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CPUE Expansion Estimation for Commercial Discards of Gulf of Mexico Gag

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Abstract

The general approach for estimating discards for the commercial reef fish fleet in the Gulf of Mexico utilizes catch-per-unit-effort (CPUE) from the reef fish observer program and total fishing effort from the commercial coastal logbook program to estimate total catch. For discard estimation, CPUE is computed for total discards, including fish released alive, released dead, released in unknown condition, and used for bait. The principal focus of this study was to apply the discard estimation methods developed for previous Gulf of Mexico species, including Red Grouper, Gray Triggerfish, Vermilion Snapper, and Scamp, to Gulf of Mexico Gag. Discard estimation was conducted separately for two gears, vertical line and bottom longline. A verification step compared annual total landed catch from logbook data with the estimated observer annual total landed catch. Once verified, Gag annual total discards in weight and number were estimated for the observer data period 2007-2019, and then hindcasted for the period 1993-2006.

Management changes relevant to discard estimation were: (1) a change in minimum size from 20" TL to 24" TL in 2000; (2) the implementation in 2010 of Individual Fishing Quotas (IFQ) for GOM Gag; (3) a change in minimum size from 24" TL to 22" TL in 2012; and (4) a change in minimum size from 22" TL to 24" TL in 2019. For vertical line gear, changes in the estimated number of discards mostly corresponded with changes in minimum size regulations, with peak levels of 80,000 to 100,000 fish per year during 2000-2005 (pre-IFQ 24" TL) and lowest levels of 7,000 to 10,000 fish during 2012-2018 (IFQ 22" TL). Discards in weight also changed according to management regime, ranging from about 6% of the total catch (kept + discards) during 1993-1999 (pre-IFQ 20" TL) to an average of 30% during the IFQ 24" TL regime (2010-11, 2019).

For bottom longline gear, increases in the estimated number of discards corresponded with implementation of IFQ, with annual discards below 1,500 fish for the pre-IFQ period (1993-2009) compared to an average of 3,000 to 5,000 fish per year during the IFQ period (2010-2019). Similarly, discards in weight also increased with implementation of IFQ, accounting for about 1% of the total catch (kept + discards) before IFQ implementation compared to an average of 25% after implementation.

Introduction

The general approach for estimating discards for the commercial reef fish fleet in the Gulf of Mexico utilizes catch-per-unit-effort (CPUE) from the reef fish observer program and total fishing effort from the commercial coastal logbook program to estimate total catch,

$$totalCatch = CPUE * totalEffort.$$

For discard estimation, CPUE is computed for total discards, including fish released alive, released dead, released in unknown condition, and used for bait. The primary metric for the reef fish observer program is CPUE by species and gear. The principal focus of this study was to apply the discard estimation methods developed for previous Gulf of Mexico species (Smith et al. 2018, 2019a, 2019b, 2020) to Gulf of Mexico Gag. This application utilized revised correction factors for Gag/Black Grouper mis-reporting in the commercial fishery prior to implementation of Individual Fishing Quotas (IFQs) in 2010 (Smith et al. 2021).

Methods

Data Sources

Catch per unit effort was determined from the reef fish observer program in which scientific observers on commercial fishing vessels recorded detailed information on catch and effort for a subset of trips (Scott-Denton et al. 2011). The program targeted two principal gears for the Gulf of Mexico (GOM) reef fishery, bottom longline and vertical lines (e.g., handlines, electric and hydraulic reels aka bandit reels). Catch by species was recorded according to disposition category: kept (landed), released alive, released dead, released undetermined, and used for bait. Length and weight were recorded for a subsample of individual fish. The reef fish observer program began in July 2006; for GOM Gag discard estimation, complete calendars years 2007-2019 were used. Time periods for the methodology can be defined in terms of the observer program, with the pre-observer time period representing years prior to 2007, and the observer time period representing years 2007 and beyond. Total effort was determined from the commercial coastal logbook program in which fishers reported basic information on effort and catch by species for every trip. The logbook program began in 1990 for a subset of vessels in the GOM, and expanded to all vessels in 1993; for GOM Gag discard estimation, complete calendar years 1993-2019 were considered.

Relevant Management History of GOM Gag

Management changes relevant to discard estimation were: (1) a change in minimum size from 20” TL to 24” TL in 2000; (2) the implementation in 2010 of Individual Fishing Quotas for GOM Gag; (3) a change in minimum size from 24” TL to 22” TL in 2012; and (4) a change in minimum size from 22” TL to 24” TL in 2019. Management regimes were defined based on the combination of changes in minimum size and implementation of IFQ.

Gear

In the reef fish observer data, Gag were observed on both vertical line and bottom longline trips. Discard estimation was conducted separately for the two gears.

Trip-Level Catch for Observer Data

Observers collected catch data at a sub-trip level (e.g., a specific set and line for vertical line gear), but it was not feasible to sample every set or line for every trip. Gear-specific procedures were applied to estimate the trip-level landed catch from the observer data (Smith et al. 2018).

Trip-Level Effort for Observer and Logbook Data

For observer data, trip-level effort for vertical lines was computed as the cumulative daily fishing time (hours) from first hook in to last hook out; this time metric included the active fishing time as well as transit time between fishing locations during a given trip day. This effort variable generally matched trip fishing time reported in logbook data (Smith et al. 2018). For bottom longlines, trip-level effort was the number of sets fished; this effort variable matched the number of sets reported in logbook data (Smith et al. 2018).

Catch Expansion Procedures and Verification

Observer CPUE was calculated using trip-level nominal effort and catch for a given time period. Statistical estimation of total catch $\hat{C}$ and associated variance followed procedures for a (Horvitz-Thompson) survey design ratio estimator (Jones et al. 1995; Lohr 2010):

$$\hat{C} = \overline{CPUE} \times \hat{X} \quad ,$$

where $\overline{CPUE}$ is observer mean CPUE and $\hat{X}$ is total logbook nominal effort. Species- and gear-specific logbook total effort $\hat{X}$ was calculated in two steps. First, logbook trip effort by gear was summed over trips reporting landings of the target species. Second, to obtain $\hat{X}$, logbook trip effort was adjusted by the proportion of observer trip effort that reported only discards of the target species. Logbook total trips *N* were calculated in a similar manner.

