StrathE2E2 version 4.0.0: Fishing fleet model description.

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Introduction

The StrathE2E2 ecology model is driven by externally supplied values of harvest, discard, and offal production rates applicable to resource guilds, and abrasion rates of sediments. These data are generated by a separate model of fishing fleets. The main input to the fleet model is the activity density of each of up to 12 fleets. A fleet is a set of vessels that are regarded as operating the same type of fishing gear. Activity density is defined as the fleet activity rate per unit of sea surface area. Each fleet is defined by its gear type, spatial distribution, gear efficiency, gear selectivity, discard, processing-at-sea, and seabed abrasion rates. Processing-at-sea refers to the practice on some types of vessels of eviscerating selected proportions of the catch and returning the viscera to the sea as offal.

We can assume that the harvest rate due to each gear type (fraction of resource guild biomass caught per unit time) is proportional to fishing effort, where the effort is defined by the product of activity density and power. The latter (fishing power) is defined for each combination of gear type and catchable guild in the ecology model, and is a measure of the efficiency of the gear at catching biomass. Power might reflect number and engine size of vessels, area sweeping rate of the gear ($m^2.h^{-1}$), its mesh-size, design and configuration. Catchable resource guilds in the ecology model are: planktivorous, demersal and migratory fish; carnivorous/scavenge and filter/deposit feeding benthos, carnivorous zooplankton, and the birds, pinniped (seal) and cetacean guild. Archetypes for the species captured from these guilds in a region such as the North Sea would be: herring, cod, mackerel, Norway lobster, scallop, squid, gannet, grey seal, and harbour porpoise. The bird, seal and cetacean guilds are included as a catchable resource mainly, but not necessarily, to reflect incidental by-catch by certain gear types.

Inputs to the fleet model

The model is coded to allow for up to 12 (N_G) different gear fleets (i)

The inputs to the model are a column matrix of whole-domain activity density (A_i, $sec.m^{-2}.d^{-1}$) for each gear:

$$A = \begin{bmatrix} A_1 \\ \vdots \\ A_{N_G} \end{bmatrix} , \qquad \text{eqn 1}$$

and a rectangular matrix of the proportional distribution ($0 \le Q_{i,k} \le 1$) of the activity of each gear (i) across the seabed habitats and deep ocean where configured ($1 \le k \le N_k$; $N_k = 9$). The habitats are divided between ($N_w = 2$) depth zones of the model; $1 \le k \le 4$ = *shallow water zone,* $5 \le k \le 9$ = *deep water zone*):

$$Q = \begin{bmatrix} Q_{1,1} & \cdots & Q_{1,N_k} \\ \vdots & Q_{i,k} & \vdots \\ Q_{N_G,1} & \dots & Q_{N_G,N_k} \end{bmatrix} \qquad \text{eqn 2}$$

where, for each i :

$$\sum_k Q_{i,k} = 1 \qquad \text{eqn 3}$$

The areas of the habitats are given as a column matrix of proportions a_k :

$$a = \begin{bmatrix} a_1 \\ \vdots \\ a_{N_k} \end{bmatrix} \qquad \text{eqn 4}$$

where :

$$\sum_k a_k = 1 \qquad \text{eqn 5}$$

Parameters of the fleet model

The gears are defined by a fishing power index, and their discard, processing-at-sea, and seabed abrasion rates.

The fishing power index of each gear (i) with respect to each resource guild (j) is defined by the rectangular matrix

$$P = \begin{bmatrix} P_{1,1} & \cdots & P_{1,N_R} \\ \vdots & P_{i,j} & \vdots \\ P_{N_G,1} & \dots & P_{N_G,N_R} \end{bmatrix} \qquad \text{eqn 6}$$

where N_R is the number of catchable resource guilds and $0 \le P_{i,j}$.

