trawls would mean changes to the selection pattern of fish up to at least age 7. Trawl designs for which the highest numbers of older fish were no longer retained predictably demonstrated the smallest landings. These included the grid with SMC, 100 mm codend and cutaway trawl designs.

A relatively large proportion of whiting is discarded at an old age. In the *Nephrops* fisheries in 2005, one-quarter of fish caught of age 4+ were subsequently discarded. Reducing fishing mortality in proportion to the numbers of these unwanted fish, combined with the limited scope for somatic growth of whiting, led to an overall reduction in landings for the scenario of a cessation of discarding in the *Nephrops* fisheries.

All these results are dependent on the validity of the assumptions made in the model and the accuracy of the input data. The absence of data from Danish vessels meant that reductions in catches with the introduction of new gears were underestimated, particularly for whiting.

It is unlikely that fishing effort, distribution, catch and discard patterns in North Sea fisheries will remain constant for the forecast period. However, the same relative differences between scenarios would be observed if any change that did occur was independent of the introduction of a new *Nephrops* trawl design.

Relaxing the assumptions relating to recruitment and inter-species effects would likely change the results. The presence of a stock-recruitment relationship would increase the differences between scenario outcomes. Similarly, introducing the multi-species effects of increased predation mortality due to enhanced stock sizes could substantially alter the predictions.

Assumptions were also made on the changes to catch patterns expected with the new trawl designs. The number of replicate trawls in the trials was low and trials took place just in one location. More tows conducted on a variety of vessels in different locations would provide greater confidence in the expected changes to catches. Moreover, the new designs were tested only against one type of *Nephrops* trawl (Table 1). The difference in catches expected with new designs relative to other types of commercial *Nephrops* trawls is unknown. However, data from the STECF indicate that 79%, 92% and 86% of cod, haddock and whiting caught with a *Nephrops* trawl in the period 2003–2005 had codends with the same mesh (80 mm) as the control trawl used in the trials.

Inclusion of an economic component in the analysis would also be revealing. The introduction of new trawl designs could mean a considerable loss of landings and revenue to fishers working on *Nephrops* trawlers, at least in the short-term. Fish landings from the trawl incorporating the grid with SMC had only 25% of the value of the control trawl (Catchpole et al., 2006).

The results provide an indication of the changes in stocks and landings that might be expected from the introduction of alternative *Nephrops* trawl designs. In the case of North Sea *Nephrops* fisheries and the trawl designs evaluated in this study, only through the implementation of a trawl with a grid combined with a square-mesh codend is there likely to be any positive effect on haddock and cod stocks. In the North Sea, the whitefish fishery (120 mm codend) is responsible for most catches of cod (57%) and haddock (49%) (2003–2005 data; STECF). A change to the catch patterns in this fishery is more likely to benefit these stocks.

Appendix A. Short-term forecasting (STF)

Population abundance for subsequent ages is calculated as:

$$N(y+1,\ a+1) = N(y,\ a)\exp(-Z(y,\ a))$$

and for the plus group as:

$$N(y+1, A) = N(y, A-1)\exp(-Z(y,\ A-1)) + N(y,\ A)\exp(-Z(y,\ A))$$

where z is the sum of the harvest rate (fishing mortality multiplied by fmult) and the natural mortality.

The selection pattern used in the forecast is taken as the arithmetic mean of fishing mortality in a specified number of recent years.

The projected catch is given by:

$$\mathrm{Catch}(y,\ A) = \frac{h(y, A)}{(h(y, A)} + m(y,\ A)) * \mathrm{stock}\ n(y,\ A) *(1-\exp(-h(y,\ A) - m(y,\ A)))$$

where h is the harvest and m is the natural mortality.

Catches are split into landings and discards using the proportional selection pattern, determined, as below, over a specified number of years.

$$Fp(a) = \mathrm{average}\left(\frac{\mathrm{landings}(y1 : y2,\ a)}{\mathrm{catch}(y1 : y2,\ a)}\right)$$

where $y1$ and $y2$ correspond to the year range specified.

Future stock weights and catch weights are also determined using the arithmetic mean over a specified number of recent years.

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