Mean CPUE was estimated by

$$\overline{CPUE} = \frac{\bar{y}}{\bar{x}} \quad ,$$

where $\bar{y}$ is average catch in numbers or weight per trip *i*,

$$\bar{y} = \frac{1}{n}\sum_i y_i \quad ,$$

$\bar{x}$ is average effort per trip *i*,

$$\bar{x} = \frac{1}{n}\sum_i x_i \quad ,$$

and *n* is the number of observer trips. Variance of total catch was estimated using

$$var\left[\hat{C}\right] = \left(1 - \frac{n}{N}\right)\left(\frac{\hat{X}}{\bar{x}}\right)^2 \frac{s^2(y|x)}{n} \quad ,$$

where *N* is the total number of logbook trips and sample variance is

$$s^2(y|x) = \frac{\sum_i (y_i - \overline{CPUE}x_i)^2}{n-1} \quad .$$

Standard error of total catch was calculated as

$$SE[\hat{C}] = \sqrt{var[\hat{C}]} \quad .$$

The CV of total catch $\hat{C}$ was estimated by

$$CV[\hat{C}] = \frac{SE[\hat{C}]}{\hat{C}} \quad .$$

A verification step compared annual total landed catch from logbook data with the estimated observer annual total catch $\hat{C}$. Once verified, the catch expansion procedure was used to estimate annual total discards in weight and number.

Spatial Domain

Per recommendation of the stock assessment analysts, discard estimates were conducted for the GOM, defined as statistical zones 1-21 (**Fig. 1**).

Hindcast Procedures

For years prior to 2007, before observer data were collected, hindcast discard estimation procedures for "Trending CPUE" described in Smith et al. (2019a) were applied to Gag. For this method, the ratio of observer CPUE in weight to logbook CPUE was computed for the observer time period, and then multiplied by the annual logbook CPUE for the hindcast time period to produce an estimated annual observer CPUE. Then, the annual observer CPUE was multiplied by annual logbook effort for the pre-observer time period to estimate total catch $\hat{C}$ in weight. An additional step computed the ratio of the observer CPUE in number to observer CPUE in weight. This ratio was then used to compute the observer estimated discards in number from the discards in weight for the hindcast period. Standard errors for the hindcast period were estimated using the respective CVs of total estimated catch $\hat{C}$ kept and discarded as described in Smith et al. (2019a). To guide selection of appropriate time periods for hindcasting, time-series of annual length compositions for kept and discarded fish from observer sampling were evaluated with respect to pre-IFQ (2007-2009) and IFQ (2010-2019) management regimes, in conjunction with minimum size time periods (20" TL, 1993-1999; 24" TL, 2000-2011 and 2019; 22"TL, 2012-2018). Verification compared total landed catch from logbook data with the estimated total catch $\hat{C}$ and standard error from observer data for the hindcast time period.

Accounting for Changing Minimum Size Regulations

The pre-IFQ observer time period (2007-2009) was under the management regime for 24" TL minimum size for Gag. The pre-observer time period included the management regime for 20" TL minimum size (1993-1999). Inspection of observer length frequency data showed that discards of Gag were mostly fish smaller than the minimum legal size during the pre-IFQ time period (e.g., **Fig. 2)**. Methods for hindcasting Gag catch and discards were modified to approximate the historical 20" TL management regime. Key steps were:
(i) The disposition for individual fish recorded by observers was re-assigned according to the associated minimum legal size, with fish smaller than the minimum size assigned as discards, and fish at or above the minimum size assigned as kept. Fish recorded without lengths were

assigned their original disposition. Standard procedures were then carried out to create an observer trip-level catch-effort dataset for the 20" TL management regime.
(ii) Standard computational formulae were used to compute observer mean CPUE and variance, and the proportions of observer trips and effort with kept fish, for each management regime.
(iii) The ratio of observer catch for the historical management regime to the current regime, $C_{20"}/C_{24"}$, was used to adjust the annual reported logbook catch during the observer time period for the historical regime.
(iv) Computations of discards for the hindcasting time period were carried out following the procedures for the Trending CPUE method.

Accounting for Gag/Black Grouper Mis-Reporting

Discard procedures were modified to account for mis-reporting problems concerning Gag and Black Grouper in commercial logbook data (Smith et al. 2021). The issue stems from some commercial fishers and dealers reporting catches of Gag as Black Grouper for marketing purposes, resulting in overestimates of landings for Black Grouper and underestimates of landings for Gag. The analysis by Smith et al. (2021) showed that mis-reporting corrections were necessary for the pre-IFQ time period (1993-2009) but were not needed after implementation of IFQ in 2010. For the pre-IFQ time period, discard estimation procedures used logbook effort $\hat{X}$ and logbook total trips N for Gag and Black Grouper combined since it was not possible to distinguish Gag-only trips due to mis-reporting. Logbook annual total catch $\hat{C}$ for Gag was computed by summing the combined total catches of Gag and Black Grouper, and then applying the proportion Gag correction factors described in Smith et al. (2021). Correspondingly, observer CPUE for the pre-IFQ time period used catch (y) of Gag, but used effort (x) for Gag and Black Grouper combined trips to match with logbook effort for expansion computations.

Results and Discussion

Vertical Line

The observer database included 1,317 vertical line trips with corresponding trip and set information. Observer sampling effort is summarized in **Table 1**, distinguishing all trips from the subset of trips that captured Gag or Black Grouper during the pre-IFQ time period (**Table 1A**) and the subset of trips that captured Gag during the IFQ time period (**Table 1B**).

For the pre-IFQ period 2007-2009, the disposition (kept or discarded) of GOM Gag corresponded with the minimum size limit of 24" TL (**Fig. 2**). Discards were mostly fish near or below the minimum size limit, and kept fish were mostly above the minimum size limit. For the IFQ period, 2010-2019, discards included fish below and above the minimum size limit. In addition, legal-sized fish were discarded on some of the same trips that kept legal-sized fish. To account for potential changes in the discard CPUE indicated by differences in the discard length frequencies, discard estimation was conducted separately for three management regimes defined by changes in quota and minimum size regulations: (i) pre-IFQ 24" TL (2007-2009), (ii) IFQ 24" TL (2010-2011, 2019), and (iii) IFQ 22" TL (2012-2018).