Similarly, the discard rate (proportion of catch rejected without processing and returned to the sea, assumed to be dead) of each gear with respect to each resource guild ($0 \le D_{i,j} \le 1$) is defined by the rectangular matrix

$$D = \begin{bmatrix} D_{1,1} & \cdots & D_{1,N_R} \\ \vdots & D_{i,j} & \vdots \\ D_{N_G,1} & \dots & D_{N_G,N_R} \end{bmatrix} \qquad \text{eqn 7}$$

The processing-at-sea rate of each gear with respect to each resource guild (proportion of retained catch which of eviscerated at sea; $0 \le Y_{i,j} \le 1$) is also defined by a rectangular matrix

$$\Upsilon = \begin{bmatrix} \Upsilon_{1,1} & \cdots & \Upsilon_{1,N_R} \\ \vdots & \Upsilon_{i,j} & \vdots \\ \Upsilon_{N_G,1} & \dots & \Upsilon_{N_G,N_R} \end{bmatrix} \qquad \text{eqn 8}$$

The seabed abrasion rate (ε_i, $m^2.s^{-1}$) of each gear is defined by the column matrix ($0 \le \varepsilon_i$)

$$\varepsilon = \begin{bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_{N_G} \end{bmatrix} \quad \text{eqn 9}$$

Derived outputs from the fleet model

Spatial dis-aggregation of activity

The whole-domain activity density of each gear fleet is first disaggregated into shallow and deep water zones (*A(w); w* = shallow (*s*) or deep (*d*)), from the scalar product of each row element of *A* and *Q*:

$$\mathrm{A(w)} = \sum_{k=k_{(w)1}}^{k=k_{(w)n}} \begin{bmatrix} \mathrm{A(w)}_{1,1} & \dots & \mathrm{A(w)}_{1,N_k} \\ \vdots & \mathrm{A(w)}_{i,k} = \frac{A_i \cdot Q_{i,k}}{a_k} & \vdots \\ \mathrm{A(w)}_{N_G,1} & \dots & \mathrm{A(w)}_{N_G N_k} \end{bmatrix} \quad \text{eqn 10}$$

where $k_{(w)1}$ and $k_{(w)n}$ are the first and last column indices in the array Q corresponding to each of the shallow and deep zones of the model domain (shallow zone $k_{(s)1}$ =1, $k_{(s)n}$ = 4; deep zone $k_{(s)1}$ =5, $k_{(s)n}$ = 9)

Fishing effort

In each of the shallow and deep zones, the Fishing Effort (*E(w); w* = shallow (*s*) or deep (*d*)) of each gear (*i*) on each resource guild (*j*) is the scalar product of each row element of A_s *or* A_d and the row elements of *P*

$$E(w) = \begin{bmatrix} E(w)_{1,1} & \dots & E(w)_{1,N_R} \\ \vdots & E(w)_{i,j} = A(w)_i \cdot P_{i,j} & \vdots \\ E(w)_{N_G,1} & \dots & E(w)_{N_G,N_R} \end{bmatrix} \quad \text{eqn 11}$$

Then, the total Effort in each zone on each resource guild (*j*) is the column sums of each of the matrices *E(w)*

$$E(w)_{T(j)} = \sum_i E(w)_{i,j} \quad \text{eqn 12}$$

Discard and offal production rate of resource guilds

In each depth zone (*w*), the total discard rate (proportion of catch rejected) for each resource guild (*j*) is the effort-weighted sum of the discard rates for each gear:

$$ED(w) = \begin{bmatrix} ED(w)_{1,1} & \dots & ED(w)_{1,N_R} \\ \vdots & ED(w)_{i,j} = E(w)_{i,j} \cdot D_{i,j} & \vdots \\ ED(w)_{N_G,1} & \dots & ED(w)_{N_G,N_R} \end{bmatrix} \quad \text{eqn 13}$$

The aggregate discard rate in each zone across all gears is then given by:

$$D(w)_{T(j)} = \frac{\sum_i ED(w)_{i,j}}{E(w)_{T(j)}}$$ eqn 14

Similarly, in each depth zone (*w*), the total offal production rate (proportion of retained catch weight returned to the sea as offal) for each resource guild (*j*) is the effort-weighted sum of the processing rates for each gear:

$$E\Upsilon(w) = \begin{bmatrix} E\Upsilon(w)_{1,1} & \cdots & E\Upsilon(w)_{1,N_R} \\ \vdots & E\Upsilon(w)_{i,j} = E(w)_{i,j} \cdot \Upsilon_{i,j} & \vdots \\ E\Upsilon(w)_{N_G,1} & \cdots & E\Upsilon(w)_{N_G,N_R} \end{bmatrix}$$ eqn 15

