Evaluation of Methods to Estimate Monkfish Discards for Calculating Total Allowable Landings

Cate O'Keefe, PhD
Principal Consultant
Fishery Applications Consulting Team, LLC

FINAL Report (July 2020)

Support for this report was provided by the New England Fishery Management Council under Award #FNA20NMF4410001

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1. Project Summary

Fishery Applications Consulting Team was contracted by the New England Fishery Management Council (NEFMC) to analyze alternative discard estimation approaches for calculating monkfish Total Allowable Landings (TAL). In response to concerns about recent high monkfish discards and potential impacts on monkfish TALs, the NEFMC prioritized an evaluation of the approach used to estimate discards for determining TALs. A large monkfish recruitment event in 2015 lead to relatively high discard estimates for 2016-2018 resulting in a substantial increase in the assumed discard percentage of catch applied for monkfish fishery specifications for 2020-2022. The NEFMC prioritized exploration of alternative approaches to determine the discards that are applied to set monkfish TALs because the 2015 year-class has since grown to harvestable size, and there have been changes in fishery allocations, spatial distribution of fishing effort and incentives for the scallop and trawl fisheries.

Several alternative approaches for estimating monkfish discards by gear type and management area were examined with associated performance evaluations. Factors that may influence discards and behavior in target and non-target fisheries were summarized and ranked, and new information about discard mortality by gear type was considered. Results indicated:

- The current 3-year average discard percent of catch approach performed relatively well when catch and discards were stable but did not perform well compared to realized discards after the strong 2015 recruitment event. Similarly, recent averages with a shorter or longer reference period (2-year and 5-year) were not good indicators of future discards.
- A longer term (2008-2015) mean or median discard percent of catch performed well compared to realized discards for both management areas for most years and could be applied to set TALs in future monkfish actions under average recruitment conditions.
- Applying the long-term (2008-2015) mean or median discard percent of catch to set TALs for most years, combined with annual monitoring of recruitment indices and greater discard assumptions when a strong recruitment event occurs may reduce the risk of exceeding TALs and improve overall monkfish management.
- Recruitment indices and growth rate estimates are informative for predicting discards, and surveys and catch data can detect strong recruitment events. Annual review of survey, catch, and growth data could be conducted to inform monkfish management.
- Recent studies on monkfish discard survival rates suggest that discard mortality varies by gear type and may be substantially lower than the currently assumed 100% rate for dredge gear. Additional peer-review is required prior to changing the discard mortality assumption, but future analyses could consider applying a discard mortality rate by gear type to estimate TALs.
- Several factors influence monkfish discard behavior in target and non-target fisheries, including spatially specific fishing effort (e.g., scallop rotational management), fishery-specific incentives, and monkfish market and price dynamics. These factors lead to variability in discards between 2008 and 2015, but the substantial increase in discards in 2016-2018 was driven by the large 2015 monkfish year-class.
- Applying a modified approach for estimating discards to calculate TALs requires examination of Fishing Year 2019 data, as well as analyses to define “strong” recruitment and identify the discard level associated with strong recruitment.

2. Background

The monkfish fishery in the US Exclusive Economic Zone (EEZ) is jointly managed under the Monkfish Fishery Management Plan (FMP) by the NEFMC and the Mid-Atlantic Fishery Management Council (MAFMC). The fishery extends from Maine to North Carolina to the continental margin with catch predominantly coming from gillnet, trawl, and dredge gear. The Councils manage the fishery in two management areas; the Northern Fishery Management Area (northern area) covers the Gulf of Maine and northern part of Georges Bank, and the Southern Fishery Management Area (southern area) extends from the southern flank of Georges Bank through the Mid-Atlantic to North Carolina (NEFMC, 2014; Figure 1).

The monkfish fishery is primarily managed by landing limits in conjunction with a yearly allocation of Days-At-Sea (NEFMC, 2017a). Specifications follow Magnuson-Stevens Act requirements that include an Acceptable Biological Catch (ABC) with an associated Annual Catch Limit (ACL). Current regulations specify that catch limits should be set every three years to include an Annual Catch Target (ACT; defined as the ACL minus management uncertainty) and Total Allowable Landings (TAL; defined as the ACT minus calculated discards). The effort controls are designed to achieve but not exceed the TAL for both management areas in each fishing year.

Monkfish are assessed through an index-based method that calculates the proportional rate of change in smoothed Northeast Fishery Science Center (NEFSC) Bottom Trawl Survey indices over the most recent three years (NEFSC, 2016). The rate of change is applied to the current ABC to revise future catch limits. Although monkfish stock assessments update the series of estimated discards, discard estimates are not included in the assessment method and are not currently used for the derivation of ABC. The 2019 Monkfish Operational Assessment examined the proportional rate of change for the 2016-2018 NEFSC Fall Survey only and the rate of the change for the NEFSC Fall and Spring Surveys combined to estimate a range for both the northern area (1.2-1.3) and southern area (0.96-1.04; NEFSC, 2020). Based on these results, the NEFMC set the 2020-2022 ABC for the northern area at 8,351mt (10% increase from 2017-2019 ABC) and for the southern area at 12,316mt (status quo 2017-2019 ABC). The Monkfish FMP includes a 3% management uncertainty buffer resulting in ACTs for the northern area of 8,101mt and the southern area of 11,947mt (Figure 2; NEFMC, 2019a).

Monkfish discards are estimated by gear, half-year and management area using observed discard-per-kept-monkfish to expand to total discards for otter trawls and gillnets and observed discard-per-all-kept-catch to expand for scallop dredges (NEFSC, 2020). Annual discards from all fisheries are combined, assuming 100% discard mortality. Monkfish landings and discards from the three most recent years of available data from each management area are averaged to calculate a discard percentage of catch, which is applied to the ACT to set TALs for the northern and southern areas. Specifications for fishing years 2020-2022 applied the average discard percentage from fishing years 2016-2018 resulting in a discard percentage of 18.2% for the northern area and 50.8% for the southern area (Figure 2).

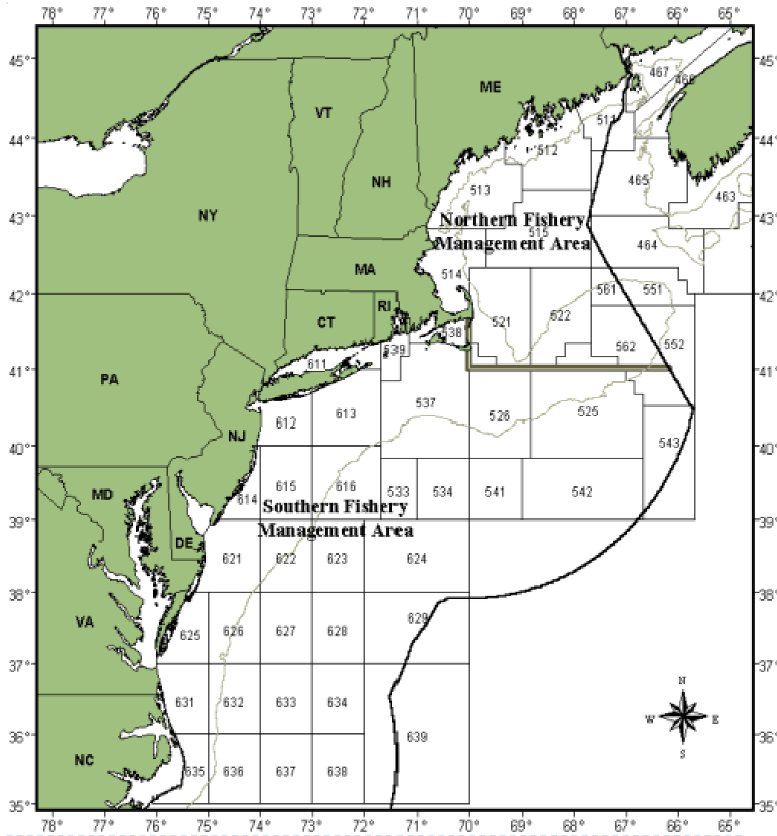


Figure 1. Monkfish fishery management areas. Figure adapted from NEFMC, 2017a.

3. NEFMC 2020 Monkfish Priority

Under current regulations, monkfish specifications are set every three years using available data from the previous three full fishing years. For example, the 2020-2022 specifications were determined in 2019 and were based on survey and discard information from 2016-2018. This approach, which includes a two-year data lag, implicitly assumes that recent discards are the best estimate of future discards. Monkfish discard mortality is currently assumed to be 100% for all gear types. These combined assumptions may not accurately characterize future discards or available biomass to set TALs for both management areas.

The 2019 Monkfish Operational Assessment described discard patterns over time and showed a general increasing trend in the most recent years (NEFSC, 2020). The proportion of discards in the northern area was approximately 13% in the 1980s, 7% during 2002-2006, 12% during 2007-2009, 14% for 2010-2015 and 18% during 2016-2018. The proportion of discards in the southern area was approximately 16% in the 1980s, 29% during 2002-2006, 24% during 2007-2009, 27% in 2010-2015 and 51% during 2016-2018 with estimated discards (mt) exceeding landings in 2017 and 2018 (Figure 3).

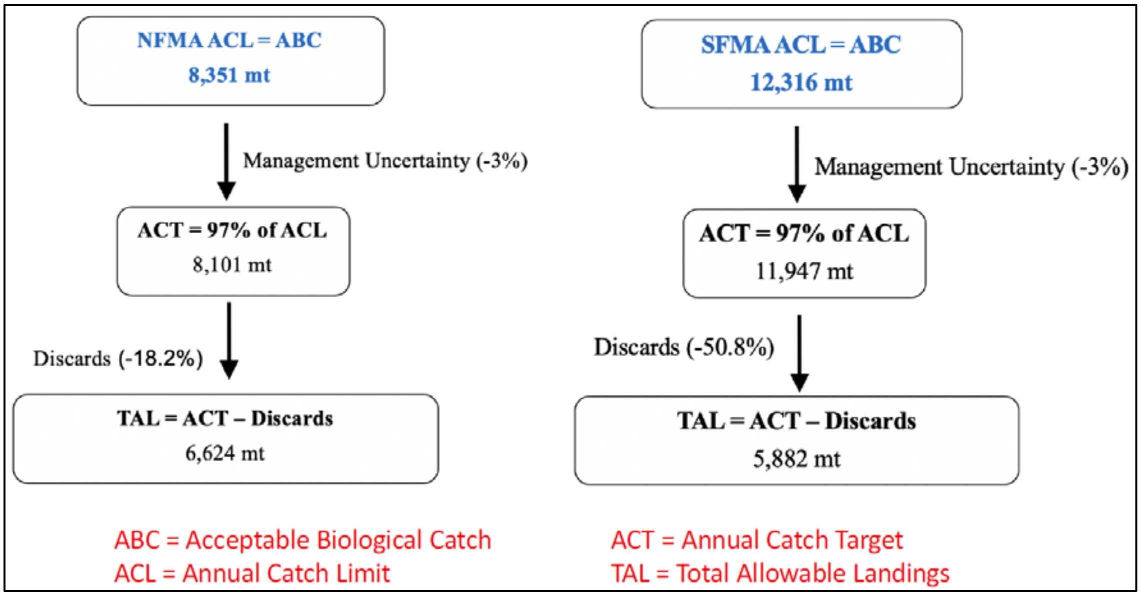


Figure 2. 2020-2022 monkfish specifications for the northern area (NFMA; left) and southern area (SFMA; right). Figure adapted from NEFMC, 2019a.