Observer data from the pre-IFQ period (2007-2009) were used for hindcasting discards for the pre-observer years 2000-2006, which had the same minimum size limit (24" TL). Pre-IFQ observer data were also used for hindcasting discards for 1993-1999 with minimum size limit 20" TL after accounting for differences in minimum size (20"TL vs. 24"TL) as described above.

Observer and logbook frequency distributions of trip-level catch, effort, and CPUE were similar for each management regime, suggesting that observer sampling of Gag trips was representative of the commercial fleet. The proportions of observer trips and effort encountering Gag that had kept fish for the IFQ time period are given in **Table 2A** by management regime, and the proportions of observer trips and effort encountering Gag and Black Grouper combined for the pre-IFQ time period are given in **Table 2B**. These proportions were used to adjust annual logbook total Gag/Black Grouper trips and effort (1993-2009) and Gag trips and effort (2010-2019) to account for logbook trips that only had discarded fish (**Table 3**). Estimates of observer mean CPUE by management regime are given in **Table 4.** These CPUEs were the basis for expansion estimates of Gag catch and discards. Ratios of observer catch for a historical management regime to the current regime (**Table 2B**) were used to adjust logbook catches and CPUE estimates (**Table 4**) for hindcasting for historical management regimes.

CPUE expansion estimates of annual total landed catch of GOM Gag compared favorably with reported logbook landings for 1993-2019 (**Fig. 3**). CPUE expansion estimates for annual discards in numbers and weight of GOM Gag are provided in **Table 5**. Changes in the estimated number of discards mostly corresponded with changes in minimum size regulations (**Fig. 4A**), with peak levels of 80,000 to 100,000 fish during 2000-2005 (pre-IFQ 24" TL) and lowest levels of 7,000 to 10,000 fish during 2012-2018 (IFQ 22" TL). Discards in weight also changed according to management regime (**Fig. 4B**), accounting for about 6% of the total catch (kept + discards) during 1993-1999 (pre-IFQ 20" TL), an average of 20% during 2000-2009 (pre-IFQ 24" TL), an average of 30% during the IFQ 24" TL regime (2010-11, 2019), and an average of 15% during the IFQ 22" TL regime (2012-2018).

Bottom Longline

The observer database included 415 bottom longline line trips with corresponding trip and set information. Observer sampling effort is summarized in **Table 6**, distinguishing all trips from the subset of trips that captured Gag or Black Grouper during the pre-IFQ time period (**Table 6A**) and the subset of trips that captured Gag during the IFQ time period (**Table 6B**).

For the pre-IFQ period 2007-2009, the disposition (kept or discarded) of GOM Gag corresponded with the minimum size limit of 24" TL (**Fig. 5**). Discards were mostly fish near or below the minimum size limit, and kept fish were mostly above the minimum size limit. For the IFQ period, 2010-2019, discards included fish below and above the minimum size limit. In addition, legal-sized fish were discarded on some of the same trips that kept legal-sized fish. To account for potential changes in the discard CPUE indicated by differences in the discard length frequencies, discard estimation was conducted separately for three management regimes defined by changes in quota and minimum size regulations: (i) pre-IFQ 24" TL (2007-2009), (ii) IFQ 24" TL (2010-2011, 2019), and (iii) IFQ 22" TL (2012-2018).

Observer data from the pre-IFQ period (2007-2009) were used for hindcasting discards for the pre-observer years 2000-2006, which had the same minimum size limit (24" TL). Pre-IFQ observer data were also used for hindcasting discards for 1993-1999 with minimum size limit 20" TL after accounting for differences in minimum size (20"TL vs. 24"TL) as described above.

Observer and logbook frequency distributions of trip-level catch, effort, and CPUE were similar for the IFQ 24" TL management regime (2010-2011, 2019), suggesting that observer sampling of Gag trips was representative of the commercial fleet. This was not the case for Gag and Black Grouper combined trips during the pre-IFQ 24" TL (2007-2009) management regime or for Gag trips during the IFQ 22" TL (2012-2018) regime. Further analysis showed that

observers sampled a higher proportion of low catch trips relative to the commercial fleet during the pre-IFQ 24" TL regime, and a higher proportion of high catch trips relative to the commercial fleet during the IFQ 22" TL regime (**Table 7**). To account for this discrepancy, observer and logbook trips were grouped into strata according to low (L) and high (H) catches by management regime for subsequent analysis and estimation.

The proportions of observer trips and effort encountering Gag that had kept fish for the IFQ time period are given in **Table 8A** by management regime and catch level strata, and the corresponding proportions of observer trips and effort encountering Gag and Black Grouper combined for the pre-IFQ time period are given in **Table 8B**. These proportions were used to adjust annual logbook total Gag/Black Grouper trips and effort (1993-2009) and Gag trips and effort (2010-2019) to account for logbook trips that only had discarded fish (**Table 9**). Estimates of observer mean CPUE by management regime are given in **Table 10.** These CPUEs were the basis for expansion estimates of Gag catch and discards. Ratios of observer catch for a historical management regime to the current regime (**Table 8B**) were used to adjust logbook catches and CPUE estimates (**Table 10**) for hindcasting for historical management regimes.

CPUE expansion estimates of annual total landed catch of GOM Gag compared favorably with reported logbook landings for 1993-2019 (**Fig. 6**). CPUE expansion estimates for annual discards in numbers and weight of GOM Gag are provided in **Table 11**. Increases in the estimated number of discards corresponded with implementation of IFQ (**Fig. 7A**), averaging about 5,000 fish during the IFQ 24" TL management regime and 3,000 fish during the IFQ 22"TL regime, compared to annual discards below 1,500 fish for the pre-IFQ period. Similarly, discards in weight also changed with implementation of IFQ (**Fig. 7B**), accounting for about 1% of the total catch (kept + discards) before IFQ implementation (1993-2009) compared to an average of 35% during the IFQ 24" TL regime (2010-11, 2019) and an average of 20-25% during the IFQ 22" TL regime (2012-2018).