The aggregate offal production rate in each zone across all gears is then given by:

$$\Upsilon(w)_{T(j)} = \frac{\sum_i E\Upsilon(w)_{i,j}}{E(w)_{T(j)}}$$ eqn 16

Seabed abrasion rate

The seabed abrasion rate (*X*; proportion of seabed area abraded per unit time) by each gear (*i*) in each habitat (*k*) is the scalar product of each row element of *A*, ε and *Q*, divided by the area-proportion of each habitat (*a*):

$$X = \begin{bmatrix} X_{1,1} & \cdots & X_{1,N_k} \\ \vdots & X_{i,k} = A_i \cdot \varepsilon_i \cdot Q_{i,k} & \vdots \\ X_{N_G,1} & \cdots & X_{N_G N_k} \end{bmatrix}$$ eqn 17

The aggregate abrasion rate in each habitat by all gears combined is then given by the column sums of *X*:

$$X_{T(k)} = \frac{\sum_i X_{i,k}}{a_k}$$ eqn 18

Proportional distribution of discard quantities generated in each depth zone (w) across habitats

Within the ecology of StrathE2E2, the total flux of discards from each resource guild to seabed corpses (proportional to *ED*) needs to be apportioned across the seabed habitats within each depth zone. The proportion of discards assigned to each habitat is given by the table *QD*, with dimensions rows = habitats (*k*), columns = resource guilds (*j*), where:

$$QD(w) = \begin{bmatrix} QD(w)_{k_{(w)1},1} & \cdots & QD(w)_{k_{(w)1},N_R} \\ \vdots & QD(w)_{k,j} = \frac{\sum_i \left(Q_{i,k} \cdot ED(w)_{i,j}\right)}{D(w)_{T(j)}} & \vdots \\ QD(w)_{k_{(w)n},1} & \cdots & QD(w)_{k_{(w)n},N_R} \end{bmatrix}$$ eqn 19

Each of the column sums of *QD(w)* = 1, so that each column (j) represents a vector of the proportional distribution of discard quantity of given resource guild across the habitats within a depth zone.

Integrated benthos damage mortality rates

The damage mortality inflicted on the regionally integrated stock of each benthos guild in each depth zone of the model (Z_j) is given by the product of the mortality rate per trawl pass (z_j), and sum of area-weighted seabed abrasion rates (X_T):

$$Z(w)_j = z_j \cdot \sum_{k=k_{(w)1}}^{k=k_{(w)n}} \left(X_{T(k)} \cdot a_k\right) \quad \text{eqn 20}$$

Scaling of fishing effort to Harvest Ratio

The integrated fishing effort on each resource guild ($E(w)_{T(j)}$) in each depth zone (w) requires to be scaled to a value for the Harvest Ratio (proportion of biomass caught per unit time) to be applied to each resource guild ($HR(w)_j$). We assume that Harvest Ratio is related to effort by a linear proportionality constant β_j which is independent of depth zone:

$$HR(w)_j = E(w)_{T(j)} \cdot \beta_j \quad \text{eqn 21}$$

Estimating parameters for the fishing fleet model

Values of β_j need to be derived from data on whole domain annual average daily catch rates of each resource guild ($\text{catch}_{i,j(cal)}$ = (processed-landings + offal)$_{i,j(cal)}$ + $\text{discards}_{i,j(cal)}$) during a calibration period when the stock in the sea ($\text{stock}_{j(cal)}$) is known from independent survey or assessment data. Note that national monitoring data on fishery landings usually refer to the live-weight of catch which is landed (i.e. processed landings + offal). Then:

$$HR_{j(cal)} = \frac{\sum_i catch_{i,j(cal)}}{stock_{j(cal)}} \quad \text{eqn 22}$$

The fishing power index (P) then needs to be estimated for the same calibration period for each gear/resource guild combination:

$$P_{i,j(cal)} = \frac{catch_{i,j(cal)}}{A_{i(cal)}} \;, \quad \text{eqn 23}$$

and then:

$$\beta_j = \frac{HR_{j(cal)}}{E_{T(j)(cal)}} \quad \text{eqn 24}$$

Collated outputs from the fleet model

Primary outputs which form the inputs to the ecology model

The various output matrices derived in the fleet model are flattened and combined into a single vector of values which is inserted into the full parameter vector which is passed to the ecology model. The vector of fleet model outputs comprises:

- Annual average daily harvest ratios in each depth zone, for each resource guild (length = $N_R \,.\, N_w$ values)
- Discard rates for each resource guild in each depth zone (length = $N_R \,.\, N_w$ values)
- Proportion of retained catch processed at sea for each resource guild in each depth zone (length = $N_R \,.\, N_w$ values)

- Proportions of discards of each resource guild occurring over each seabed habitat class (length = $N_R . N_k$ values)
- Proportions of offal from each resource guild produced over each seabed habitat class (length = $N_R . N_k$ values)
- Viscera weight of each resource guild as a proportion of live weight (length = N_R)
- Seabed abrasion rate in each habitat (length = N_k values)
- Daily damage mortality rate for each benthos guild (length = 2 . N_w values)

Secondary outputs for post processing the ecology model results

The vector of values passed from the fleet model into the ecology model does not contain any information pertinent to individual fishing gears. Hence, the data on landings, discards and offal production for each depth zone and resource guild which are output from the ecology model, are aggregated values across all gears. In order to conduct a posterior disaggregation the ecology model outputs and recover the landings, discards and offal by individual gears, we need to store some secondary outputs from the fleet model. The required fleet model outputs are:

For each depth zone, the proportional distribution across gears of the total effort on each resource guild ($p(w)_E$)

$$p(w)_E = \begin{bmatrix} p(w)_{E_{1,1}} & \cdots & p(w)_{E_{1,N_R}} \\ \vdots & p(w)_{E_{i,j}} = \frac{E(w)_{i,j}}{E(w)_{T(j)}} & \vdots \\ p(w)_{E_{N_G,1}} & \cdots & p(w)_{E_{N_G,N_R}} \end{bmatrix} \quad \text{eqn 25}$$

For each depth zone, the proportional distribution across gears of the total discard quantity for each resource guild ($p(w)_D$)

$$p(w)_D = \begin{bmatrix} p(w)_{D_{1,1}} & \cdots & p(w)_{D_{1,N_R}} \\ \vdots & p(w)_{D_{i,j}} = \frac{ED(w)_{i,j}}{D(w)_{T(j)}} & \vdots \\ p_{(w)D_{N_G,1}} & \cdots & p(w)_{D_{N_G,N_R}} \end{bmatrix} \quad \text{eqn 26}$$

For each depth zone, the proportional distribution across gears of the total offal quantity for each resource guild ($p(w)_Y$)

$$p(w)_{\Upsilon} = \begin{bmatrix} p(w)_{\Upsilon_{1,1}} & \cdots & p(w)_{\Upsilon_{1,N_R}} \\ \vdots & p(w)_{\Upsilon_{i,j}} = \frac{E\Upsilon(w)_{i,j}}{\Upsilon(w)_{T(j)}} & \vdots \\ p_{(w)\Upsilon_{N_G,1}} & \cdots & p(w)_{\Upsilon_{N_G,N_R}} \end{bmatrix} \quad \text{eqn 27}$$

The outputs from the ecology model consist of, for each depth zone, daily values for each resource guild (*j*) of:

- Integrated processed weight landed over daily intervals (*TL(w)*$_j$)
- Integrated discarded weight over daily intervals (*TD(w)*$_j$)
- Integrated weight of offal produced over daily intervals (*TY(w)*$_j$)

The integrated catch, live and processed weights landed, discard weights and offal weights over any interval of days are then distributed across gears in proportion to effort as defined by the fleet model:

$$\delta D(w) = \left[p(w)_{D_{i,j}}\right] \cdot \left(TD(w)_j\right) \qquad \text{eqn 28}$$

where *δD(w)* is a matrix of discard quantities in zone *w* with dimensions N_G, N_R

$$\delta \Upsilon(w) = \left[p(w)_{\Upsilon_{i,j}}\right] \cdot \left(T\Upsilon(w)_j\right) \qquad \text{eqn 29}$$

where *δY(w)* is a matrix of offal quantities in zone *w* with dimensions N_G, N_R