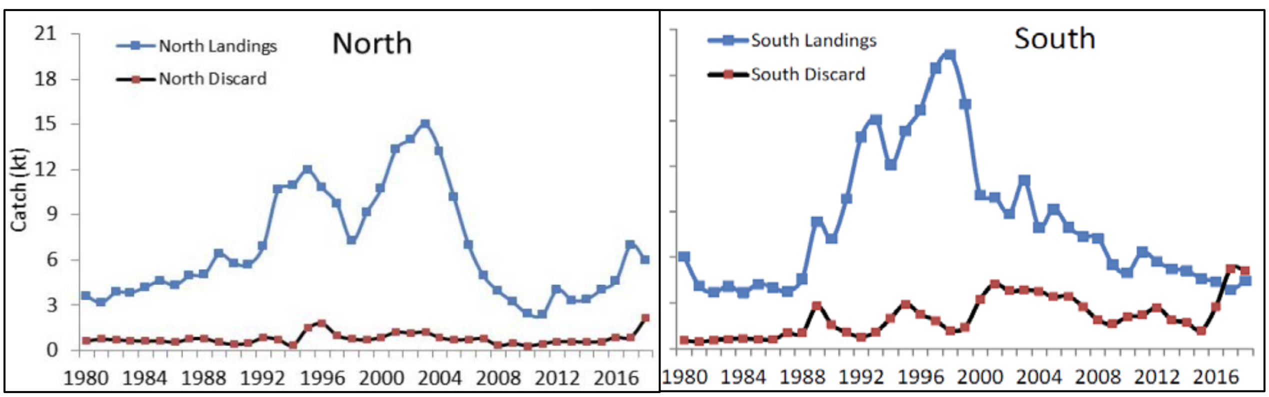


Figure 3. Monkfish landings and discards (kt) in the northern (left) and southern (right) areas from 1980-2018. Figure adapted from NEFSC, 2020.

The recent increase in discarding reflects a large 2015 monkfish recruitment event. In the northern area, the ME/NH Inshore Bottom Trawl Survey observed an increase in abundance in 2015, and overall recruitment indices suggested a strong 2015 year-class. The abundance index in the southern area in fall 2015 was more than three times greater than the previous high in the R/V Bigelow survey time series (2009-2015; NEFSC, 2016). Total discards increased in both management areas starting in 2016 with a large increase in discarding of small fish in the southern area dredge and trawl fisheries (NEFSC, 2020). The 2016 and 2019 monkfish assessment Working Group noted that monkfish landings by the scallop fishery were low and discards were high due to regulatory and economic disincentives to land monkfish, whereas the gillnet fishery consistently had the lowest discard ratios in both areas. The 2015 year-class has now grown into the exploitable size range (43+cm), suggesting that trends in future discards may differ from the recent past.

In 2019, during the development of the 2020-2022 Monkfish Specifications, the Monkfish Plan Development Team (PDT) noted that the discard rate of monkfish had recently increased in both management areas, likely due to the large 2015 year-class. The PDT discussed alternate methods for calculating discards for the southern area but concluded at the time there were no alternative approaches available that appeared more appropriate than the use of the 3-year average discard percent of catch using data from the most recent years available (2016-2018). The PDT recommended possible investigation of alternative discard prediction approaches in a future action. The Monkfish Advisory Panel raised similar concerns about the discard prediction approach and recommended status quo specifications for the southern area TAL for 2020-2022 with an additional recommendation to prioritize research related to discard estimation methods and discard mortality of monkfish. The Monkfish Committee also raised concerns about the discard predictions and recommended setting monkfish specifications for only one year (2020) accompanied by a recommended Council priority to develop new monkfish specifications for 2021-2022 based on alternative discard calculation methods. The NEFMC ultimately chose to set monkfish specifications for the northern and southern areas for 2020-2022 based on updated information from the 2019 Monkfish Operational Assessment and apply the 3-year average discard percent of catch approach to set TALs. The Council recognized concerns about the discard estimation approach and included the following in the list of 2020 Priorities:

> *Conduct an analysis of alternative methods for estimating discards of monkfish to apply to future specifications and consider available information on discard mortality. If warranted, consider adjusting specifications for FY2021-2022 (NEFMC, 2019b).*

4. Analyses and Results

Monkfish discard estimates have been updated through the assessment process in recent years, but the Council could consider an alternative approach for assuming future discards within the Monkfish FMP. The index-based monkfish assessment does not rely on application of discard estimates to determine ABCs/ACLs, and the Council may consider alternative ways to estimate and apply discards to set TALs. Alternative approaches for determining the discards that are deducted from the ACT were explored; these did not include any changes to the current method to estimate discards by gear type, as described in the 2019 Monkfish Operational Assessment (e.g., SBRM approach on a half-year basis). Any of the approaches that were explored could be reviewed through a future assessment or external peer-review process before application to the Monkfish FMP.

Analyses included:

1. Retrospective examination of the differences between the discard estimates used to calculate the TAL and realized discards from gillnet, trawl and dredge gear;
2. Analysis of potential trends in discards during different time periods for application as the discard reference period;
3. Consideration of the Monkfish PDT recommendation to apply the highest discard estimate in the time series in place of a reference period;
4. Analysis of gear specific discard estimates (e.g., alternatives to the current approach to combine all gear discards);

5. Application of alternative estimation approaches to analyze trends in past discards (e.g., long-term mean, weighted mean, and median discard percent of catch);
6. Consideration of the use of a monkfish recruitment index to inform discard estimates.

4.1 Realized vs. Estimated Discards

Monkfish landings, discards and total catch, as reported in the 2019 Monkfish Operational Assessment, were examined for comparison to the realized discard percent of catch and the estimated discard percent of catch that was applied to set TALs in the FMP. The analysis considered the full time series of information by management area and gear type, starting in 1989. The objective of comparing the realized discard percent of catch to the values applied in the FMP was to examine performance of the current approach that uses a moving 3-year average of combined gears discards to total catch.

Figure 4 shows the realized discard percent of catch for the northern and southern areas overlaid with the values applied to the Monkfish FMP. Panels A and C include data from the full time series available (1989-2022), and panels B and D focus on the period between 2008 and 2022 when the monitoring and reporting requirements of SBRM were implemented. The longer time series indicates variability in discard behavior in both the northern and southern areas through the 1990s with more stable discard behavior starting in the early 2000s. Discards as a percent of total catch increased slightly in the northern area between 2008-2011 and remained relatively stable until the large increase in 2018. In the southern area, discards as a percent of total catch were relatively stable between 2000 and 2015, fluctuating between 20-30%, with a large increase starting in 2016.

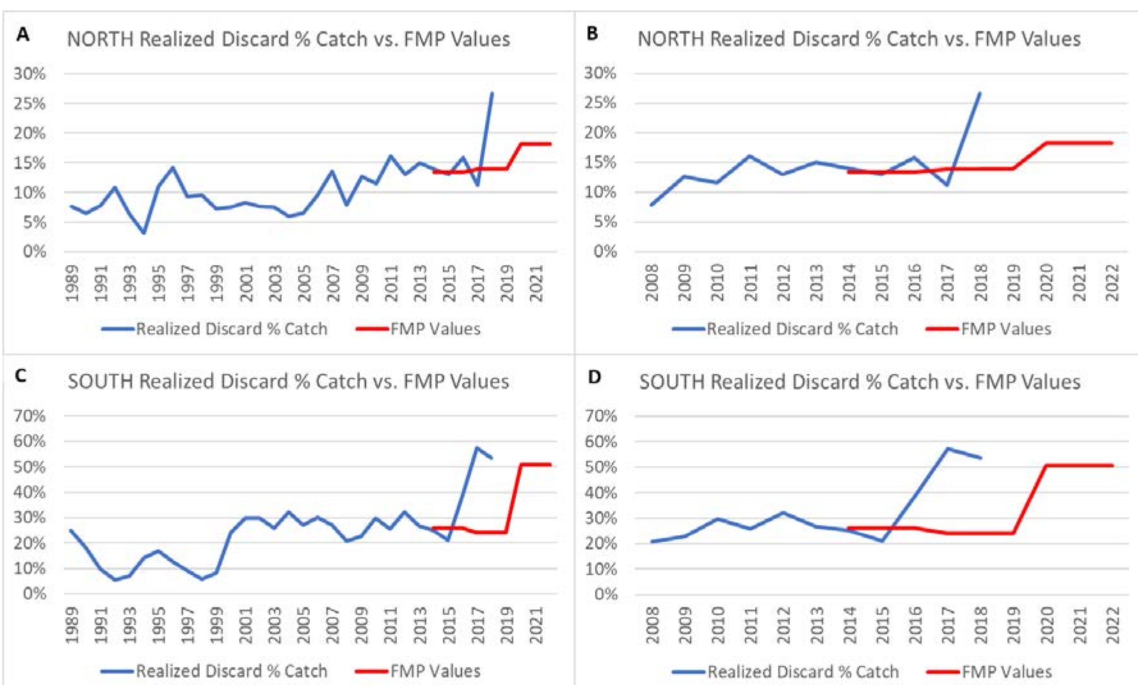


Figure 4. Realized discard percent of catch (blue) compared to Monkfish FMP discard percent of catch (red) for the northern area 1989-2022 (A) and 2008-2022 (B) and the southern area 1989-2022 (C) and 2008-2022 (D).

The discard percent of catch values that were applied to set the TALs starting in 2014 did not perform well compared to realized discards. In the northern area, the FMP value underestimated discard percent of catch by ~50% in 2018 (FMP value = 13.9%; realized discard percent of catch = 26.6%). The FMP value applied to set the TAL in the southern area was underestimated by over 50% in 2017 and 2018 (FMP value = 24.6%; realized discard percent catch = 57.4% and 53.6% for 2017 and 2018, respectively).

4.2 Alternative Discard Estimation

Based on the retrospective examination of realized discard percent of catch, alternative approaches to estimate discards to calculate the monkfish TALs were considered. The 3-year weighted average of discards (weighted by total catch) currently used in the Monkfish FMP to set area-specific TALs reflects recent discarding behavior without consideration of changes in the monkfish resource, target fisheries or non-target fisheries. The method has been applied in the FMP since 2014, but the analysis back-calculated what the 3-year estimates would have been starting in 2008 (Figure 5).

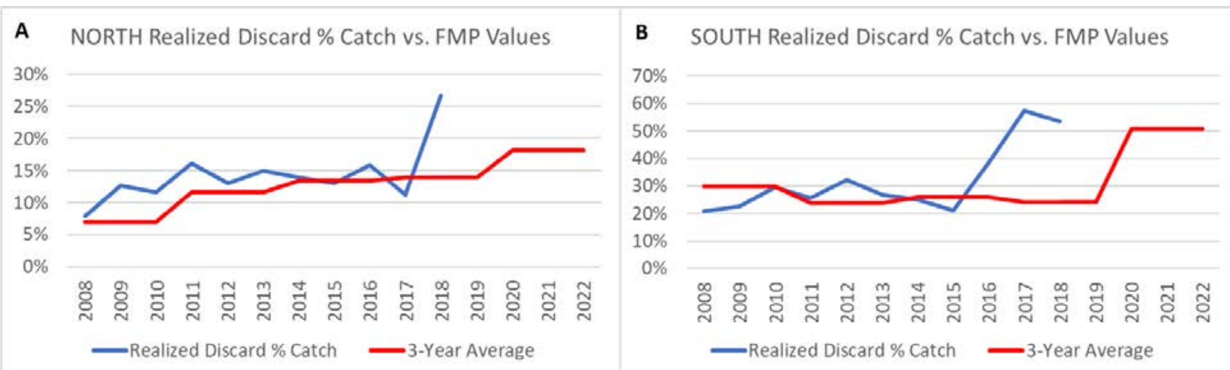


Figure 5. Realized discard percent of catch (blue) compared to back-calculated three-year average discard percent of catch (red) for the northern area (A) and southern area (B).

The 3-year average approach overestimated and underestimated discards in both the northern and southern areas. Because the method applies data from a past period to predict future discards, the resulting estimates are "chasing" recent trends. The magnitude of overestimation or underestimation was relatively small for both management areas between 2008 and 2015, indicating that this method performed relatively well during a period of stability in the monkfish resource and fishery. The major divergence occurred after 2015 when discards increased in both management areas from the large 2015 monkfish year-class. This divergence may continue under the current 2020-2022 Monkfish Specifications as the 2015 year-class has entered the fishery and discards may be reduced. The following alternatives were considered as possible approaches to improve future discard estimates.

