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Methods for examining in-season behavior of the cumulative discard estimation in the Greater Atlantic Region

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A working paper in support of the Cumulative Discard Methodology Peer Review

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INTRODUCTION

We examined the in-season behavior of the cumulative discard methodology to better understand how stratum definitions and transition rate strategies influenced the monitoring of discards across all relevant fisheries. Our analysis involved the data used to support discard estimation for several Fishery Management Plans (FMPs) administered by NOAA Fisheries in the Greater Atlantic Region including the New England multispecies, scallop, longfin squid, herring, and herring/mackerel fisheries. We focused on information from the most recent completed fishing seasons (e.g., 2014 and 2015), with earlier years included for certain fisheries as needed. The design-based estimation procedures followed recommendations from the Standardized Bycatch Reporting Methodology (SBRM) originally outlined by Wigley et al. (2007).

As part of this effort we built a custom R package (R Core Team 2016) called "`discaRd`" (Galuardi et al. 2016) to support current and future attempts at discard estimation with SBRM approaches. The package allows one to easily provide observer and trip data for a given fishery and year(s) of interest to calculate estimates of discard rate means and variances, and required observer samples (e.g., trips and/or sea days) to meet precision objectives. Importantly, the package enables calculation of daily cumulative estimates for in-season monitoring that incorporates between-year transition rates and accommodates the small sample sizes typical of early-season monitoring. Also included is a nonparametric bootstrapping procedure to estimate variability in the cumulative daily estimates. Our approach allows flexibility in specifying and simulating the design of the in-season monitoring and can be easily adapted to test a variety of assumptions used to calculate discards.

We defined discards as the total live pounds of species/stocks that are caught unintentionally and either returned to the water or retained, depending on the fishery. As an example, some large volume fisheries must retain discards for operational or regulatory reasons (e.g., haddock in the herring fishery). The SBRM calculations were consistent across fisheries despite some differences in data streams and stratum definitions. To understand how discard estimation influenced in-season quota monitoring, allocated species/stocks required information on total landings in addition to discards, while unallocated species/stocks were restricted to discards. In both cases, we refer to the in-season monitoring of total catch with the interpretation of "catch" being specific to the species/stock of interest.

METHODS

Data

In-season monitoring of discards uses two forms of data:

1) Observer data collected by the Northeast Fisheries Observer Program (NEFOP) and for multispecies trips, the At-Sea Monitoring Program (ASM). The NEFOP and ASM deploy fisheries observers on commercial fishing trips in New England and Mid-Atlantic waters. For this analysis, NEFOP and ASM data were drawn from final versions of the Observer Database System (OBDBS) data.
2) Data for total pounds of all species kept on specific trips relevant to each fishery were sourced from the Data Matching and Imputation System (DMIS). DMIS data are dealer-reported landings data matched to trip or subtrip-based data from Vessel Trip Reports (VTR) and Vessel Monitoring System (VMS) activity code declarations. VTRs are the source for area fished, landings date, and fishing gear used. VMS information is used to determine Access/Open area fishing as well as fleet type.

Discard estimation

Previous work – including the original SBRM (Wigley et al. 2007) and subsequent working papers (Nitschke 2010, Palmer 2010) – has explored the use of estimators for calculating discards in the Greater Atlantic Region and identified several sampling design and analysis choices that affect accuracy and precision. Here we used the separate ratio estimator (Cochran 1977, Palmer 2010) to facilitate a general calculation procedure that could be easily adapted to a variety of stratification schemes (e.g., month, gear) depending on the fishery. The separate ratio estimator equates to the combined ratio estimator (i.e., pooled discard rate) when the observer coverage rates across strata are equal. As recommended, we considered the total kept weight of all species as the measure of fishing effort in the discard ratio (Wigley et al. 2007). As such, within each fishery the ratio of discard to kept pounds for species or species group j within stratum h is defined as:

(1) $$r_{jh} = \frac{\sum_{i=1}^{n_h} d_{jih}}{\sum_{i=1}^{n_h} k_{ih}}$$

with total lives pounds of discard:

(2) $$\widehat{D}_j = \sum_{h=1}^{L} K_h r_{jh}$$

where r_{jh} is the separate ratio for species j in stratum h;

d_{jih} is discards of species j from observed trip i in stratum h;

k_{ih} is the kept pounds of all species on observed trip i;

n_h is the number of observed trips in stratum h;

N_h is the number of total trips in stratum h;

L is the number of strata;

$\widehat{D}_j$ is the total estimated discarded pounds for species j;

K_h is the total kept pounds of all species in stratum h

The analytic variance of $\widehat{D}_j$ is defined as:

(3) $$V(\widehat{D}_j) = \sum_{h=1}^{L} K_h^2 \left(\frac{N_h - n_h}{n_h N_h}\right) \frac{1}{\left(\frac{\sum_{i=1}^{n_h} k_{ih}}{n_h}\right)^2} \left[\frac{\sum_{i=1}^{n_h}\left(d_{jih}^2 + r_{jh}^2 k_{ih}^2 - 2 r_{jh} d_{jih} k_{ih}\right)}{n_h - 1}\right]$$

And the coefficient of variation (CV) for $\widehat{D}_j$ is defined as:

(4) $$CV(\widehat{D}_j) = \frac{\sqrt{V(\widehat{D}_j)}}{\widehat{D}_j}$$

Equations (1) and (2) are used for in-season monitoring of total discards, with separate discard rates for each specified stratum or combined across the fishery if $L = 1$. Equations (3) and (4) are most useful for assessment after the fishing season has ended and stratum-specific sample sizes are fixed. Changes in CV under different stratification scenarios can be used to inform which strata are important for discard estimation.

While the fishery-wide estimates are typically of greatest interest, the summation across strata can be removed from Equations 2–4 to generate stratum-specific estimates (e.g., $\widehat{D}_{jh}$).

Sample size analyses

We calculated the necessary sample sizes to achieve some target CV (e.g., 30%) using slightly modified versions of the equations presented in Wigley et al. (2007) with a focus on the variance of the total discard. The variance of the sample is defined as follows:

(5) $$\hat{S}_{jh}^2 = \left[\frac{\sum_{i=1}^{n_h}\left(d_{jih}^2 + r_{jh}^2 k_{ih}^2 - 2r_{jh} d_{jih} k_{ih}\right)}{n_h - 1}\right]$$

Using this sample variance, the number of trips required to achieve CV_{targ} is as follows:

(6) $$\hat{T}D_{CV,jh} = \frac{\frac{K_h^2}{\bar{k}_h^2}\hat{S}_{jh}^2}{CV_{targ}^2 \widehat{D}_{jh}^2 + \frac{\frac{K_h^2}{\bar{k}_h^2}\hat{S}_{jh}^2}{N_h}}$$

Note that the total discard is stratum specific in Equation (6). This equation can then be converted to the required number of sea days as follows:

(7) $$\hat{S}D_{CV,jh} = \hat{T}D_{CV,jh}\overline{DA}_h$$

where $\overline{DA}_h$ is the average trip length for a given stratum. We can also calculate the required observer coverage (i.e., proportion of trips observed) as follows:

(8) $$\hat{O}BS_{CV,jh} = \frac{\hat{T}D_{CV,jh}}{N_h}$$

These calculations can be made across a range of target CV values to produce curves illustrating how the variance decreases as the number of trips, sea days, and/or observer coverage increases. The CV curves are likely more informative as a fishery-wide diagnostic, particularly for comparisons across stratification scenarios. We calculated two weighted means for observer coverage within a fishery for a given species:

(9)
$$\overline{OBS}_{CV,j} = \sum_{h=1}^{L} \left(\frac{\hat{T}D_{CV,jh}}{N_h}\right)\left(\frac{N_h}{\sum_{h=1}^{L} N_h}\right)$$