$$\delta \mathrm{L}(w) = \left[p(w)_{\mathrm{L}_{i,j}}\right] \cdot \left(T\mathrm{L}(w)_j\right) \qquad \text{eqn 30}$$

where *δL(w)* is a matrix of processed weights landed from zone *w* with dimensions N_G, N_R

$$\delta C(w) = \delta L(w) - \delta D(w) - \delta \Upsilon(w) \qquad \text{eqn 31}$$

where *δC(w)* is a matrix of processed catch weight in zone *w* with dimensions N_G, N_R

$$\delta \Omega(w) = \delta L(w) + \delta \Upsilon(w) \qquad \text{eqn 32}$$

where *δΩ(w)* is a matrix of live-weight landed from zone *w* with dimensions N_G, N_R

Parameterisation of damage mortality inflicted on benthic fauna by the passage of fishing gears

Collateral, or non-capture mortality inflicted on the benthos fauna in the ecology model is assumed to be proportional to the aggregate abrasion rate (proportion of seabed area abraded per unit time) in each depth zone (w) by all gears combined (*XT(k);* equation 18, for *k* = 1 to 4, and *k* = 5 to 8).

The proportionality coefficient relating integrated abrasion rate to benthos mortality rate (proportion of biomass killed per unit time) was obtained from a global synthesis of the impacts of trawling on the seabed, which shows a linear increase in proportion of benthos killed per trawl-pass, and the penetration depth of the gear into the seabed sediments (Hiddink *et al.*, 2017). At 5cm penetration depth the proportion of benthos lost was 20%

Parameterisation of demersal fish catch composition

Intensive management systems for fisheries, such as in EU waters, apply species-by-species restrictions on the quantities and minimum sizes of fish that can be landing and, since 2014 in EU waters, whether undersize and unwanted catch can be discarded at sea. However, these restrictions do not apply to all species. The demersal fish community can be divided into species which are subject to such rules, and those which are not. The former are the predominantly targeted for their commercial value but typically also represent the main fraction of the community biomass. The latter are mainly low-value by-catch species but may be the main part of the species richness. Some of the questions that we may wish to address with the model involve the distinction between the ‘quota-limited’ demersal fish species which are subject to rules and regulations, and the ‘non-quota’ species which are not, especially with respect to discarding practices. We do not model the dynamics of these two groups explicitly, but instead parameterise their proportions in catches and their discard rates implicitly, using empirically-based density dependent relationships.

The empirical evidence for density dependent relationships describing catch and discard composition comes from analysis of catch per unit effort data in research vessel trawl surveys carried out in the North Sea during quarter 1 of each year since 1980, and the corresponding species composition of annual commercial landings and discards (Heath & Cook, 2015). The analysis shows that at the scale of the whole North Sea the proportion of non-quota demersal fish species in the commercial catch has been indirectly related to the community biomass. There may be a number of explanations for this, but most likely is that depletion of the community biomass reflects the selective targeting of the valuable quota-limited species by the fisheries. In the model, we can represent this relationship by a negative exponential function.

$$p_{(non\text{-}quota)} = a_{pnq} \, . \, exp(-b_{pnq} \, . \, N_{dem.fish}) \qquad \text{eqn 33}$$

where b_{pnq} is a scaling parameter, and ($N_{dem.fish)}$) is the survey-based demersal fish biomass per unit swept area (mMN.m^{-2}), as measured on 1st January.

Capture efficiency of the survey trawl is only approximately known, so to facilitate incorporation of this relationship in the model we included a proportionality constant (*φ)* to relate survey catch per unit swept area to nitrogen mass per unit sea surface area ($M_{dem.fish}$) as simulated in the model:

$$p_{(non\text{-}quota)} = a_{pnq} \, . \, exp(-b_{pnq} \, . \, \varphi.M_{dem.fish}) \qquad \text{eqn 34}$$

Parameterisation of the proportion of demersal fish catch which is smaller than the legal or *de-facto* marketable landing size