4.2.1 Multi-Year Average Alternatives

Examination of alternate time periods (2-year and 5-year weighted averages) did not show substantial improvement over the 3-year average approach. Figure 6 shows the performance of using 3-year, 2-year, and 5-year averages of discards to total catch in relation to the realized discards. In the northern area, the 2-year average performed slightly better than the 3-year and 5-year average between 2008 and 2013, but all the methods substantially underestimated discards in 2018. All the approaches performed similarly in the southern area with substantial underestimation in 2017 and 2018. Similar to the current 3-year average approach applied in the FMP, the approaches using averages of different time periods of recent data do not account for changes in the monkfish resource or fisheries and would not improve future performance during periods of instability.

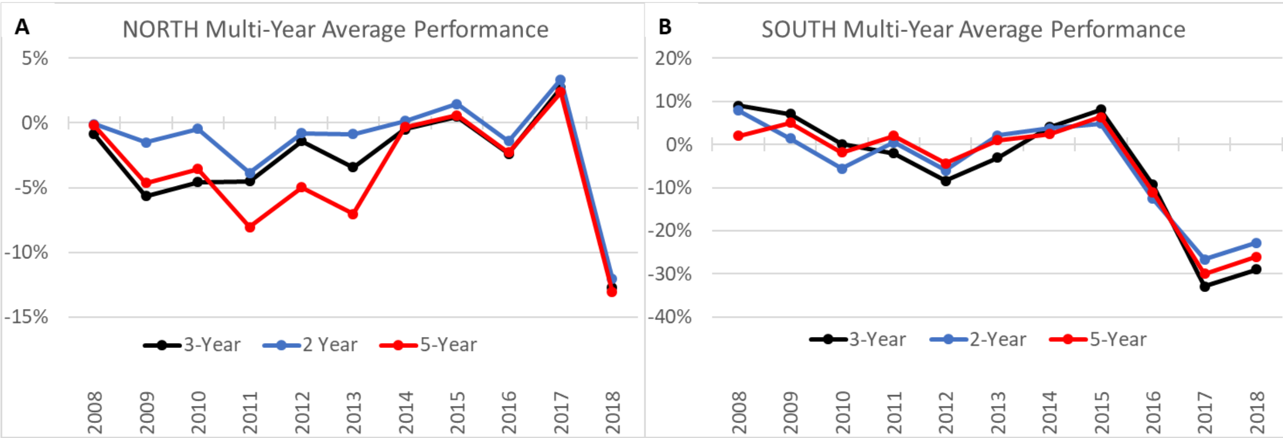


Figure 6. Performance of 3-year (black), 2-year (blue), and 5-year (red) average discard percent of catch shown as percent difference from realized discards for the northern area (A) and southern area (B).

4.2.2 Highest Discard Value

Applying the highest discard value in the time series was considered as a potential alternative value to be used for setting area-specific TALs. The Monkfish PDT considered the option to use the highest discard value in the time series during the development of the 2020-2022 Monkfish Specifications. The highest values for the northern area and southern area were 2,161mt and 5,250mt, respectively. Using the 3-year average discard percent of catch resulted in subtracting 1,477mt and 6,065mt from the 2020-2022 ACTs for the northern area and southern area TALs, respectively. The PDT did not support this approach for the 2020-2022 specifications but recommended additional investigation on the topic. Although using the highest value in the time series for the 2020-2022 specifications would have resulted in less discards being removed from the ACT for the southern area, it would have resulted in greater reductions for the northern area, and there was no evidence that the highest discard values would persist into the future.

4.2.3 Gear-Specific Discards

Discarding by gear type was examined to determine if there were apparent trends that could better inform overall discard estimation and application to set TALs. In both management areas, TALs have increased since 2007 (Table 1), but percent catch and discards by gear type has remained relatively stable until the most recent years, with some exceptions. Figure 7 shows percent of total catch and total discards by gear type for the northern and southern areas. In the northern area, catch by trawl gear was ~80% of total catch between 2008 and 2017 (2011 data reported in the 2019 Monkfish Operational Assessment may be erroneous as combined catches exceed 100%). Catch by dredge gear was 10% or less of total catch until 2018 when discards increased compared to trawl gear. Discards by trawl and dredge gear fluctuated through the time series, but the proportion of total catch by gear type was stable. In the southern area, catch by gear type was relatively stable between 2008 and 2014, after which dredge gear total catch increased due to increased discards. Gillnet catch and discards have remained stable in both management areas since 2008.

Table 1. ABC, ACT and TAL for the northern and southern areas 2007-2018.

	NORTH							SOUTH						
Fishing Year	ABC	ACT	TAL	Landings (mt)	% ABC Caught	% ACT Caught	% TAL Caught	ABC	ACT	TAL	Landings (mt)	% ABC Caught	% ACT Caught	% TAL Caught
2007			5,000	5,050			101%			5,100	7,180			141%
2008			5,000	3,528			71%			5,100	6,751			132%
2009			5,000	3,344			67%			5,100	4,800			94%
2010			5,000	2,834			57%			5,100	4,484			88%
2011	7,592	6,567	5,854	3,699	49%	56%	63%	12,316	11,513	8,925	5,801	47%	50%	65%
2012	7,592	6,567	5,854	3,920	52%	60%	67%	12,316	11,513	8,925	5,184	42%	45%	58%
2013	7,592	6,567	5,854	3,596	47%	55%	61%	12,316	11,513	8,925	5,088	41%	44%	57%
2014	7,592	6,567	5,854	3,403	45%	52%	58%	12,316	11,513	8,925	5,415	44%	47%	61%
2015	7,592	6,567	5,854	4,080	54%	62%	70%	12,316	11,513	8,925	4,733	38%	41%	53%
2016	7,592	6,567	5,854	5,447	72%	83%	93%	12,316	11,513	8,925	4,345	35%	38%	49%
2017	7,592	7,364	6,338	6,807	90%	92%	107%	12,316	11,947	9,011	3,802	31%	32%	42%
2018	7,592	7,364	6,338	6,168	81%	84%	97%	12,316	11,947	9,011	4,600	37%	39%	51%

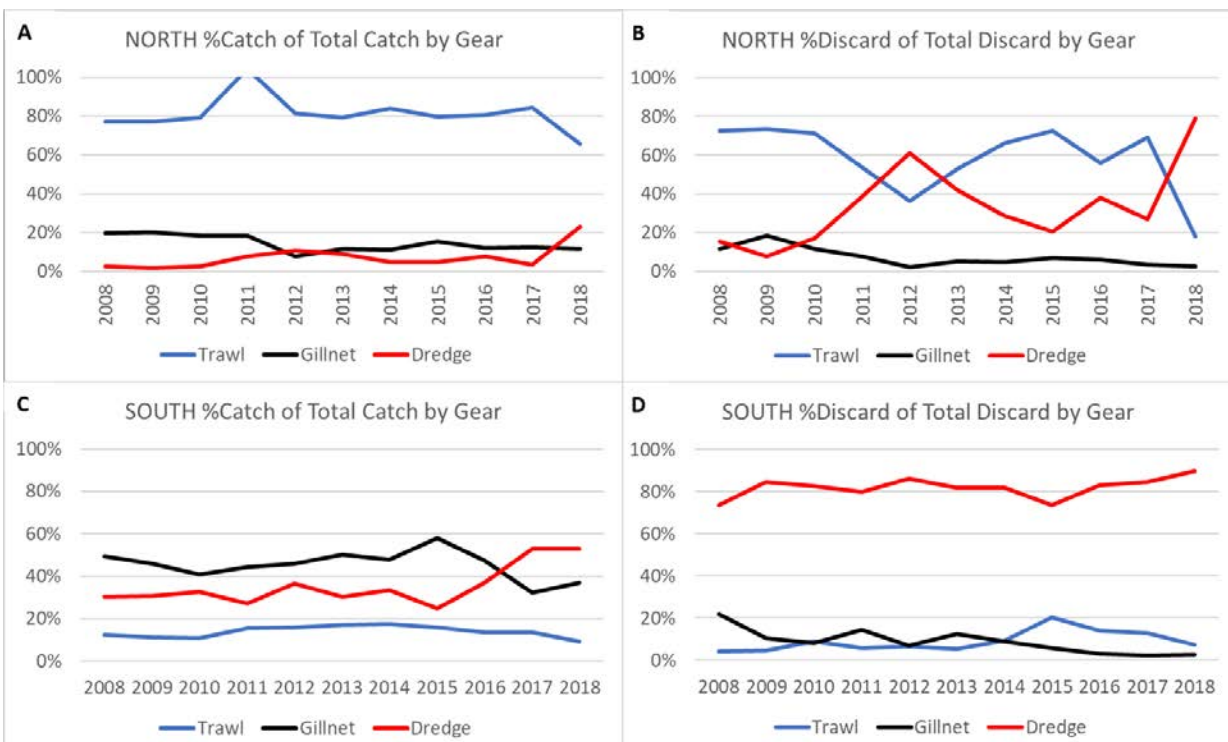


Figure 7. Percent catch and discard by gear type of total catch and discards for the northern area (A and B) and southern area (C and D).

Further analysis of discard trends by gear type showed that the use of a combined gear discard estimate performs relatively well. The current approach of combining discards for all gears implicitly weights the discard percent of catch by the total catch. Although discards as percent of catch by gear type vary, the relative stability in percent of total catch by gear results in a combined estimate that reflects realized discards. For example, trawl discards influence overall discard percent of catch in the northern area because trawl catch makes up over 80% of catch. Dredge discards as a percent of dredge catch are much higher than trawl discards, but overall dredge catch averaged 10% or less. In the southern area, where dredge discards approached 100% of dredge catch in recent years, the overall discard percent of catch reflects the relatively low level of discarding by gillnet and trawl gears (Figure 8).

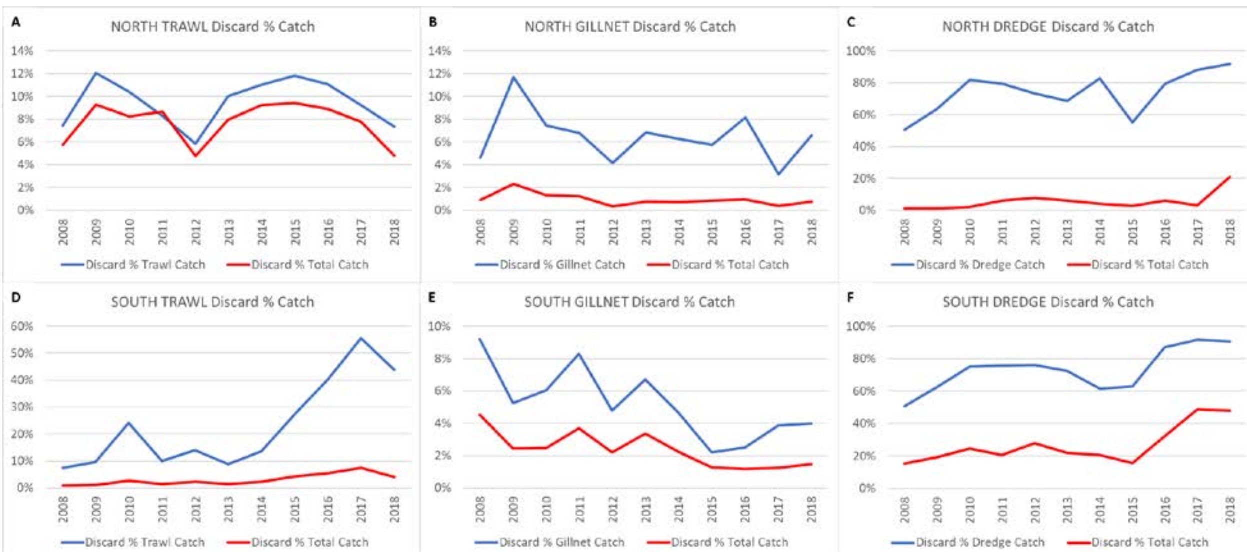


Figure 8. Discards by trawl, gillnet, and dredge gear as a percent of catch by gear and total for the northern area (A, B, C) and southern area (D, E, F).