(10)
$$\overline{OBS}^{*}_{CV,j} = \sum_{h=1}^{L} \left(\frac{\hat{T}D_{CV,jh}}{N_h}\right)\left(\frac{\hat{D}_{jh}}{\sum_{h=1}^{L} \hat{D}_{jh}}\right)$$

The mean in Equation (9) is weighted by the number of commercial trips within each stratum, while the mean in Equation (10) is weighted by the estimated discard. Although the sampling design cannot allocate observers to strata based on unrealized discard estimates, CV curves using the discard-weighted observer coverage can serve as another diagnostic for comparing stratification scenarios. The trips-weighted mean is the standard measure of fishery-wide observer coverage, but may over-emphasize the required coverage for strata that are highly variable despite having low total discards. The discard-weighted mean recognizes that uncertainty is more important for strata with large total discards, but is potentially vulnerable to bias from small sample sizes. The realized observer coverage ($\sum n_h / \sum N_h$) can be similarly weighted by the discard estimates.

Transition of discard rates between seasons

In-season monitoring of the cumulative discard for a given species and fishery requires the application of a discard rate to all completed VTR trips up to the day of calculation. During the early part of the fishing season, or for strata representing trips with uncommon attributes, the sample size of observed trips may be too small for a stable and reasonable estimate of the discard rate. To improve in-season estimates of discard, information from the previous fishing year(s) is used in varying degrees as an adjustment.

The standard practice in the Greater Atlantic Region is calculate a weighted mean between the estimated discard rate of the previous year and that for the current year when the number of observed trips, n_h, is > 0 and < 5. The weighted mean is calculated as follows:

(11) $$r_{jh}^{*} = \left(\frac{0.7}{n_h}\right) r_{jh,t-1} + \left(1 - \frac{0.7}{n_h}\right) r_{jh,t}$$

where r_{jh}^{*} is the transition discard rate;

$r_{jh,t-1}$ is the "assumed" discard rate from the previous year $(t-1)$;

$r_{jh,t}$ is the "in-season" discard rate from the current year (t)

Under this approach, discards are estimated using the assumed rate when $n_h = 0$ and with the in-season rate when $n_h \geq 5$. For the transition rate, the coefficient induces a negative exponential relationship between the number of in-season samples and the weighting of the assumed rate from the previous year. In this way, the influence of information from the previous year decreases as the number of in-season observations increases. The exploration of stratum definitions sometimes resulted in strata with uncommon attributes being poorly represented in the observer data. To improve accuracy, any strata with < 5 observed trips during the previous year were assigned an assumed rate that matched the mean discard rate of the entire fishery.

We explored an alternative approach where a moving window is used to combine previous year observations with in-season observations to calculate a transition discard rate. For this method, the data used to calculate discard rate in Equation (1) on day f of the fishing year consisted of the combination of observations from day F_{start} to day f of the current year and those from day $f+1$ to day F_{end} of the previous fishing year, where the F values represent the start and end of the selected period (e.g., typically 1 and 365 for a full fishing season). The moving window approach induces a graduated linear weighting toward in-season observations as the sample sizes increase.

Bootstrapping in-season cumulative discards

We used non-parametric bootstrap methods to assess the behavior of cumulative in-season discards and estimate the daily variance. While a formula for the analytic variance is provided in Equation (3), this calculation is most useful for the full sample of observed trips for a fishing season. Small sample sizes may violate assumptions of the variance estimation (Wigley et al. 2007, Palmer 2010) and this problem is amplified during in-season estimation before sampling has been completed. In addition, there is no straightforward approach for calculating the variance when information from the previous year has been incorporated.

Our bootstrap adjusted for finite population inferences (Booth et al. 1994) by resampling *without* replacement after inflating the observed samples (n_h) to match the size of the total population (N_h) before resampling. For example, if $n_h = 20$ and $N_h = 100$, the observed samples would be replicated 5 times and then resampled without replacement, producing a new sample set with a size matching the original. The new sample set was then used to estimate the weekly cumulative in-season discard during the time period of interest. This procedure was repeated for 1,000 iterations to form the bootstrap distribution.