The prototype version of StrathE2E2 (Heath, 2012) included an empirically parameterised relationship between the proportion of demersal fish in commercial catches which were discarded on account of being undersize, and the biomass of demersal fish in the sea. The relationship expressed an exponentially declining discard rate with increasing biomass:

$$p_{(discarded)} = a_{disc} \, . \, exp(-b_{disc} \, . \, N_{dem.fish}) \qquad \text{eqn 35}$$

where b_{pnq} is a scaling parameter, and ($N_{dem.fish)}$) is a survey-based demersal fish biomass per unit swept area (mMN.m^{-2}), as measured on 1st January. Capture efficiency of the survey trawl is only approximately known, so to facilitate incorporation of this relationship in the model we included a proportionality constant (φ) to relate survey catch per unit swept area to nitrogen mass per unit sea surface area ($M_{dem.fish}$) as simulated in the model:

$$p_{(discarded)} = a_{pnq} \cdot exp(-b_{pnq} \cdot \varphi.M_{dem.fish}) \qquad \text{eqn 36}$$

The explanation for the density dependent relationship between discard rate and biomass lies in the observed decrease in mean body size of demersal fish with declining community biomass. This is typically summarised for ecosystem assessment purposes by the Large Fish Indicator (LFI) which, in the North Sea, is defined as the proportion by weight of fish in the community which are larger than 40cm in length (Greenstreet *et al.*, 2010; Shephard *et al.*, 2014). In StrathE2E2 the discard rates for each guild, integrated across all gears, is explicitly passed to the ecology model from the fleet model, so there is no need to rely on the empirical relationship as the basis for discard rates. Instead, we re-frame the density dependence of demersal fish discard rates as a relationship between the proportion of ‘undersize’ fish in catches and biomass in the sea. By ‘undersize’, we mean smaller than the effective landing size. In reality, this proportion is, of course, a function of both the community structure of the fish biomass, and the selectivity of the fishing gears.

Technically, there is no minimum legal landing size for most non-quota by-catch species. However, there will be a de-facto minimum marketable size, below which there is no incentive to land the fish (Heath & Cook, 2015). Hence, separate parameters are needed for the quota-limited and non-quota fractions of the demersal fish catch.

$$p_{(undersize)Q} = a_{undersizeQ} \cdot exp(-b_{undersizeQ} \cdot \varphi.M_{dem.fish}) \text{ (for quota limited catch)} \qquad \text{eqn 37}$$

$$p_{(undersize)NQ} = a_{undersizeNQ} \cdot exp(-b_{undersizeNQ} \cdot \varphi.M_{dem.fish}) \text{ (for non-quota limited catch)} \qquad \text{eqn 38}$$

The parameters *a* and *b* of the exponential relationships defining the non-quota and undersize fraction are fixed from the survey data (see Heath & Cook 2015), and passed into the ecology model. The scaling coefficient φ is treated as one of the suite of fitting parameters for the model, constrained by the observed overall discard rate of demersal fish assuming that the majority of discarded fish are undersize.

Within the ecology model, the empirically-based estimates of the proportion of catch comprising non-quota species, and the undersize fractions of the non-quota and quota-limited components of the catch, are set annually depending on the simulated demersal fish mass on the first calendar day of each simulation year.

Options for creating scenarios of gear selectivity and discarding practices for demersal fish

Discarding practices for demersal fish are complex, since the catch is typically sorted by species and size aboard the fishing vessels rather than being landed in bulk as for most planktivorous fish. Grading of the catch to retain only the most valuable sizes or species (‘high-grading’), and regulations concerning how much of each species can be landed (quotas) and which can be discarded are an integral part of the management of demersal fisheries. Some of the questions that StrathE2E2 was designed to answer concern the ecosystem effects of these regulations.

The fishing fleet model generates a value for the discard rate of the whole demersal catch based on the input data for the individual gear components of the fishery. However, the fleet model configuration also includes user-defined options (switches) to configure alternative scenarios of demersal fish capture and discarding within the ecology model, overriding the discard rate passed from the fleet model.

Two option switches for demersal fish catches are coded into the model. First is a switch to either accept the demersal fish harvest ratio supplied by the fleet model, or simulate a systematic change in the selectivity of demersal gears such that undersize fish are no longer captured. This change in selectivity is represented in the ecology model as an attenuation of the harvest ratio supplied by the fleet model.