4.2.4 Long-Term Trends

Based on results of the analyses related to realized discards, multi-year averaging approaches, and gear-specific trends in discards, an examination of long-term trends in discards as a percent of catch was conducted. Similar to the other analyses, the time period considered was 2008-2018, reflective of SBRM protocols. Several iterations of long-term trends were examined, including mean discard percent of catch, weighted mean discard percent of catch, and median discard percent of catch for the periods 2008-2018 (full time series) and 2008-2015 (period of stability for the monkfish resource prior to 2015 recruitment event).

Table 2 and Figure 9 show the long-term discard percent of catch for each management area under the various iterations. There was <1% difference between the mean discard percent of catch and the weighted mean (weighted by total catch) for both management areas for both time periods (2008-2015 and 2008-2018), so only the weighted mean is shown. In both management areas, the 2008-2015 weighted mean and median discard percent of catch were similar (Table 2) and performed well relative to realized discards during the same time period. The 2008-2018 weighted mean overestimated discard percent of catch for nearly all years in both areas except the most recent years when discarding increased. The 2008-2018 median estimate performed relatively well as a reflection of realized discard percent of catch in the northern area but overestimated several years in the southern area. The results suggest the use of a long-term weighted mean or median may be reflective of future discards when the monkfish resource is relatively stable. The 2008-2015 mean and median estimates performed well for both areas compared to realized discards within the same time period. A similar analysis was conducted for the time periods 1989-1999 and 2000-2007 for both management areas with similar results; the long-term discard estimates were reflective of realized discards during periods when the monkfish resource was relatively stable.

Table 2. Numerical values of the long-term weighted (wtd) mean and median discard percent of catch.

Area	08-15 Wtd Mean	08-15 Median	08-18 Wtd Mean	08-18 Median
NORTH	12.8%	12.9%	15.0%	13.8%
SOUTH	25.6%	26.7%	33.2%	29.3%

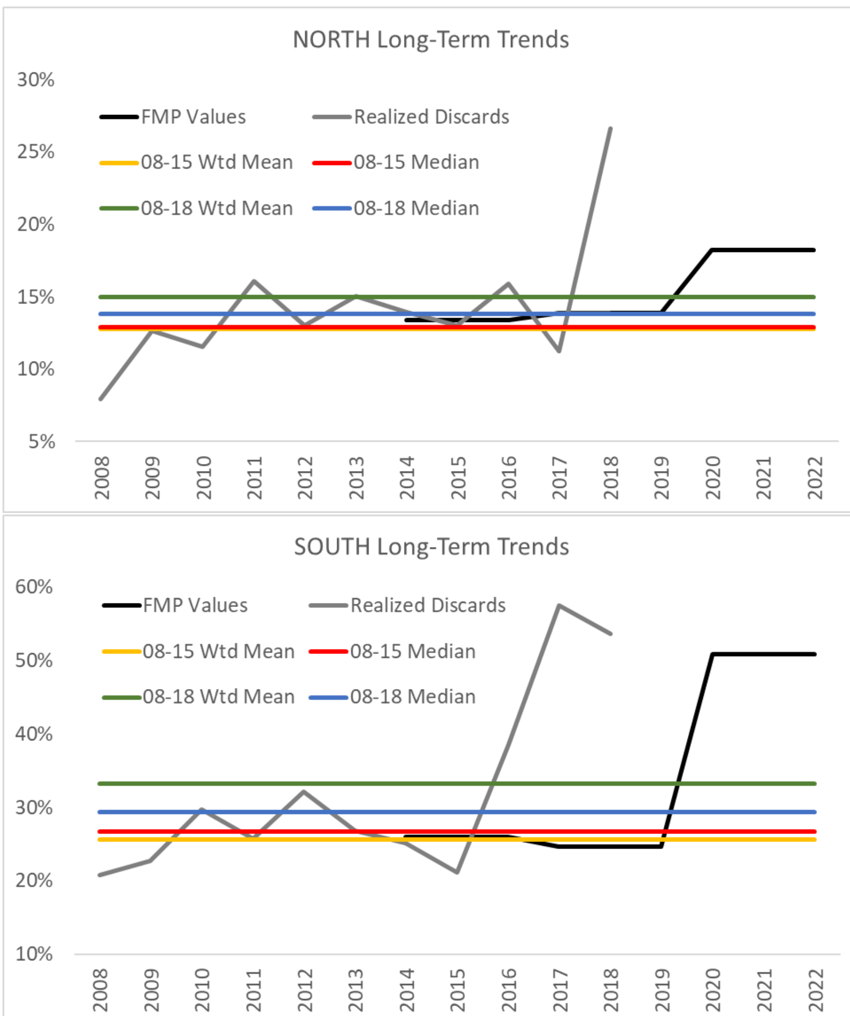


Figure 9. Long-term (2008-2015 and 2008-2018) discard percent of catch (weighted mean and median) compared to FMP values and realized discards in the northern area (top) and southern area (bottom).

4.2.5 Recruitment Index and Growth

The large 2015 monkfish recruitment event was the most likely factor leading to increased discarding in both management areas starting in 2016. Information from this recent recruitment event can be used to evaluate monkfish recruitment generally and justify possible deviations from the long-term mean discards in the TAL derivation. The large year-class was first observed in the northern and southern areas by the 2015 NEFSC Surveys, as well as the ME/NH Inshore Survey and the NEFSC/Virginia Institute of Marine Science (VIMS) Scallop Dredge Survey (Figure 10; Table 3). The 2016 Monkfish Operational Assessment indicated that the 2015 year-class was one of the largest in several decades, and the 2019 assessment reflected the growth of this year-class through 2018.

Data presented in the 2019 Monkfish Operational Assessment suggested that multiple surveys can detect strong monkfish recruitment events. In the northern area, the NEFSC Fall Survey observed high numbers of monkfish per tow under 10cm in 2015 and 2016. Similarly, the 2015 and 2016 ME/NH Inshore Survey observed the highest catch of monkfish under 10cm in the time series since 2000 (Figure 11). In the southern area, the NEFSC/VIMS Scallop Dredge Survey and the NEFSC Spring Survey observed large catches of small monkfish in 2015 and 2016, respectively (Figure 12). The ability of these surveys to detect strong recruitment events could be useful for predicting future discards. For example, the strong recruitment observed in 2015-2016 is the most likely factor that lead to increased discarding in 2017-2018. Table 3 highlights years when mean survey abundance exceeded the 75th percentile. Notably, several of the surveys detected increased abundance in 2015 and 2016, which is an indicator of a strong year-class.

Commercial catch data may provide an additional source of information about catch at size that could be used in combination with survey indices to detect strong recruitment events. Large amounts of small monkfish were caught in the northern area in 1994 and 1999, reflecting large year-classes that were observed in surveys. Similarly, there was a large number of fish under 40cm caught in the southern area in 2016, reflecting the large 2015 year-class (NEFSC, 2020).

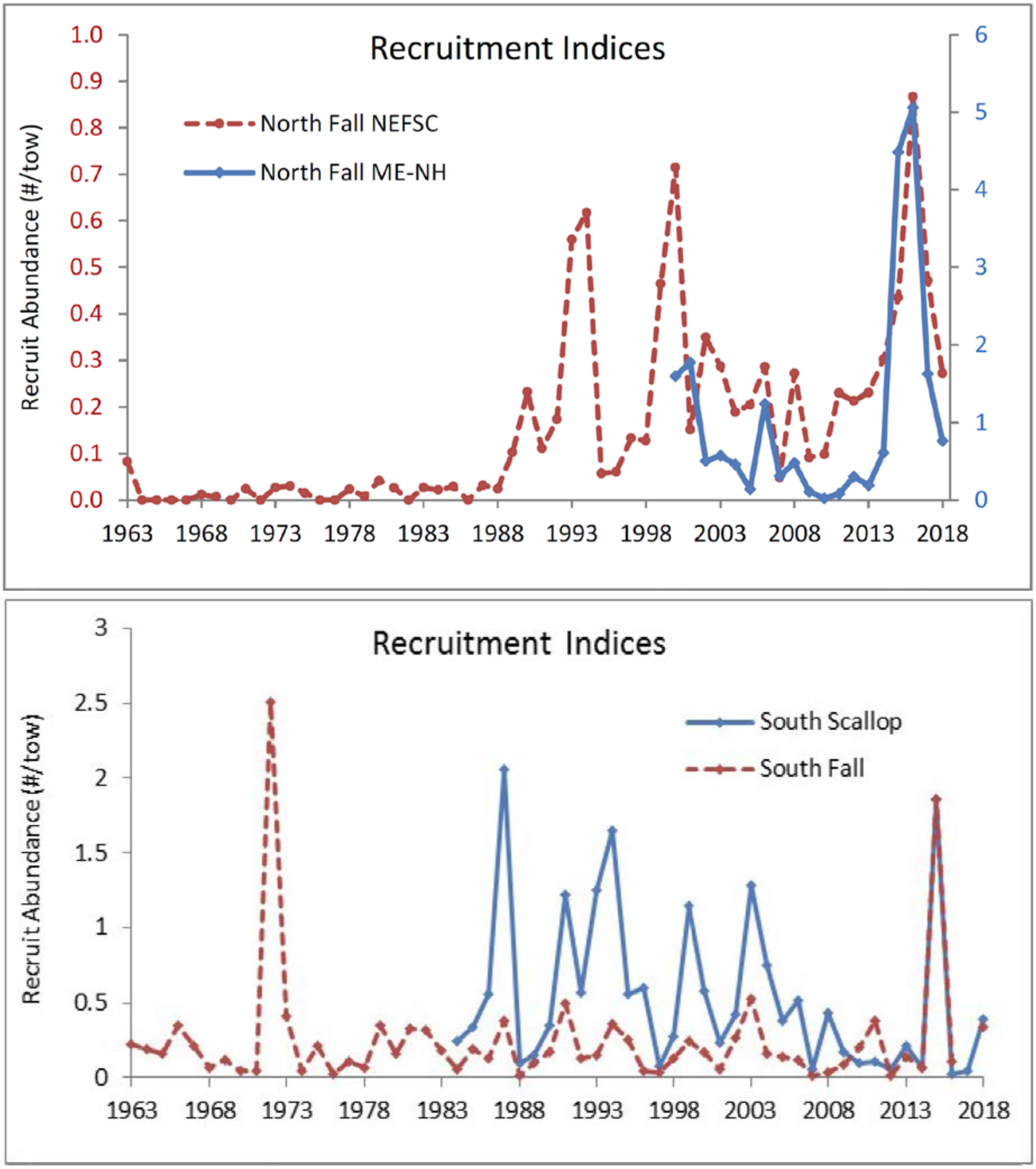


Figure 10. Recruitment indices for the northern area from the NEFSC Fall BTS and ME/NH BTS (top) and the southern area from the NEFSC Fall BTS and NEFSC/VIMS Scallop Dredge Survey (bottom). Figure adapted from NEFSC, 2020.

Table 3. Survey results from the NEFSC Fall and Spring Surveys, ME/NH Fall Survey, and NEFSC/VIMS Dredge Survey with associated CVs for 1989-2019 for the northern and southern areas. Highlighted values are above the 75th percentile.