The bootstrap results can be interpreted as an approximation to a posterior distribution (Friedman et al. 2001) to enable estimating the probability of two management relevant outcomes – premature closure and quota exceedance – and attributes related to these outcomes. As previously explained, the quota monitoring of total catch for allocated species/stocks requires both the estimated discard and total landings; unallocated species/stocks have total catches that consist solely of estimated discards. Bootstrap iterations that deviate from the "true" estimated catch (hereafter, realized catch) represent situations where sampling variability had a measureable effect on management inferences. The probability of premature closure is simply the proportion of bootstrap iterations where the estimated catch exceeds the specified quota before the realized catch. The maximum number of potential fishing days lost to the closure can be calculated as the difference between the first day any bootstrap iteration (or the q^{th} iteration, where q is some quantile) exceeded the quota and the day the realized catch exceeded the quota (defaulting to the last fishing day for realized catches that did not exceed). Conditional on the realized catch having exceeded the quota at some point, the probability of allowing the fishery to operate for x days beyond quota exceedance can be calculated. Finally, the magnitude of potential quota exceedance can be quantified, accounting for the number (x) of allowed fishing days beyond when the quota was met and a projection of the discard during that time (e.g., average discard per day). For fisheries or scenarios where the realized catch did not meet or exceed the quota, the probability and magnitude were both zero by default. Other summaries of these results can be easily derived.

WORKED EXAMPLE

Here we illustrate a brief example from the Atlantic sea scallop (*Placopecten magellanicus)* fishery involving the bycatch estimation of southern windowpane flounder (*Scophthalmus aquosus*; WP) in the southern New England/Mid-Atlantic (SNE/MA) Broad Stock Area (Galuardi 2016). We present small sections of an R script to read/summarize data and calculate discard statistics using the `discaRd` package (Galuardi et al. 2016).

After obtaining the observer data for scallop trips in SNE/MA, the data are summarized to the trip level to calculate the observed discard for the species of interest. Here the code "125" is the Northeast species code that corresponds to WP.

```
bdat = ddply(obs, 'STRATA' ,function(x) get.bydat(x, load = F, bspec = 125))

##            STRATA BYCATCH     KALL   FY yday fday  SEADAYS
## 1 046_MID_dredge   100.0 34561.55 2009   11  316 4.152778
## 2 046_MID_dredge     0.0 25692.22 2009    1  306 2.611111
## 3 046_MID_dredge     3.0 37217.10 2009   26  331 6.812500
## 4 046_MID_dredge     1.5 28962.98 2009   31  336 4.834722
## 5 046_MID_dredge   283.0 64889.06 2009   54  359 6.000000
## 6 046_MID_dredge    52.0 35710.59 2010   87   28 4.021528
```

The unique strata are extracted from both the observer data (`bdat`) and the DMIS trips data (`ddat`) to ensure that even unobserved strata are represented in the analysis.

```
strata_complete =  unique(c(bdat$STRATA, ddat$STRATA))
strata_complete

##  [1] "046_MID_dredge" "046_MID_trawl"  "046_SNE_dredge" "047_MID_dredge"
##  [5] "047_MID_trawl"  "047_SNE_dredge" "047_SNE_trawl"  "046_SNE_trawl"
##  [9] "046_MID_other"  "047_SNE_other"  "047_MID_other"
```

We subset the data for the relevant years of interest, which requires specifying a focal year and obtaining observer and DMIS trips for both the focal year and the previous year to facilitate transition rate calculations. These data are then used by the `cochran.trans.calc` function to estimate the per-strata discard ratios and total discard on every day during the time period of interest (`time_span`) starting on the first realized fishing day (`minday`). The transition approach used here was the default ("ntrips") where the previous year's discard rate is weighted against the in-season discard rate using a negative exponential relationship until $n_h = 5$.