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Table 1. (A) Number of GOM total and Gag/Black Grouper combined observer vertical line trips by year for the pre-IFQ time period (2007-2009). **(B)** Number of GOM total and Gag observer vertical line trips by year for the IFQ time period (2010-2019).

(A) Pre-IFQ Time Period

Year	Total Trips	Gag/Black Grouper Combined Trips
2007	97	59
2008	53	32
2009	45	27

(B) IFQ Time Period

Year	Total Trips	Gag Trips
2010	54	29
2011	103	66
2012	253	162
2013	125	63
2014	108	48
2015	201	92
2016	142	70
2017	67	22
2018	39	20
2019	30	10

Table 2. Gag vertical line effort and catch adjustment factors by management regime for (**A**) IFQ and (**B**) Pre-IFQ time periods. For the Pre-IFQ 20”TL historical management regime (B), the disposition of individual fish (kept or discarded) was re-assigned according to the associated minimum legal size. The proportions of observer trips and effort with kept Gag (IFQ time period) or kept Gag and Black Grouper (pre-IFQ time period) were used to respectively adjust annual logbook total trips and effort (Table 3) to account for logbook trips that only had discarded fish. Ratios of observer catch for a historical management regime to the current regime were used to adjust logbook catches and CPUE estimates (Table 4) for hindcasting for historical management regimes.

(A) IFQ Time Period

Management Regime	Number of Observer Trips (n)	Proportion of Observer Data with Kept Gag	
		Trips	Effort
IFQ 24”TL (2010-2011, 2019)	105	0.8190	0.8885
IFQ 22”TL (2012-2018)	473	0.8478	0.8987

(B) Pre-IFQ Time Period

Management Regime	Number of Observer Trips (n)	Proportion of Observer Data with Kept Gag & Black Grouper		Observer Catch Data Ratios for Hindcasting	
		Trips	Effort	Description	Ratio
Pre-IFQ 24”TL (2000-2009)	118	0.8390	0.8837	$C_{24”}/C_{24”}$	1.0
Pre-IFQ 20”TL (1993-1999)	118	0.8390	0.8837	$C_{20”}/C_{24”}$	1.1594

Table 3. Annual time-series of vertical line logbook trips (number) and effort (hours) for GOM Gag. For pre-IFQ years 1993-2009, trips and effort reflect combined Gag and Black Grouper data; for IFQ years 2010-2019, trips and effort reflect Gag data only.

	Logbook Trips		Logbook Effort	
Year	Reported	Adjusted (*N*)	Reported	Adjusted $(\hat{X})$
1993	4,003	4,771	141,642	160,275
1994	4,530	5,399	150,731	170,560
1995	4,702	5,604	156,503	177,091
1996	5,116	6,098	170,252	192,649
1997	5,403	6,440	178,111	201,541
1998	6,841	8,154	186,993	211,592
1999	6,992	8,334	203,044	229,755
2000	6,680	7,962	201,105	227,560
2001	6,034	7,192	190,536	215,601
2002	6,037	7,196	197,250	223,199
2003	5,960	7,104	196,950	222,858
2004	5,547	6,612	177,357	200,688
2005	4,584	5,464	159,978	181,023
2006	4,404	5,249	170,600	193,042
2007	3,570	4,255	154,690	175,039
2008	3,534	4,212	145,690	164,855
2009	3,535	4,213	167,436	189,463
2010	2,281	2,785	109,392	123,114
2011	1,863	2,275	90,219	101,536
2012	2,285	2,695	104,355	116,122
2013	2,112	2,491	103,751	115,450
2014	2,263	2,669	107,743	119,892
2015	1,836	2,166	83,452	92,862
2016	2,162	2,550	99,011	110,176
2017	1,885	2,223	82,179	91,446
2018	1,721	2,030	69,976	77,867
2019	1,658	2,024	65,530	73,750

Table 4. Estimated observer mean CPUE in weight and numbers by management regime for expansion estimates of vertical line GOM Gag catch and discards.

Management Regime	Observer CPUE, pounds per hour		Observer CPUE, numbers per hour	
	Kept	Discard	Kept	Discard
IFQ 24”TL (2010-2011, 2019)	2.4593	1.1131	0.2230	0.2796
IFQ 22”TL (2012-2018)	2.6896	0.4313	0.2264	0.0863
Pre-IFQ 24”TL (2000-2009)	3.3974	0.7825	0.2933	0.1953
Pre-IFQ 20”TL (1993-1999)	3.9389	0.2409	0.4035	0.0852

Table 5. Time-series of CPUE expansion estimates for GOM Gag vertical line discards in weight (lbs.) and number (with associated standard errors).

Year	Estimated Discards in Weight	SE of Estimated Discards in Weight	Estimated Discards in Number	SE of Estimated Discards in Number
1993	48,329.2	10,202.4	17,084.7	3,769.4
1994	47,592.1	10,046.8	16,824.1	3,711.9
1995	53,723.1	11,341.0	18,991.5	4,190.1
1996	60,078.0	12,682.6	21,238.0	4,685.8
1997	63,207.2	13,343.1	22,344.2	4,929.8
1998	94,755.7	20,003.1	33,496.8	7,390.4
1999	79,604.3	16,804.6	28,140.7	6,208.7
2000	336,879.8	74,128.3	84,100.5	18,833.2
2001	402,610.5	88,592.0	100,509.9	22,507.8
2002	371,423.9	81,729.5	92,724.3	20,764.3
2003	319,866.3	70,384.6	79,853.2	17,882.0
2004	342,821.2	75,435.7	85,583.7	19,165.3
2005	318,613.8	70,109.0	79,540.5	17,812.0
2006	187,795.9	41,323.3	46,882.4	10,498.7
2007	136,964.2	30,138.1	34,192.5	7,656.9
2008	128,995.0	28,384.6	32,203.0	7,211.4
2009	148,250.0	32,621.5	37,009.9	8,287.9
2010	137,038.1	31,489.0	34,423.4	8,761.7
2011	113,020.1	25,970.1	28,390.2	7,226.1
2012	50,086.9	7,340.8	10,015.7	1,598.6
2013	49,796.9	7,298.3	9,957.7	1,589.3
2014	51,713.1	7,579.1	10,340.9	1,650.5
2015	40,054.2	5,870.4	8,009.5	1,278.4
2016	47,522.0	6,964.8	9,502.8	1,516.7
2017	39,443.2	5,780.8	7,887.3	1,258.9
2018	33,586.2	4,922.4	6,716.1	1,071.9
2019	82,091.5	18,863.2	20,621.0	5,248.6

Table 6. (A) Number of GOM total and Gag/Black Grouper combined observer bottom longline trips by year for the pre-IFQ time period (2007-2009). **(B)** Number of GOM total and Gag observer bottom longline trips by year for the IFQ time period (2010-2019).