	NORTH						SOUTH					
	NEFSC Fall Survey	CV	NEFSC Spring Survey	CV	ME/NH Fall Survey	CV	NEFSC Fall Survey	CV	NEFSC Spring Survey	CV	NEFSC/VIMS Dredge	CV
1989	0.51	0.18	0.619	0.21			0.46	0.22	0.20	0.23	1.00	0.10
1990	0.71	0.15	0.283	0.21			0.35	0.27	0.21	0.11	1.53	0.10
1991	0.70	0.17	0.592	0.18			0.83	0.28	0.32	0.25	2.26	0.10
1992	0.94	0.17	0.493	0.31			0.34	0.16	0.18	0.25	1.95	0.10
1993	1.23	0.16	0.681	0.13			0.35	0.23	0.20	0.23	2.83	0.00
1994	1.34	0.12	0.453	0.18			0.60	0.19	0.11	0.23	3.33	0.10
1995	0.93	0.12	1.009	0.16			0.49	0.21	0.20	0.20	2.26	0.10
1996	0.63	0.17	0.666	0.22			0.23	0.21	0.14	0.20	2.01	0.10
1997	0.50	0.18	0.32	0.25			0.31	0.17	0.12	0.21	1.12	0.10
1998	0.62	0.19	0.416	0.14			0.33	0.24	0.25	0.14	1.06	0.10
1999	1.08	0.15	0.827	0.16			0.45	0.12	0.34	0.14	2.57	0.10
2000	2.34	0.14	1.132	0.12	4.8	0.29	0.42	0.17	0.24	0.17	2.29	0.10
2001	1.61	0.11	1.669	0.12	10.7	0.21	0.38	0.17	0.24	0.20	1.73	0.10
2002	1.28	0.13	1.743	0.10	4.1	0.56	0.83	0.14	0.32	0.33	1.70	0.10
2003	1.07	0.12	0.813	0.20	3.7	0.31	0.95	0.17	0.31	0.16	2.75	0.10
2004	0.52	0.19	0.907	0.17	2.9	0.31	0.47	0.20	0.12	0.25	2.89	0.10
2005	0.60	0.18	0.718	0.16	1.8	0.22	0.58	0.20	0.26	0.27	2.01	0.10
2006	0.77	0.15	0.367	0.27	2.9	0.22	0.45	0.19	0.17	0.20	1.44	0.10
2007	0.64	0.15	0.548	0.23	3.1	0.26	0.20	0.22	0.26	0.16	0.08	0.10
2008	0.79	0.21	0.674	0.17	4.1	0.33	0.20	0.25	0.19	0.31	1.03	0.10
2009	0.39	0.10	0.331	0.10	2.0	0.45	0.22	0.13	0.16	0.14	0.08	9.80
2010	0.51	0.09	0.382	0.14	1.0	0.32	0.40	0.19	0.16	0.21	0.07	9.90
2011	0.67	0.07	0.465	0.13	1.0	0.37	0.62	0.13	0.28	0.14	0.09	12.50
2012	0.68	0.07	0.538	0.14	0.8	0.35	0.28	0.14	0.30	0.09	1.00	
2013	0.73	0.07	0.551	0.07	0.8	0.39	0.29	0.17	0.20	0.17	0.81	
2014	0.95	0.09	0.614	0.12	1.0	0.32	0.16	0.12	0.14	0.13	0.55	
2015	1.22	0.09	0.537	0.09	7.0	0.33	1.96	0.28	0.11	0.16	2.29	
2016	1.84	0.07	0.685	0.07	6.8	0.21	0.63	0.20	0.46	0.10	2.17	
2017	1.47	0.09	0.681	0.10	4.1	0.30			0.46	0.18	1.62	
2018	1.29	0.06	1.041	0.08	2.9	0.24	0.47	0.17	0.33	0.16	0.99	
2019			0.874	0.08					0.29	0.11		

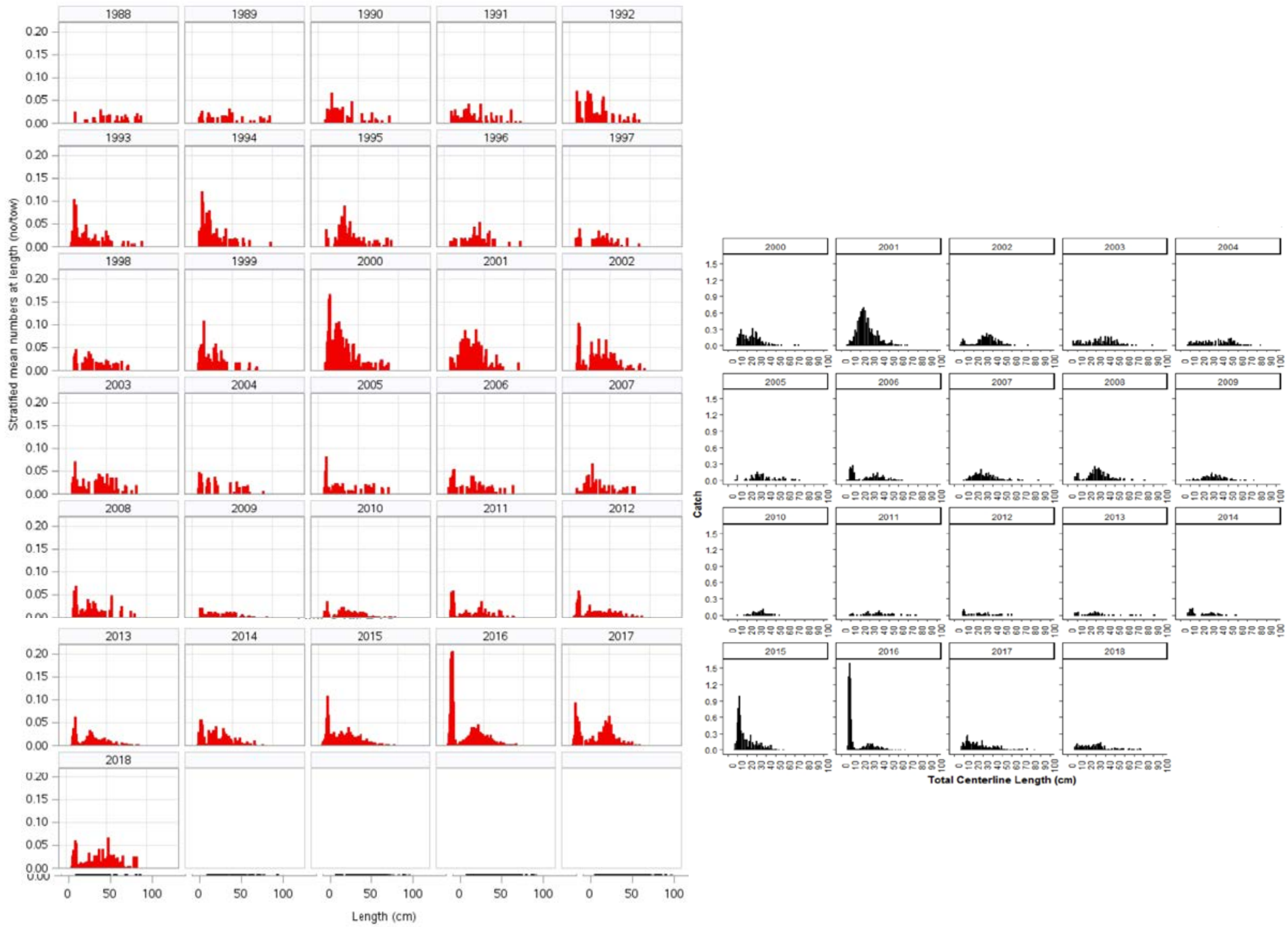


Figure 11. Abundance at length from the NEFSC Fall Survey (left) and ME/NH Fall Survey (right) in the northern area. Figure adapted from NEFSC, 2020.

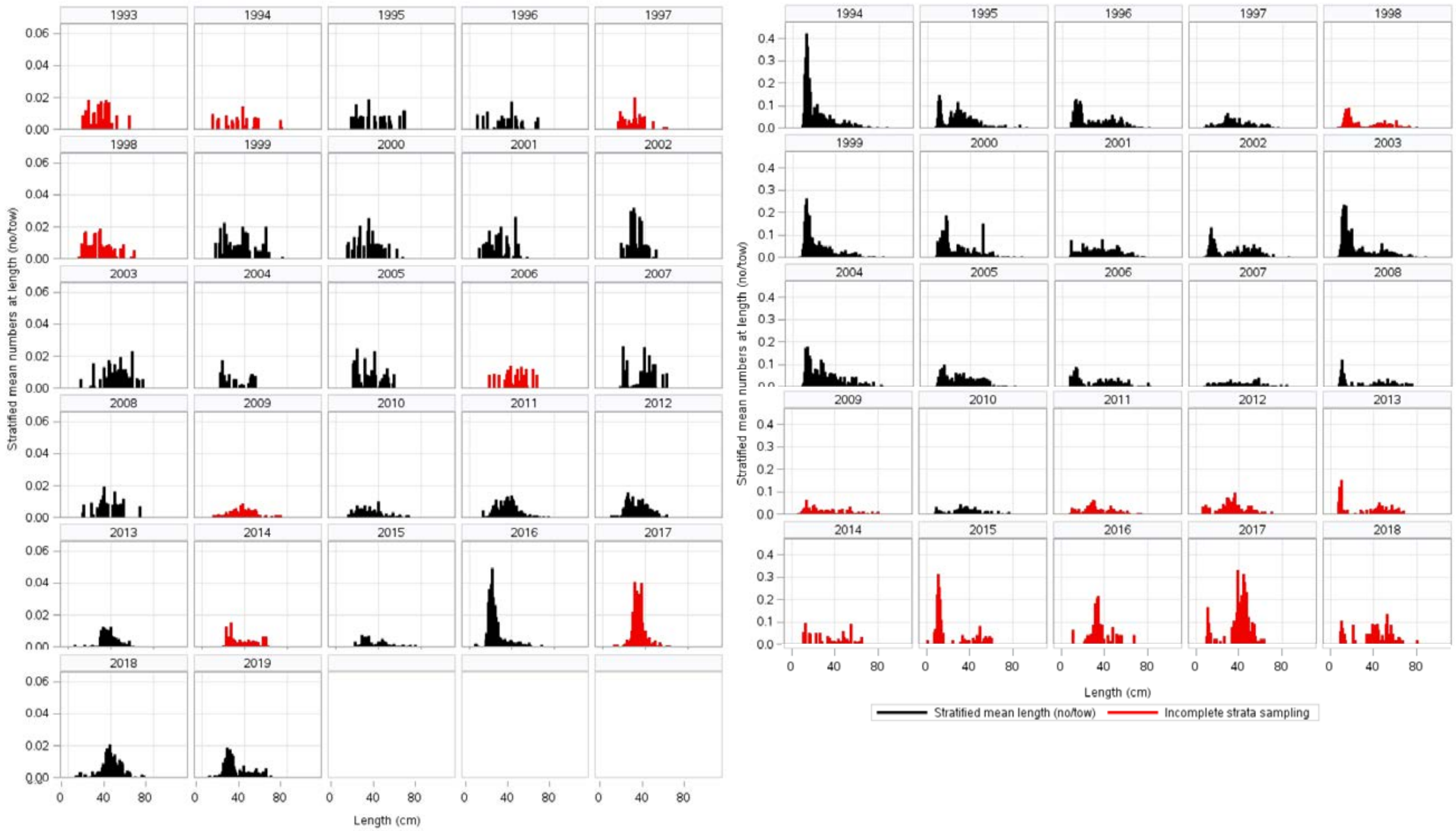


Figure 12. Abundance at length from the NEFSC Spring Survey (left) and NEFSC/VIMS Scallop Dredge Survey (right) in the southern area. Figure adapted from NEFSC, 2020.

New information about monkfish growth rate at early ages may be informative about future discards. The 2019 assessment estimated growth by modal progression of the 2015 year-class and suggested that monkfish grow to ~25cm by age 1 and reach the size at maturity (~40cm) by age 2 (Figure 13; NEFSC, 2020). Exploitable biomass is defined as 43+cm, which is likely reached before age 3. The rapid growth rate at early ages indicates that monkfish enter the fishery within three years of recruitment to surveys, which suggests that the high level of discarding of small monkfish in 2016-2018 may be substantially reduced by 2020-2022 compared to the predicted levels in the specifications. Combining this new understanding about growth with recruitment indices from multiple surveys may improve predictions of future discarding and be more reflective of actual discards than the 3-year average approach.