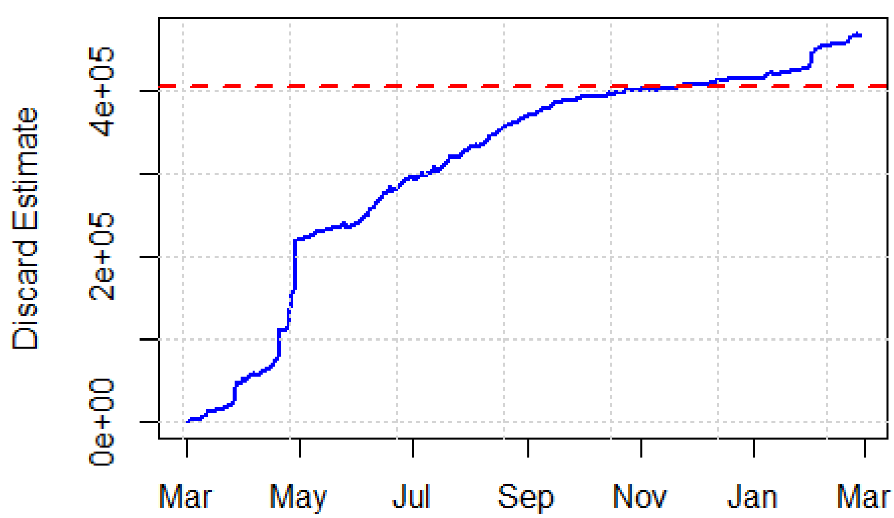
```
# Subset the data
focal_year = 2015

minday = min(c(unique(subset(bdat, FY==focal_year)$fday)), unique(subset(ddat
, FY==focal_year)$fday))

bydat_focal = subset(bdat, FY == focal_year)
bydat_prev = subset(bdat, FY == focal_year - 1)
trips_focal = subset(ddat, FY == focal_year)
trips_prev = subset(ddat, FY == focal_year - 1)

dest <- cochran.trans.calc(bydat_focal = bydat_focal, trips_focal = trips_foc
al, bydat_prev = bydat_prev, trips_prev = trips_prev, CV_target =.3, strata_n
ame = "STRATA", strata_complete = strata_complete, time_span = c(minday, 365)
, trans_method = "ntrips")
```

The total cumulative discard across the fishery can easily be plotted from the dest object by summing across strata.