(A) Pre-IFQ Time Period

Year	Total Trips	Gag/Black Grouper Combined Trips
2007	11	9
2008	5	1
2009	33	24

(B) IFQ Time Period

Year	Total Trips	Gag Trips
2010	53	40
2011	81	71
2012	19	16
2013	82	68
2014	27	22
2015	26	22
2016	55	45
2017	14	11
2018	4	3
2019	5	5

Table 7. Definition of bottom longline trip catch level strata for GOM Gag for the Pre-IFQ 24”TL and IFQ 22”TL management regimes, and corresponding percentages of logbook and observer vertical line trips. Trips during the pre-IFQ period were considered for Gag and Black Grouper combined; trips during the IFQ period were considered for Gag only.

Management Regime	Trip Catch Level	Stratum Code	% Trips	
			Logbook	Observer
Pre-IFQ 24”TL	Low, catch ≤ 237.7 lbs.	L	51.5	68.7
	High, catch > 237.7 lbs.	H	48.5	31.3
IFQ 22”TL	Low, catch ≤ 160.0 lbs.	L	49.9	40.1
	High, catch > 160.0 lbs.	H	50.1	59.9

Table 8. Gag bottom longline effort and catch adjustment factors by management regime and catch level strata for (**A**) IFQ and (**B**) Pre-IFQ time periods. Catch level strata are defined in Table 7; catch level stratum 'All' is all levels (i.e., no stratification). For the Pre-IFQ 20"TL historical management regime (B), the disposition of individual fish (kept or discarded) was re-assigned according to the associated minimum legal size. The proportions of observer trips and effort with kept Gag (IFQ time period) or kept Gag and Black Grouper (pre-IFQ time period) were used to respectively adjust annual logbook total trips and effort (Table 9) to account for logbook trips that only had discarded fish. Ratios of observer catch for a historical management regime to the current regime were used to adjust logbook catches and CPUE estimates (Table 10) for hindcasting for historical management regimes.

(A) IFQ Time Period

Management Regime	Catch Level	Number of Observer Trips (n)	Proportion of Observer Data with Kept Gag	
			Trips	Effort
IFQ 24"TL (2010-2011, 2019)	All	116	0.8017	0.8227
IFQ 22"TL (2012-2018)	L	79	0.8987	0.9140
	H	106	1.0	1.0

(B) Pre-IFQ Time Period

Management Regime	Catch Level	Number of Observer Trips (n)	Proportion of Observer Data with Kept Gag & Black Grouper		Observer Catch Data Ratios for Hindcasting	
			Trips	Effort	Description	Ratio
Pre-IFQ 24"TL (2000-2009)	L	24	0.9167	0.9060	$C_{24"}/C_{24"}$	1.0
	H	10	1.0	1.0	$C_{24"}/C_{24"}$	1.0
Pre-IFQ 20"TL (1993-1999)	L	24	0.9167	0.9060	$C_{20"}/C_{24"}$	1.0326
	H	10	1.0	1.0	$C_{20"}/C_{24"}$	1.0029

Table 9. Annual time-series of bottom longline logbook trips (number) and effort (hours) by catch level strata for GOM Gag. For pre-IFQ years 1993-2009, trips and effort reflect combined Gag and Black Grouper data; for IFQ years 2010-2019, trips and effort reflect Gag data only.

		Logbook Trips		Logbook Effort	
Year	Catch Level	Reported	Adjusted (N)	Reported	Adjusted $(\hat{X})$
1993	L	528	576	14,898	16,443
	H	385	385	14,278	14,278
1994	L	715	780	20,194	22,288
	H	348	348	13,295	13,295
1995	L	672	733	15,682	17,308
	H	352	352	12,646	12,646
1996	L	765	835	17,573	19,395
	H	417	417	14,074	14,074
1997	L	711	776	17,835	19,685
	H	477	477	16,284	16,284
1998	L	560	611	12,166	13,428
	H	598	598	19,062	19,062
1999	L	614	670	15,944	17,597
	H	532	532	16,961	16,961
2000	L	507	553	11,891	13,124
	H	584	584	17,654	17,654
2001	L	404	441	7,815	8,626
	H	714	714	21,891	21,891
2002	L	420	458	8,440	9,315
	H	649	649	18,615	18,615
2003	L	459	501	8,329	9,193
	H	746	746	19,677	19,677
2004	L	439	479	7,886	8,704
	H	756	756	18,215	18,215
2005	L	351	383	5,381	5,939
	H	733	733	15,539	15,539
2006	L	539	588	9,736	10,746
	H	654	654	13,420	13,420
2007	L	403	440	8,131	8,974
	H	443	443	10,417	10,417
2008	L	481	525	10,999	12,140
	H	414	414	9,679	9,679
2009	L	230	251	5,638	6,223
	H	191	191	5,144	5,144
2010	All	339	423	10,055	12,222
2011	All	358	447	10,647	12,942
2012	L	196	218	5,355	5,859
	H	207	207	5,987	5,987
2013	L	197	219	5,795	6,340
	H	279	279	7,921	7,921
2014	L	269	299	8,400	9,190
	H	250	250	8,635	8,635

2015	L	262	292	8,573	9,379
	H	275	275	9,647	9,647
2016	L	273	304	8,890	9,726
	H	336	336	11,401	11,401
2017	L	311	346	10,865	11,887
	H	253	253	9,221	9,221
2018	L	293	326	10,018	10,960
	H	211	211	7,777	7,777
2019	All	432	539	14,643	17,799

Table 10. Estimated observer mean CPUE in weight and numbers by management regime and catch level strata for expansion estimates of bottom longline GOM Gag catch and discards.