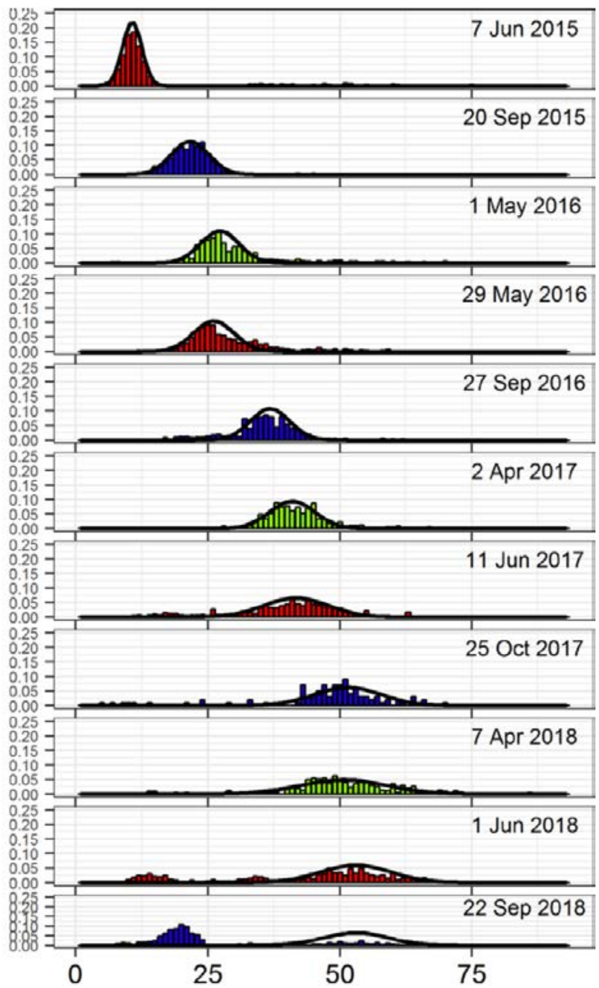


Figure 13. Length frequency distributions of monkfish in the southern area from the NEFSC/VIMS Dredge Survey (red), NEFSC Fall Survey (blue), and NEFSC Spring Survey (green) illustrating growth rates of the 2015 year-class. Figure adapted from NEFSC, 2020.

4.3 Future Discards in TAL Calculations

The combined data analyses and examinations of alternative approaches to estimate discards to calculate monkfish TALs suggest that using a long-term weighted mean or median of monkfish discards as a percent of catch would be a robust predictor of future discards in periods of relative stability in the monkfish resource for most years. In addition to using a long-term metric, periodic review of monkfish recruitment indices could indicate strong recruitment and justify a temporarily increased discard rate assumption for future specification periods. Incorporating these methods in combination when calculating TALs to set specifications is expected to improve predictability of discard behavior and overall monkfish management. The long-term mean discard percent of catch performed well during several periods of stability in the monkfish resource, including the most recent period from 2008-2015. In both the northern and southern areas, the long-term (2008-2015) mean and median was <5% different than realized discards between 2008 and 2015. Discard percent of catch increased by nearly 50% in both management areas after the 2015 recruitment event, suggesting that higher discard rates occurred in conjunction with high abundance of small monkfish. Applying an increased discard estimate to set TALs in years following strong recruitment could more accurately characterize fishing behavior to ensure TALs are not exceeded.

The TALs in both the northern and southern areas have rarely been exceeded, but inaccurate estimates of discards can be detrimental to both the monkfish resource and fishery. Underestimating discards can result in exceeding TALs, but overestimating discards can reduce fishery yield and profit. Much of the concern about the increased discard estimates that were applied to the 2020-2022 specifications was related to the southern area. The southern area TAL has not been achieved in over a decade with recent harvest at ~50% of the TAL (Table 1). However, the 2020-2022 specifications maintained status quo ABC and ACT with a reduced TAL due to the predicted increase in discards. If monkfish landings increase as a result of the 2015 year-class entering the fishery, total catch could approach or exceed the TAL. Less concern about the increased discard estimate was focused on the northern area, but the TAL in this area was exceeded in 2017 and near 100% in 2016 and 2018. Overestimating discards in the northern area could further reduce the TAL and either increase the risk of the fishery exceeding the TAL or reduce yield. An approach that combines a relatively stable discard estimate on a long-term basis with the ability to modify discard predictions in response to changes in the monkfish resource could reduce scientific uncertainty in the Monkfish FMP.

5. Discard Mortality

In addition to improving estimates of total monkfish discards, incorporating information about monkfish discard mortality may improve estimates for calculating TALs. Currently, monkfish discard mortality is assumed at 100% for all gear types. New studies suggest that monkfish may be robust to stress caused by capture in dredge gear and have a high survivability rate when discarded. Although there is substantial uncertainty about monkfish survival post-capture and additional research and review is needed prior to changing assumptions about discard mortality when calculating TALs, consideration of past and recent studies on this topic may inform future research priorities or assessment assumptions.

5.1 Scallop Dredge Gear

Between 2008 and 2015, the scallop dredge fishery caught ~10% of total monkfish catch in the northern area and 20% in the southern area. Although the portion of dredge caught monkfish has been historically low compared to total catch, the discard rate has been continuously high, averaging between 70-80% and increasing to over 90% since 2015 (Figure 8). The increase in monkfish discards in the scallop fishery between 2016-2018 influenced the overall discard percent of catch that was applied to the 2020-2022 Monkfish Specifications. Recent studies conducted through the Scallop Research Set-Aside (RSA) Program suggest that discarding of monkfish in the scallop fishery is relatively high, but discard mortality of monkfish caught in dredge gear may be much lower than the assumed 100%.

Weissman et al. (2018) assessed the effect of capture and handling stress on monkfish in the scallop dredge fishery through tests for reflex responses and injury condition. They found that monkfish displayed significant increases in injury condition and significant decreases in number of reflexes present as air exposure time and tow duration increased. However, 80% of sampled monkfish displayed little to no physical trauma suggesting that the manifestation of stress in monkfish may be a cryptic response. A follow-up study conducted by VIMS and the New England Aquarium examined post-release mortality of monkfish caught in scallop dredge gear during standard fishing practices (Rudders and Sulikowski, 2019). The study assessed over 5,000 monkfish between June and October 2017 to determine injury conditions and reflex responses, of which 60 fish were released with PSAT tags and tracked for 14 to 28 days to assess post-release mortality. Results indicated that discard mortality was highest in June (73%) and lowest in July and September (17%). They suggested that the higher mortality observed in June may be associated with reproductive activity when gonadosomatic indices are highest. They estimated a total discard mortality for monkfish caught in scallop dredge gear at ~27%, suggesting that monkfish can recover from physiological stress associated with capture and handling. Further, they recommended future studies across all seasons because the mortality rates were higher when monkfish were reproductively active and fishing effort may shift by season and area (Rudders and Sulikowski, 2019).

5.2 Trawl Gear

Monkfish discards from trawl gear were less than 20% of trawl catch for both monkfish management areas prior to the large 2015 year-class. Although discard rates have been historically low in the trawl fishery, there was a substantial increase in the southern area between 2016 and 2018 (Figure 8). Monkfish discard mortality resulting from trawl gear is highly uncertain and few studies exist on the topic. The original Monkfish FMP (NEFMC, 1998) references research conducted by the Massachusetts Division of Marine Fisheries that indicated discard survival rates ranging from 8-57% for trawl caught monkfish in relatively shallow water. The FMP suggested that discard mortality in offshore waters was likely to be higher than inshore waters. Additionally, during the development of the FMP, regional scientific experts were consulted about monkfish discard mortality from mobile gear. The experts advised that monkfish discard mortality was at least 70% for mobile gears and could be higher depending on the type of gear, length of tow, and season (NEFMC, 1998). Future research specific to estimating discard mortality of monkfish caught in trawl gear would be useful to improve understanding of overall monkfish discard estimates as well inform future stock assessments.

6. Factors Influencing Monkfish Discarding

Understanding the various factors that influence monkfish discarding could inform options for how discards are applied to calculate TALs. Discard rates vary by gear type and management area as a reflection of specific behaviors and incentives in the monkfish, groundfish and scallop fisheries. Discards have also varied over time in response to changes in the monkfish resource, as well as market demand and seafood prices. A qualitative ranking of factors that influence monkfish discarding behavior and discard magnitude may be useful when considering options for alternative discard estimation approaches. Several members of the fishing industry provided information related to incentives, trends, markets, and forecasts of future behavior for the monkfish, scallop and groundfish fisheries in both the northern and southern areas.

6.1 Monkfish Biology

The analyses of realized discards over time suggested that substantial changes in the monkfish resource are a major driver of increased or decreased discards. Increased discards were observed in conjunction with strong recruitment events in the mid-1990s and early 2000s in the northern area and southern area, respectively. The most significant increase in discards for both management areas was observed after the large 2015 recruitment event. There is currently no known stock-recruit relationship for monkfish and drivers of strong recruitment are not understood, which prohibits the ability to predict recruitment events. However, several regional surveys can detect strong recruitment when it occurs, so consideration of a recruitment index to inform future discard estimates would likely improve the performance of the FMP. As described in the 2019 Monkfish Operational Assessment, monkfish grow at a rapid rate at early ages and likely enter the fishery by age-3. Consideration of this growth information could also inform the discard estimate used to calculate TALs.

6.2 Scallop Fishery Effort and Incentives

The Atlantic Sea Scallop FMP utilizes rotational area management on an annual basis to direct fishing effort and removals among a suite of scallop access areas. In fishing years 2015-2018, the scallop fishery removed a total of ~60 million pounds of scallops from the Mid-Atlantic Access Area (NEFMC 2015; 2016; 2017b; 2018; Figure 14). Several scallop recruitment events in the Mid-Atlantic region during 2009-2014 resulted in more concentrated scallop fishing effort in the Mid-Atlantic Access Area between 2016-2018. Additionally, in 2016 all rotational areas on Georges Bank and the open area on the southern flank of Georges Bank were closed to scallop fishing, which forced more effort into the Mid-Atlantic region under increased Days-At-Sea (NEFMC, 2016). Anomalous increases in dredge effort in the southern area occurred in 2016-2018 due to the presence of nematodes in scallop meats. The parasites reduced scallop meat quality and lead to increased effort due to searching for higher quality product (NOAA, 2020). The combination of these events during 2016-2018 resulted in increased interaction of the scallop fishery with the large 2015 monkfish year-class resulting in high levels of discards (Figure 15). Scallop specifications for fishing years 2019 and 2020 reduced the allocation to the Mid-Atlantic Access Area, and the abundance of monkfish in the southern area has decreased since 2016-2017. These factors may result in lower monkfish discards from the scallop fishery than those observed in 2016-2018.

The price differential between scallops and monkfish created a disincentive for the scallop fishery to retain and process monkfish. Average annual price per pound for all combined monkfish market categories peaked in 2011 at approximately $1.40/pound. Since 2011, prices have trended downwards and reached a 15-year low in 2018 at an average of $0.67/pound (Figure 16). The lower prices in recent years may have created disincentives for the scallop fishery to land marketable-size monkfish, resulting in increased discarding. In contrast, scallop prices have tripled since 2003 reaching peak values of approximately $12/pound in 2014-2016 (Figure 16). Prices for scallops from the Mid-Atlantic Access Area have fluctuated in recent years depending on market size category, with larger scallops getting a premium price. As scallop biomass in the Mid-Atlantic Access Area has been fished down, smaller scallops (20-30 meat count) have become more common in the landings. The changes in prices for monkfish and scallops may impact fishery behavior and incentives and affect assumptions about monkfish discards in future years.