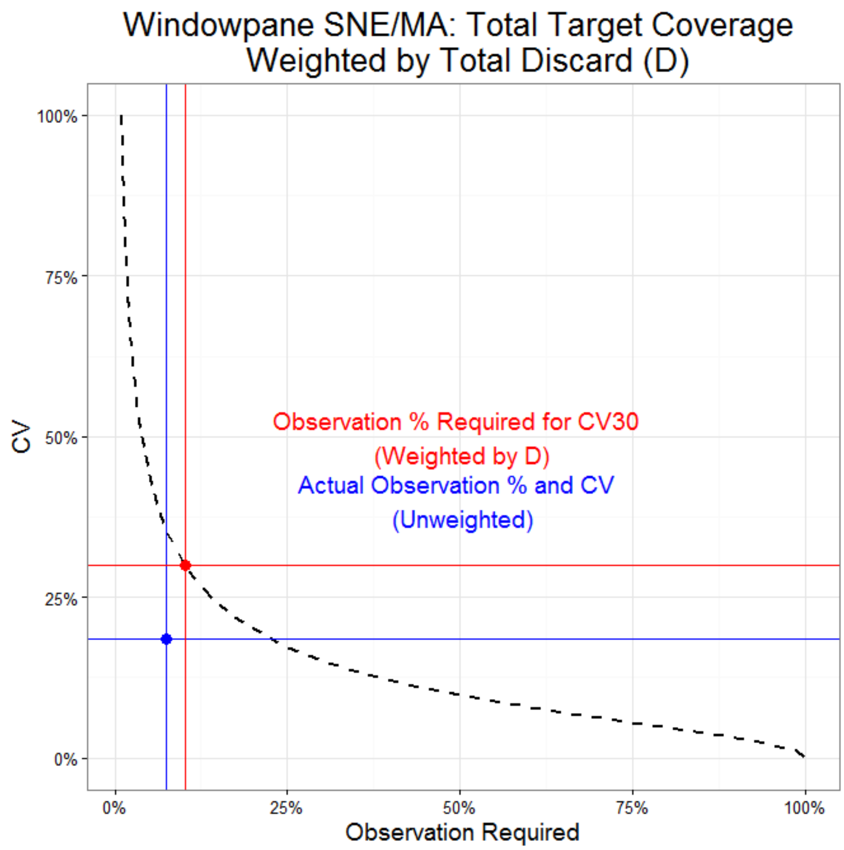
While the daily cumulative discards are necessary for in-season monitoring (with transition rates), the full sample of observed trips from the focal year can be summarized to obtain a number of metrics for each stratum including number of DMIS trips (`N`) and observed trips (`n`), estimates of the discard rate means (`r_mean`) and CVs (`r_rse`), and sample design recommendations such as the required samples, coverages, and seadays for the target CV.

```
dest2 <- get.cochran.ss.by.strat(bydat_focal, trips_focal, targCV =.3, strata
_name = "STRATA", strata_complete = strata_complete)

data.table(dest2$C)

##            STRATA    N   n       r_mean        r_var         r_se
## 1: 046_MID_dredge 1514 178 0.0002171917 2.104664e-09 4.587662e-05
## 2: 046_SNE_dredge  524  98 0.0076819380 3.014883e-06 1.736342e-03
## 3: 047_MID_dredge 2331  94 0.0017150358 1.553467e-07 3.941404e-04
## 4:  047_MID_trawl  284   3 0.0001276292 5.955807e-09 7.717387e-05
## 5: 047_SNE_dredge 1224  77 0.0054396970 9.072881e-07 9.525167e-04
## 6:  047_SNE_trawl  290   7 0.0136161114 3.885237e-05 6.233167e-03
##        r_rse CV_TARG REQ_SAMPLES    REQ_COV REQ_SEADAYS           D
## 1: 0.2112264     0.3    93.80288 0.06195699   628.07671  33489.1252
## 2: 0.2260291     0.3    60.52430 0.11550438   534.89506 378499.8736
## 3: 0.2298147     0.3    56.09677 0.02406554   622.70195  19226.1523
## 4: 0.6046727     0.3    11.80571 0.04156941   163.05001    171.6202
## 5: 0.1751047     0.3    27.36789 0.02235938   260.88201  23531.3661
## 6: 0.4577788     0.3    15.79280 0.05445794    78.11797  11066.3207
##              K           k       d
## 1: 154191578.8 10673522.10  2318.2
## 2:  49271404.3  3616027.62 27778.1
## 3:  11210350.7   479815.07   822.9
## 4:   1344678.8    15670.40     2.0
## 5:   4325859.7   231685.70  1260.3
## 6:    812737.2    18823.29   256.3
```

This function can be used to explore a range of target CVs to calculate the observation coverage needed to meet a specified value.