Management Regime	Catch Level	Observer CPUE, pounds per hour		Observer CPUE, numbers per hour	
		Kept	Discard	Kept	Discard
IFQ 24”TL (2010-2011, 2019)	All	6.6666	3.9544	0.4303	0.3479
IFQ 22”TL (2012-2018)	L	2.0789	2.4693	0.1448	0.1390
	H	19.8870	2.6895	1.2516	0.2009
Pre-IFQ 24”TL (2000-2009)	L	3.2306	0.2054	0.2242	0.0444
	H	27.9963	0.1642	1.4844	0.0351
Pre-IFQ 20”TL (1993-1999)	L	3.3360	0.0999	0.2399	0.0287
	H	28.0784	0.0821	1.4982	0.0213

Table 11. Time-series of CPUE expansion estimates for GOM Gag bottom longline discards in weight (lbs.) and number (with associated standard errors).

Year	Estimated Discards in Weight	SE of Estimated Discards in Weight	Estimated Discards in Number	SE of Estimated Discards in Number
1993	2,115.5	561.9	588.0	141.7
1994	2,402.9	638.2	673.4	162.2
1995	2,363.1	627.6	660.0	159.0
1996	2,890.8	767.8	808.6	194.8
1997	2,798.5	743.3	778.8	187.6
1998	2,937.7	780.2	806.7	194.4
1999	2,970.0	788.8	819.1	197.4
2000	6,068.3	1,442.5	1,303.5	304.9
2001	7,393.6	1,757.6	1,586.2	371.0
2002	7,583.8	1,802.8	1,626.7	380.5
2003	8,049.5	1,913.5	1,726.9	403.9
2004	7,894.7	1,876.7	1,693.1	396.0
2005	6,790.9	1,614.3	1,456.5	340.7
2006	6,284.3	1,493.9	1,350.5	315.9
2007	3,553.6	844.8	763.8	178.6
2008	4,082.6	970.5	878.4	205.4
2009	2,122.7	504.6	456.7	106.8
2010	48,332.2	8,955.6	4,252.4	687.3
2011	51,177.8	9,482.9	4,502.7	727.8
2012	30,569.4	8,668.2	2,017.1	501.2
2013	36,959.6	10,480.2	2,472.5	614.4
2014	45,917.7	13,020.3	3,012.2	748.5
2015	49,106.8	13,924.6	3,241.8	805.6
2016	54,680.7	15,505.2	3,642.3	905.1
2017	54,153.2	15,355.6	3,504.8	870.9
2018	47,981.3	13,605.5	3,085.9	766.8
2019	70,385.7	13,042.0	6,192.7	1,001.0

Figure 1. Map of sampling areas in the Gulf of Mexico.

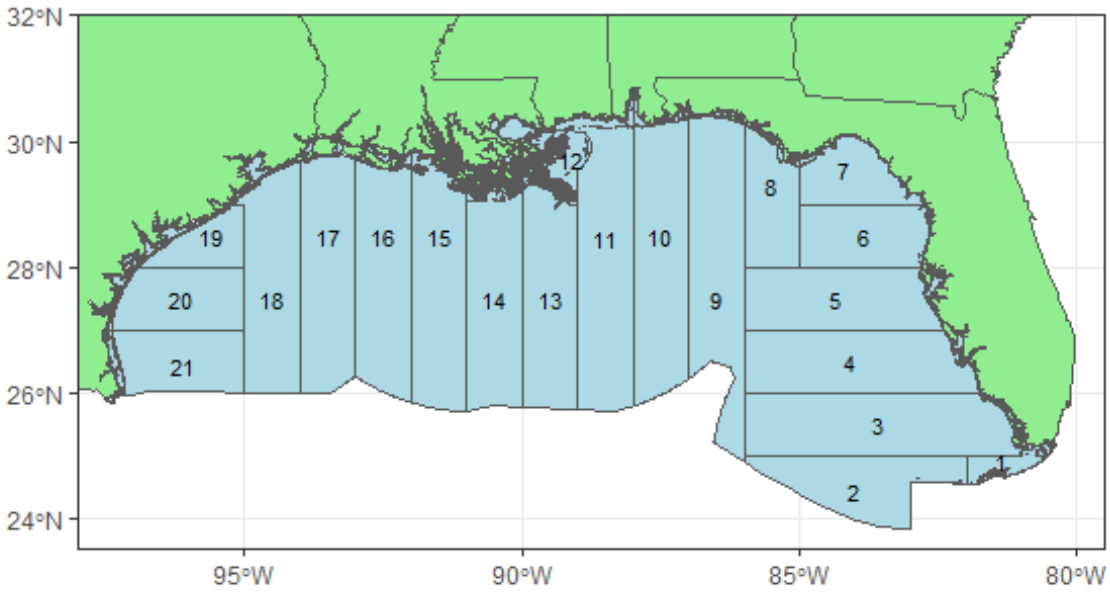
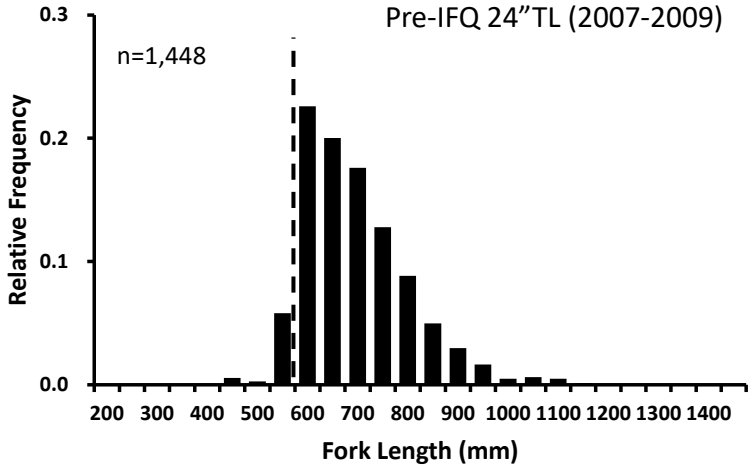
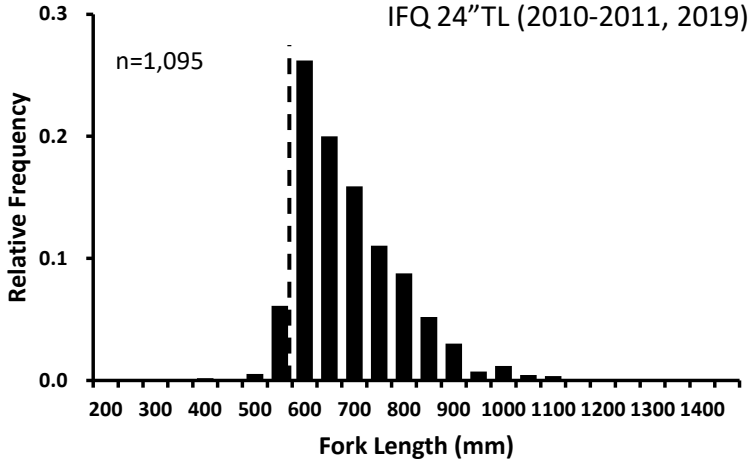