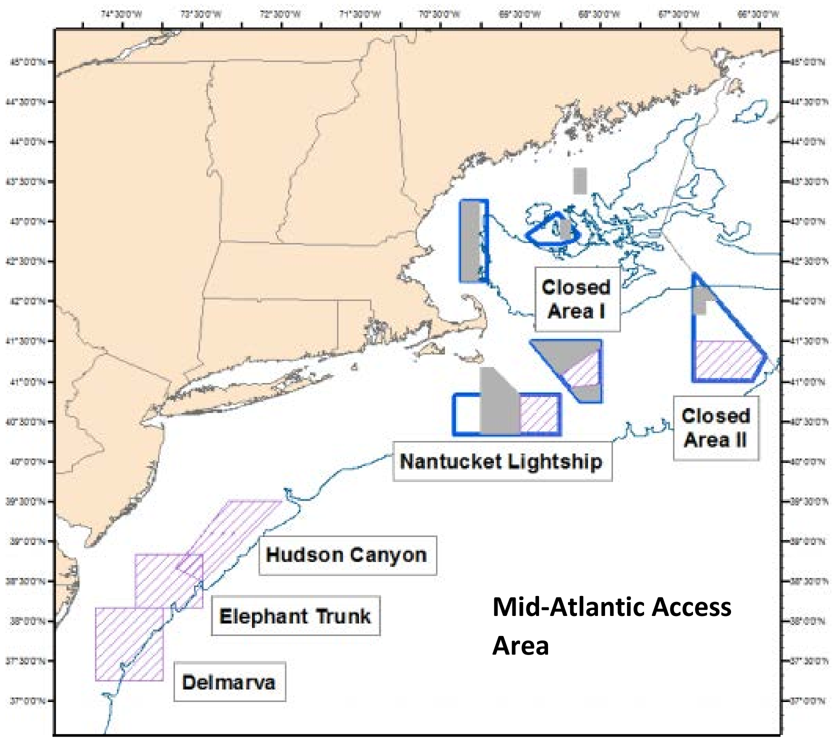


Figure 14. Scallop access areas showing the Mid-Atlantic Access Area as the combined areas of the Hudson Canyon, Elephant Trunk and Delmarva. Figure adapted from NEFMC, 2015.

Another possible influence of monkfish discards in the scallop fishery was the proposal for catch share management of the monkfish fishery developed between 2011 and 2017. This proposed management change may have incentivized increased landings from individuals in both the scallop and trawl fisheries to establish a catch history to meet potential qualification criteria. The proposal to develop catch shares in the monkfish fishery was ultimately not supported by the NEFMC and MAFMC (NEFMC, 2017c), which in turn may have disincentivized landing monkfish in 2017 and 2018. Although the importance of this influence on monkfish discard rates is unknown, it is unlikely that a renewed proposal for monkfish catch share management would arise again in the next few years. If a future proposal for catch shares is prioritized, it may be useful to consider incentives related to monkfish discards.

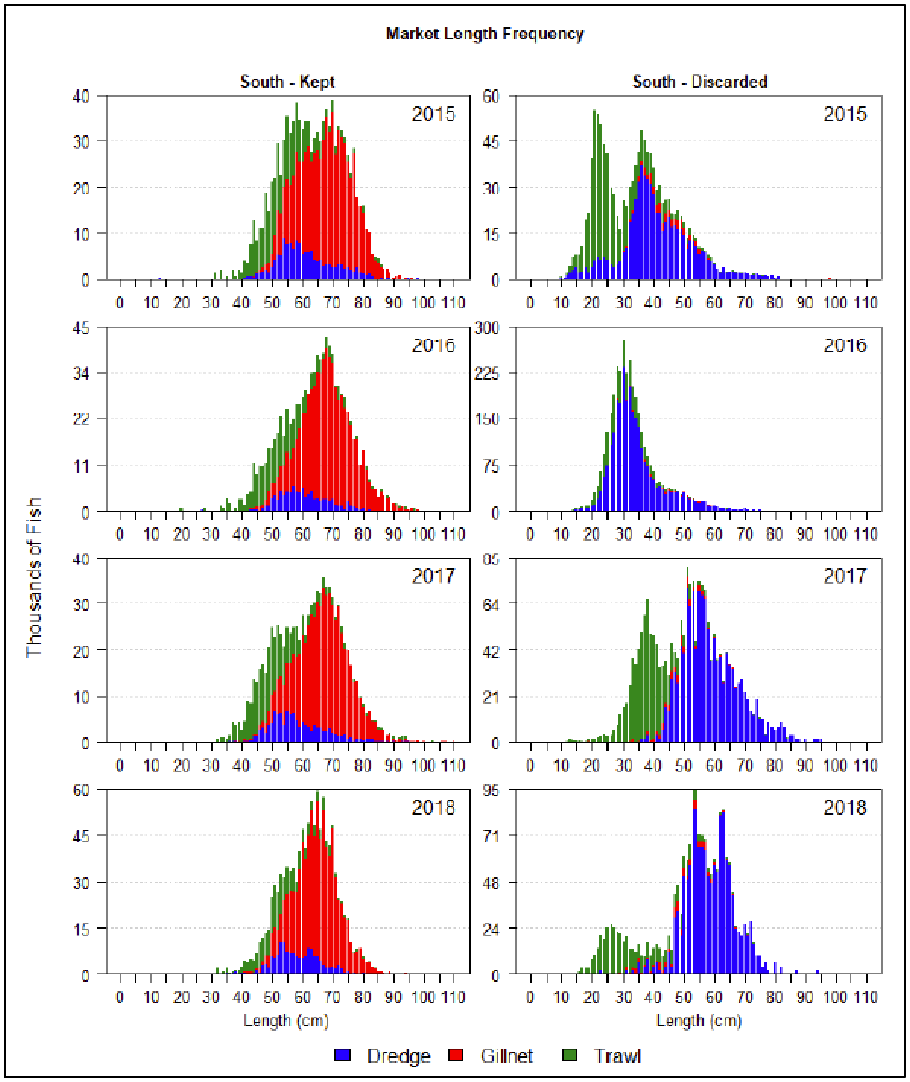


Figure 15. Estimated length of kept and discarded monkfish by gear in the southern area. Figure adapted from NEFSC, 2020.

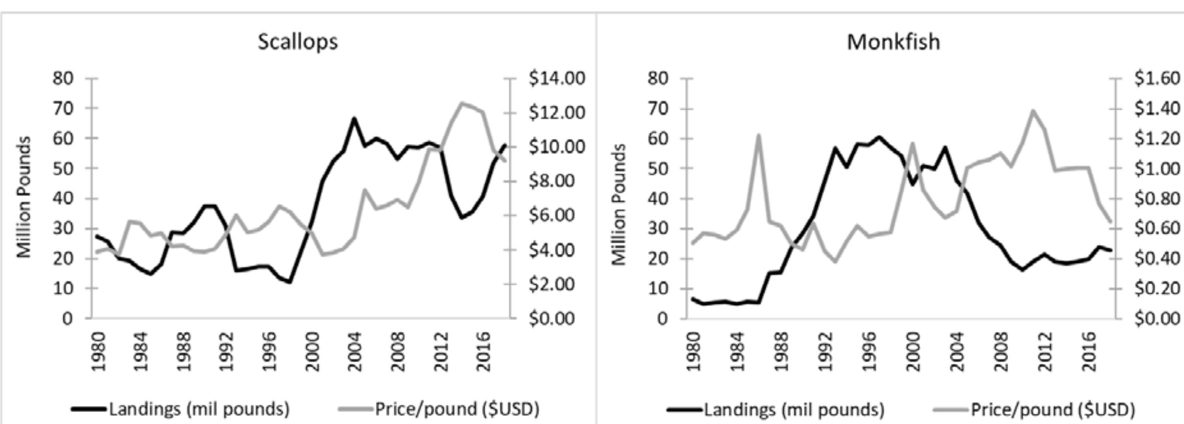


Figure 16. Scallop and monkfish landings (million pounds) and average price per pound ($USD) from 1980-2018. (Note difference in scale of secondary y-axis.).

6.3 Groundfish Fishery Effort and Incentives

Most of the monkfish catch in the northern area comes from the trawl fishery with overlapping participation in the groundfish fishery. The northern area TAL has been nearly fully harvested or exceeded in recent years (Table 1) with over 80% of catch landed. Discards in the northern area have historically been ~15% of total catch (Figure 1A) despite the declining trend in monkfish price. The Northeast Multispecies FMP is based on catch share management that includes “sectors” as voluntary cooperatives that utilize annual allocation and leasing of stocks (NEFMC, 2009). Vessels with monkfish and multispecies permits can catch monkfish under the Days-At-Sea program either incidentally or through concentrated effort. Due to reduced quotas and increased lease prices of several groundfish stocks, concentrated effort on monkfish has increased over the last decade and monkfish landings have become a main source of income for a faction of vessels operating in the northern area. Unlike the scallop fishery, the groundfish fishery values monkfish and has strong incentives to land rather than discard catch. Strong recruitment in 2015 and 2016 in the northern area was most likely a major influence in increased discards in 2018, but there is no indication that high levels of discards will persist in the future due to strong incentives to land monkfish.

6.4 Market Drivers

Market conditions and global supply chains may have influenced monkfish discarding in recent years. The monkfish market has experienced changes with decreasing prices for all market categories and market depression from substitute products, predominantly from Asia and Africa. Monkfish harvested in US waters are sold both domestically in the fresh market and internationally to Asian and European markets (Figure 17). Whole (head-on) monkfish have traditionally been exported to South Korea as a delicacy product at a premium price. However, a different monkfish species, the yellow goosefish (*Lophius litulon)* distributed throughout the Yellow and China Seas, has begun to dominate the South Korean market. The yellow monkfish is considered a lower quality product than *Lophius americanus* and is sold at lower prices, which has impacted overall price for monkfish resulting in price reductions for US exported fish. Europe has also provided a traditional market for monkfish, specifically France and regions of Spain, and Italy. This market includes imports of US fish, as well as eastern Atlantic and Mediterranean monkfish species (anglerfish, *Lophius piscatorius* and blackbellied anglerfish, *Lophius budegassa*). In recent years, the European market has shifted to imports from Africa, specifically Namibia where devil anglerfish (*Lophius vomerinus)* and shortspine African anglerfish (*Lophius vaillanti)* are harvested, processed and exported. These substitute products combined with a lower general demand for monkfish have impacted prices for US caught fish.

Figure 17. Monkfish is traditionally stewed whole in South Korea (left), whereas tails are roasted or braised as fillets and steaks in Europe (center and right).

The market for domestically sold monkfish tails has also changed in recent years and the price differential between "large" and "small" tails has decreased. Oversupply of large tails has been partly responsible for the price decline, and reduced consumer demand in general has impacted the market. Monkfish has not traditionally been a "value-added" product and has become less competitive in retail markets as value-added products have become dominant. Fresh and frozen tails and fillets are sold in restaurants and retail stores, but consumer demand has declined over time. Despite the changing market conditions, monkfish landings have not declined and there is no indication that that near-term discards would increase from the directed fisheries.

7. Conclusions and Recommendations

The combined analyses of realized discards and explorations of alternative approaches to estimate discards to calculate TALs suggest that the current 3-year average discard percent of catch approach performed relatively well when catch and discards were stable but did not perform well after the strong 2015 recruitment event. Similarly, recent averages based on shorter or longer reference periods (2-year and 5-year) were not good indicators of future discards. A longer term (2008-2015) mean or median discard percent of catch performed well compared to realized discards for both management areas and could be applied to set TALs in future monkfish actions in most years (i.e., under average recruitment conditions).

Recruitment indices and growth rate estimates are informative for predicting discard levels and behaviors, and surveys and catch data can detect strong recruitment events. Annual review of survey, catch, and growth data could be conducted to evaluate whether discard assumptions and monkfish specifications should be temporarily revised to more accurately reflect discarding behavior in the near future.