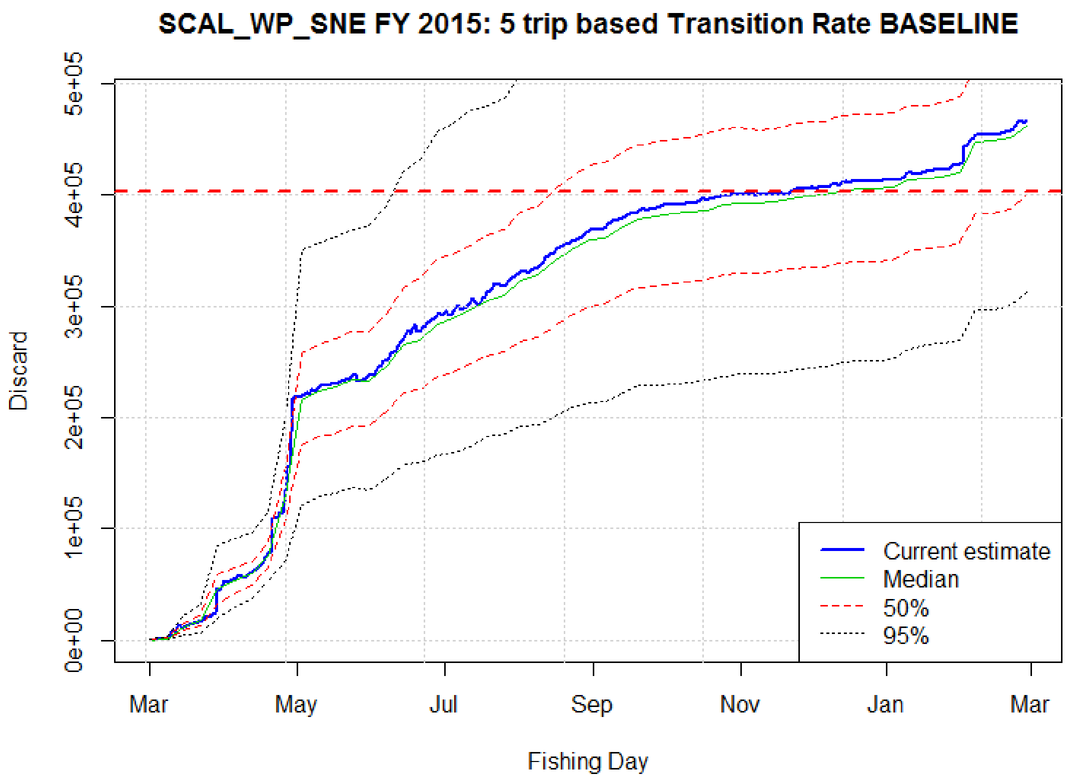
Finally, the in-season behavior of the cumulative discard estimate can be bootstrapped to quantify uncertainty and calculate the probability of observing certain events (e.g., premature closure) conditional on treating the observed discard estimate as the “truth”. Here, parallel processing techniques are used to speed up the computational time needed.

```
ncores = detectCores()
cl = makeCluster(ncores)
registerDoParallel(cl, cores = ncores)


# Number of resamples
nboot = 1000

bout.list = foreach(1:nboot) %dopar% {
    library(discaRd)
    bootr.strat(bdat = bdat, ddat = ddat, focal_year = focal_year, strata_nam
e = 'STRATA', strata_complete = strata_complete, time_inter = 7, trans_method
= "ntrips", time_span = c(minday, 365))
}
```

As before, the resulting estimates of discard can be plotted and compared to the predetermined catch cap or quota limit (horizontal dashed red line) for the species in this fishery. In this example, the estimated discard exceeded the quota shortly after the start of November, but there was a 2.5% probability that sampling variability in the estimated discard would have incorrectly suggested the quota had been met before July (indicated by the dotted black line).



CONCLUSIONS

The framework provided here facilitates assessment of the discard estimation procedures currently used by NOAA Fisheries in the Greater Atlantic Region for the purposes of in-season quota monitoring. The `discaRd` package (Galuardi et al. 2016) enables a standardized approach to assessment across the relevant fisheries and can be easily modified or adapted to accommodate changes to the data structures, ratio estimators, transition rate methods, and other calculations and data wrangling decisions that are necessary for discard estimation. The assessment outlined here and those executed in the other working papers represent a fraction of the questions that could be addressed with `discaRd`. Further development of the R package could allow for expanded assessments, including more in-depth analyses of discard estimation procedures within and between species, stocks, and/or fisheries.

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