Figure 2. Length-frequency plots of observer vertical line GOM Gag for **(A)** kept and **(B)** discarded fish by management time period. For discards (**B**), left panels show trips with no kept fish, right panels show trips with kept fish. Vertical dashed lines denote the minimum size limit; n is the number of measured fish.

(A) Kept





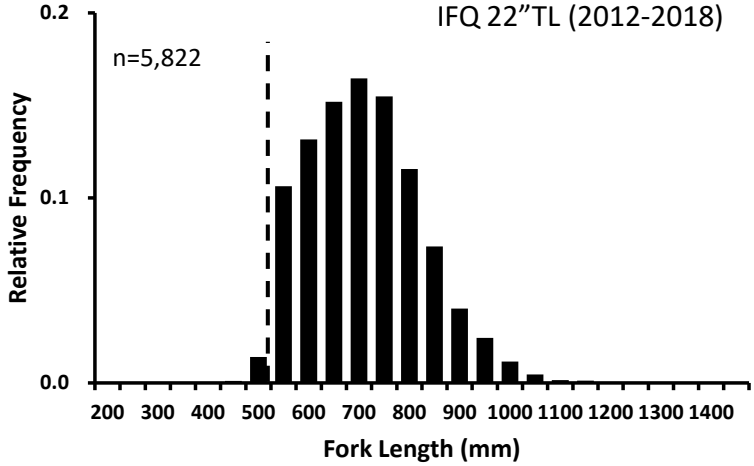


Figure 2. (cont.)