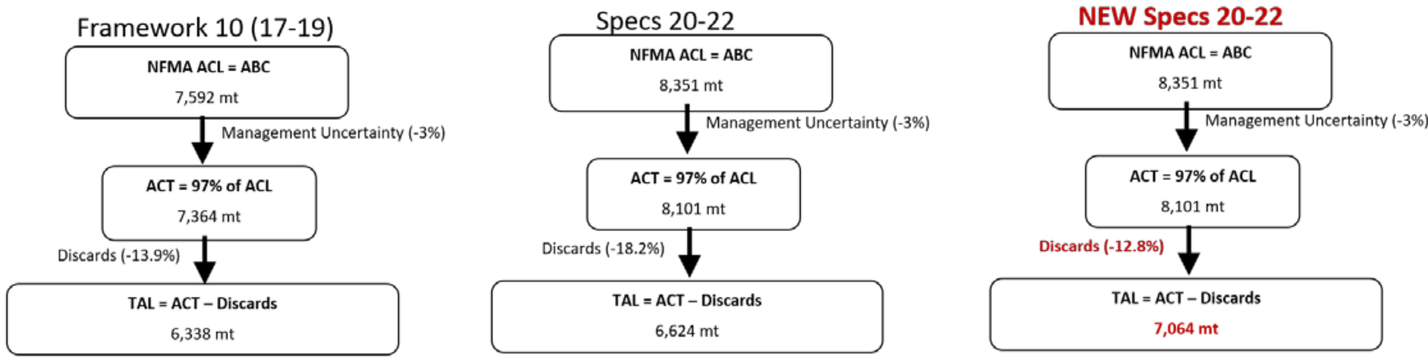
Applying the long-term (2008-2015) mean or median discard percent of catch to set TALs, combined with temporary increases in the discard assumptions following strong recruitment events, may reduce the risk of exceeding TALs and improve overall monkfish management. An example of such a combined approach is described in Figures 18 and 19. Consideration of applying this type of combined approach for estimating discards to calculate TALs requires examination of Fishing Year 2019 data, as well as analyses to define "strong" recruitment and identify the discard level associated with strong recruitment. The new information about rapid growth rate at early ages suggests that the 2015 year-class of monkfish would have entered the fishery by Fishing Year 2019 and discards would be reduced from the 2016-2018 levels. Data from FY2019 should be considered prior to changing the method for calculating TALs to confirm whether discards decreased to levels consistent with the long-term mean/median values.

Criteria for defining "strong" recruitment and associated discard predictions need to be developed and reviewed by the Monkfish PDT. This report presented an example criterion of multiple survey abundance values greater than the 75^{th} percentile of the survey time series as a possible definition of strong recruitment. Further analyses to develop criteria for defining strong recruitment may consider different survey abundance percentile values, specific survey recruitment indices, variability in survey estimates, and examination of fishery-dependent data. Determining the discard level to apply to strong recruitment periods is necessary prior to adopting a new approach for calculating TALs. In response to the 2015 recruitment event, discards increased in the northern and southern areas by ~50%. Predicting discard levels associated with strong recruitment could include a qualitative approach that compares future recruitment strength to the 2015 year-class and associated discard levels observed in 2016-2018. Developing a predictive function that uses the recruitment index as a variable to indicate what discard estimates should be used when strong recruitment occurs would also be a useful next step to identify an accurate discard level for use in a combined approach for applying discards to calculate TALs.

Recent studies on monkfish discard survival rates suggest that discard mortality varies by gear type and may be substantially lower than the currently assumed 100% rate for dredge gear. Additional peer-review is required prior to changing the discard mortality assumption, but future analyses could consider applying a discard mortality rate by gear type to estimate TALs.

Several factors influence monkfish discard behavior in target and non-target fisheries, including spatially specific fishing effort, fishery-specific incentives, and monkfish market and price dynamics. These factors lead to variability in discard levels between 2008-2015, but the substantial increase in discards in 2016-2018 was driven by the large 2015 monkfish year-class. Information provided by members of the fishing industry suggests that trends observed between 2008 and 2015 will likely persist in the near-term. Incentives for landing monkfish by the directed and incidental gillnet and trawl fisheries remain, while high levels of monkfish discarding in the scallop fishery are likely to continue. Market dynamics for monkfish are difficult to predict, but there is no indication that price or demand will substantially change in the near-term.

<u>Example specifications under “average recruitment” scenario</u>



<u>Example specifications under “strong recruitment” scenario</u>

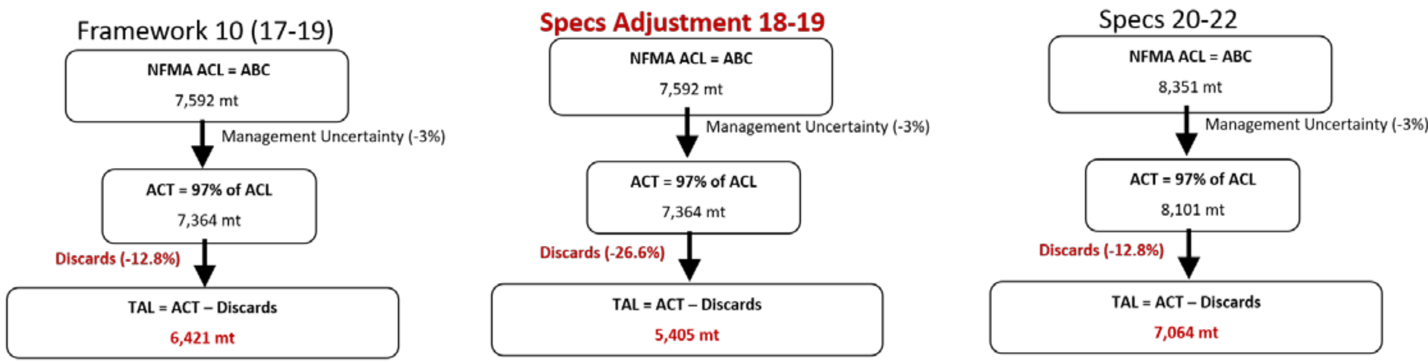
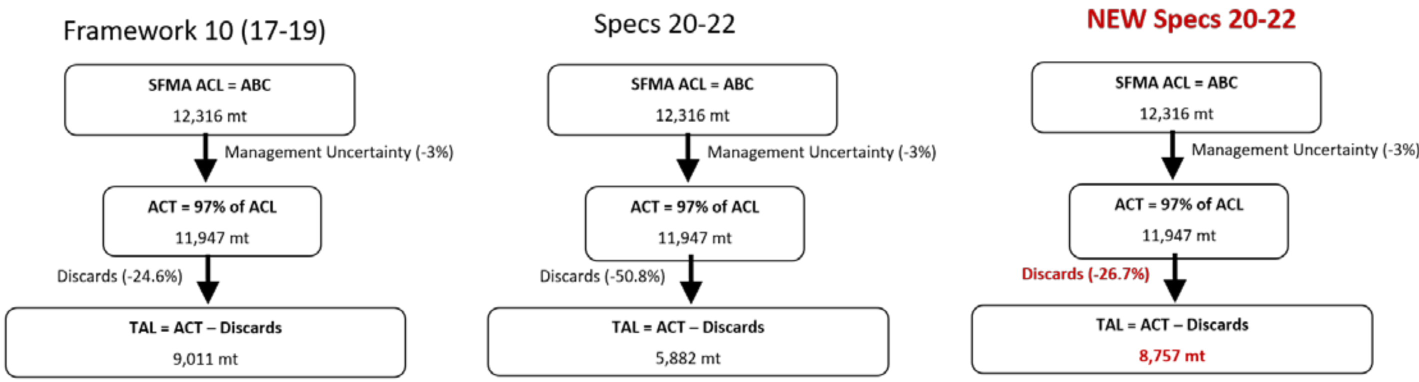


Figure 18. Example of combined approach to estimate discards to calculate TALs for the northern area. The top panel shows an example of how discards would be applied to set TALs during a period of average recruitment. The left flowchart shows the specifications that were implemented for fishing years 2017-2019 under Monkfish Framework 10 using the 3-year average discard percent of catch approach that resulted in subtracting 13.9% from the ACT to set the TAL. The center flowchart shows the 2020-2022 Monkfish Specifications where the discard estimate was based on data from 2016-2018 resulting in an increase to 18.2% that was subtracted from the ACT. The right flowchart presents an alternative that would apply the long-term (2008-2015) mean discard percent of catch (12.8%) to set the TAL. The bottom panel shows an example of how discards would be applied to set TALs following a period of strong recruitment. The left flowchart shows the 2017-2019 TAL value with the long-term mean discard percent catch applied. The center flowchart shows how specifications could be adjusted based on review of survey and catch information that indicated strong recruitment in 2015-2016. The example applies the realized discard percent catch that was observed during 2016-2018 (26.6%) to adjust the TAL for 2018-2019 to more accurately reflect discard levels that follow strong recruitment. The right flowchart shows how specifications would return to the long-term mean after a large year-class enters the fishery.

Example specifications under "average recruitment" scenario



Example specifications under "strong recruitment" scenario

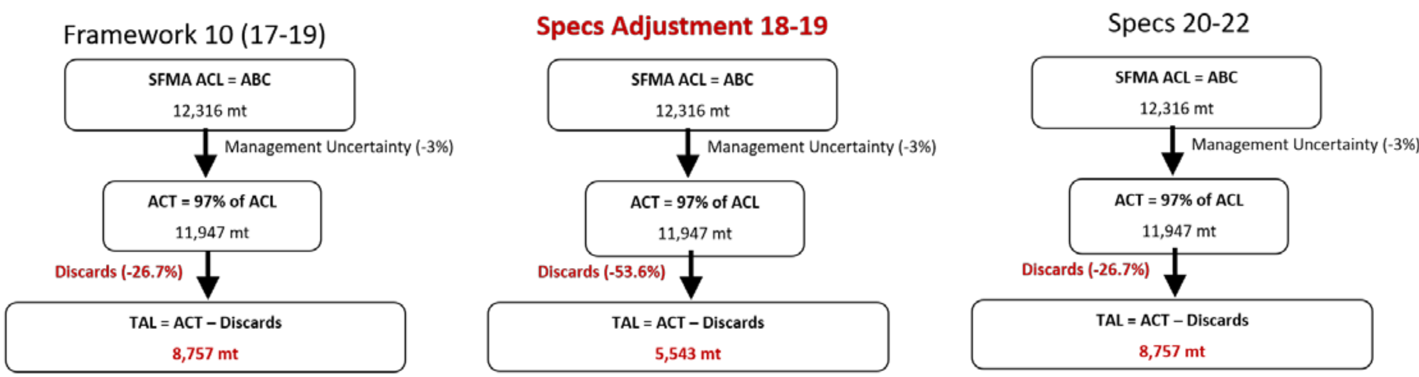


Figure 19. Example of combined approach to estimate discards to calculate TALs for the southern area. The top panel shows an example of how discards would be applied to set TALs during a period of average recruitment. The left flowchart shows the specifications that were implemented for fishing years 2017-2019 under Monkfish Framework 10 using the 3-year average discard percent of catch approach that resulted in subtracting 24.6% from the ACT to set the TAL. The center flowchart shows the 2020-2022 Monkfish Specifications where the discard estimate was based on data from 2016-2018 resulting in an increase to 50.8% that was subtracted from the ACT. The right flowchart presents an alternative that would apply the long-term (2008-2015) mean discard percent of catch (26.7%) to set the TAL. The bottom panel shows an example of how discards would be applied to set TALs following a period of strong recruitment. The left flowchart shows the 2017-2019 TAL value with the long-term mean discard percent catch applied. The center flowchart shows how specifications could be adjusted based on review of survey and catch information that indicated strong recruitment in 2015-2016. The example applies the realized discard percent catch that was observed during 2016-2018 (53.6%) to adjust the TAL for 2018-2019 to more accurately reflect discard levels that follow strong recruitment. The right flowchart shows how specifications would return to the long-term mean after a large year-class enters the fishery.

8. Acknowledgements

Fishery Apps acknowledges the assistance of NEFMC Deputy Director, Chris Kellogg, who served as the Council's principal liaison and technical monitor for the project. We thank the Monkfish PDT for reviewing the methods and analyses and providing feedback on approaches for alternative estimation methods. We are especially grateful for the information about monkfish fisheries, markets, and incentives provided by Terry Alexander (NEFMC; F/V Jocka), Czssie Canastra (BASE New Bedford), Peter Hughes (MAFMC; Atlantic Capes Fisheries), Eric Reid (NEFMC; Seafreeze Shoreside, Inc.), and Kevin Wark (F/V Dana Christine).

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