The second switch affects the representation of discarding practices for demersal fish aboard the vessels. The baseline option is to apply the integrated discard rate supplied by the fleet model. Alternatives scenarios are to override the fleet model discard rate, and instead discard only the undersize portion of the catch (of either quota-limited or all demersal fish) imputed by the empirically based density dependent relationships, or land the entire catch with no discarding, By selecting setting for both the harvest ratio and discarding switches, a range of demersal fishery scenarios can be configured to contrast with the baseline inputs provided by the fleet model (Table 1).

TABLE 1. Setting for the demersal fish harvest ratio switch (DF_HR_SWITCH) and discarding switch (DF_DISC_SWITCH) in the fishing fleet model parameter file *fishing_fleet_parameters*.csv*, and the resulting scenario configuration in the ecology model.

Harvest ratio switch value	Discarding switch value	Harvest ratio action	Discard rate action
0	0	Harvest ratios for demersal fish according to the external data on gear activity and power (selectivity), as processed by the fleet model.	Discard rates for demersal fish set internally by the ecology model to equal the undersize fractions of quota-limited and non-quota fractions, overriding the externally supplied discard rates.
1	0	Implicit changes in gear selectivity to minimise catches of undersize fish - the externally set harvest ratios for demersal fish are attenuated by a factor equal to the lesser of the proportion of undersize quota-limited and non-quota fish in catches, as derived by the ecology model.	Discard rates for demersal fish set internally by the ecology model, overriding the externally supplied discard rates. But, due to the implicit changes in selectivity, there are no undersize catches of either quota-limited or non-quota demersal fish so discard rates are set to zero.
0	1	Harvest ratios for demersal fish according to the external data on gear activity and power (selectivity), as processed by the fleet model.	Discard rate of demersal fish set according to the external data in the discard rate parameter file for the fleet model. The ecology model first attempts to meet this rate by discarding the internally derived undersize fractions of quota-limited and non-quota fish. If this is insufficient to meet the external rate then the code increases discards of quota-limited fish - i.e. implicitly representing high-grading or over-quota discards. If the external rate is less than the internal rate arising from undersize quota-

			limited and non-quota fish then the code reduce discards of non-quota fish until to overall rate equals the externally set value.
1	1	Implicit changes in gear selectivity to minimise catches of undersize fish - the externally set harvest ratios for demersal fish are attenuated by a factor equal to the lesser of the proportion of undersize quota-limited and non-quota fish in catches, as derived by the ecology model.	Discard rate of demersal fish set according to the external data in the discard rate parameter file for the fleet model. But as a result of the implicit changes in selectivity there are no catches of undersize fish. So the implication is that all discards represent high-grading or over-quota discarding. Hence, the ecology model attempts to meet the externally defined overall discard rate first by increasing the discard rate of quota-limited fish, and if this is insufficient then by increasing the discard rate of non-quota fish.
0	2	Harvest ratios for demersal fish according to the external data on gear activity and power (selectivity), as processed by the fleet model.	Discard rates for non-quota demersal fish are set internally by the ecology model to equal the undersize fraction. Discard rates for quota-limited demersal fish are set to zero regardless of external data or the internally derived undersize fraction - i.e. this forces all the catch of quota-limited to be landed including undersize fish. This option mimics the EU Common Fisheries Policy Landing Obligation.
1	2	Implicit changes in gear selectivity to minimise catches of undersize fish - the externally set harvest ratios for demersal fish are attenuated by a factor equal to the lesser of the proportion of undersize quota-limited and non-quota fish in catches, as derived by the ecology model.	This has the same effect as setting discard rate switch to 0, i.e. due to the implicit changes in selectivity, there are no undersize catches of either quota-limited or non-quota demersal fish so discard rates are set to zero.
0	3	Harvest ratios for demersal fish according to the external data on gear activity and power (selectivity), as processed by the fleet model.	Discard rates for both quota-limited and non-quota demersal fish are set to zero regardless of external data or the internally derived undersize fractions - i.e. this forces all the catch of all demersal fish to be landed including undersize fish.
1	3	Implicit changes in gear selectivity so that there are no catches of undersize fish - the externally set	This has the same effect as setting the discard rate switch to 0, i.e. due to the implicit changes in selectivity, there are

		harvest ratios for demersal fish are attenuated by an amount proportional to the undersize fractions of quota-limited and non-quota fish in catches, as derived by the ecology model.	no undersize catches of either quota-limited or non-quota demersal fish so discard rates are set to zero.

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