(B) Discarded

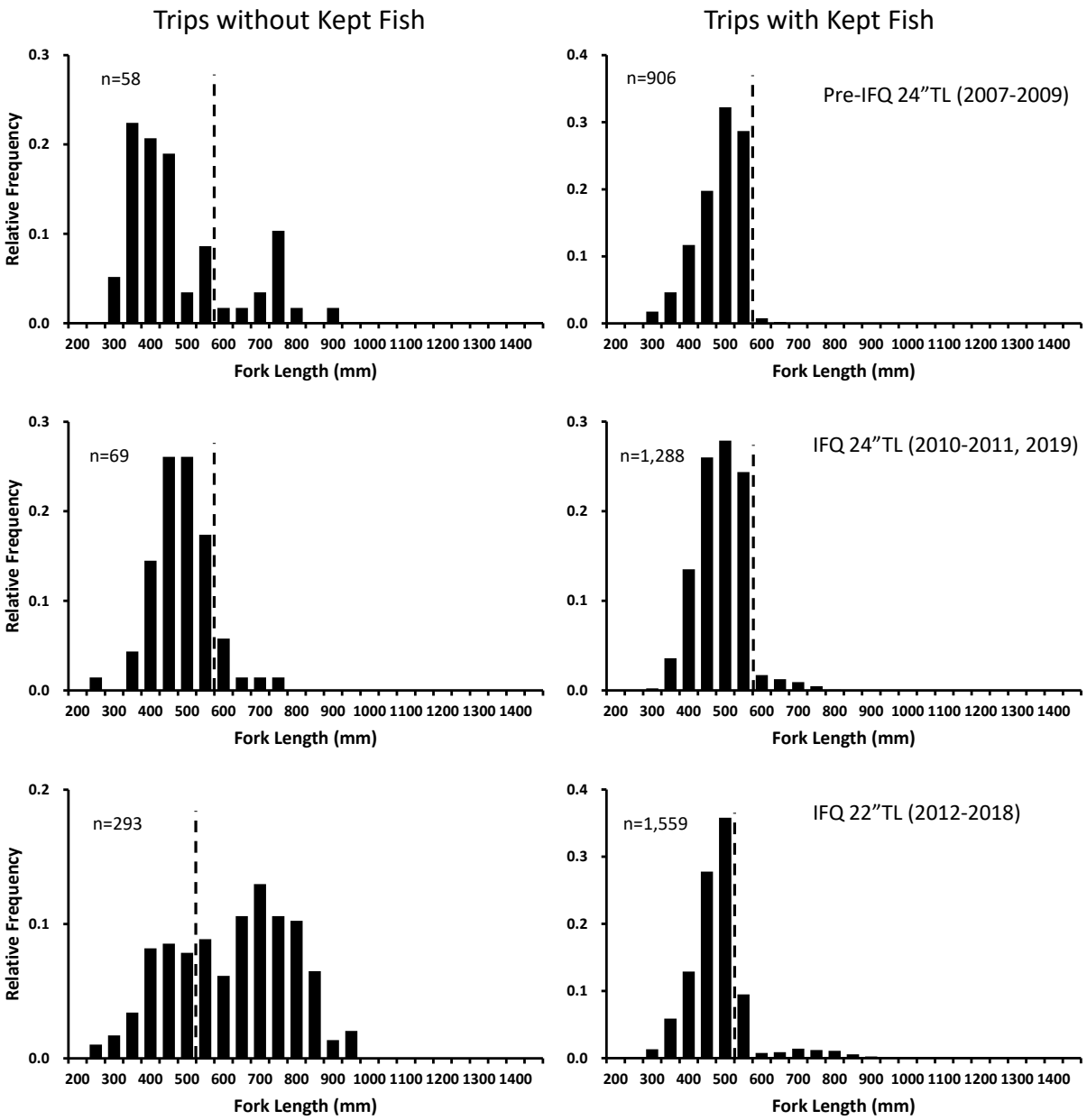


Figure 3. Comparison of vertical line reported annual logbook landings of GOM Gag (solid dots and black line) with CPUE expansion estimates from observer data (open squares). Error bars (SE) are shown for observer estimates.

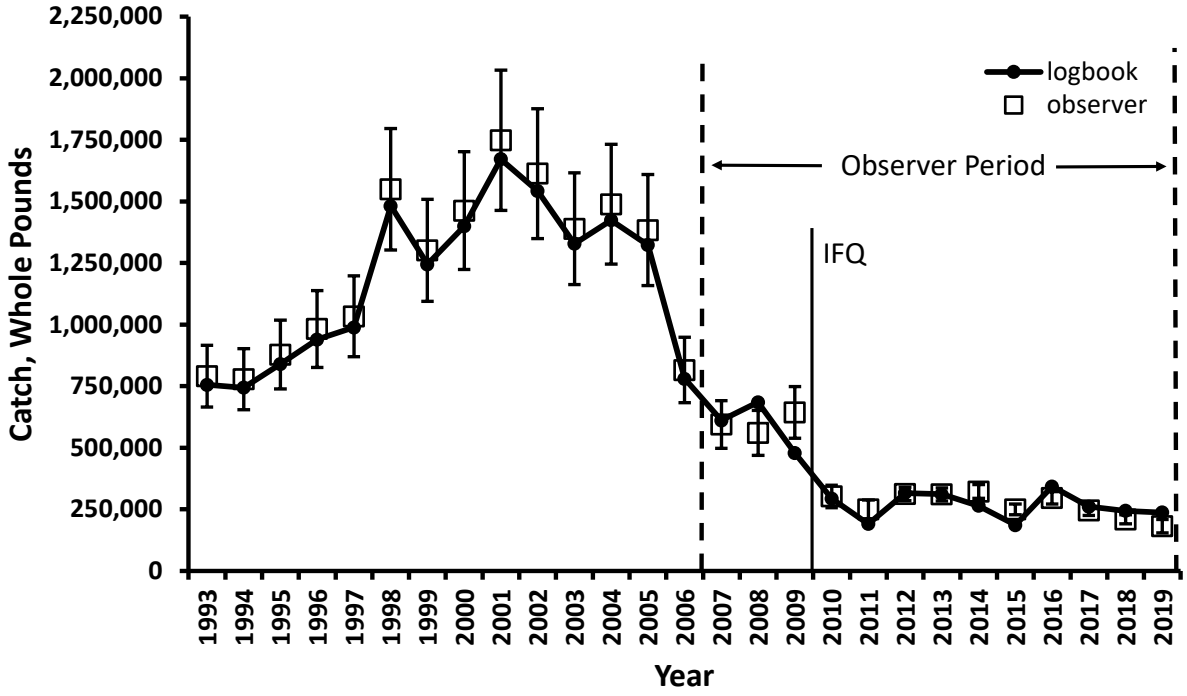
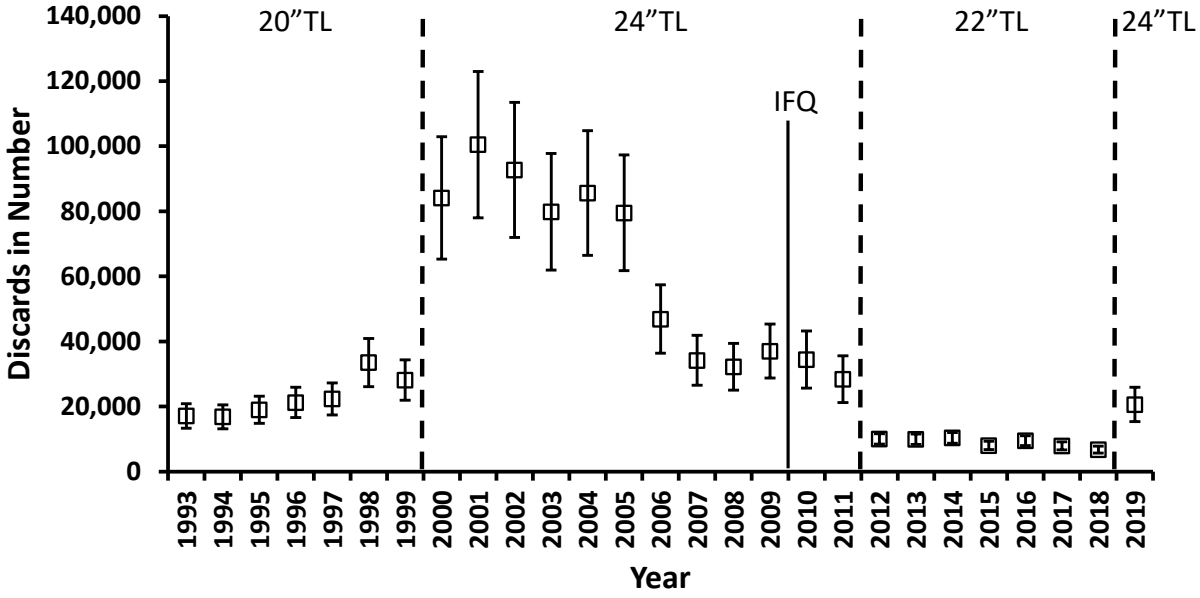


Figure 4. Observer CPUE expansion estimates of GOM Gag vertical line annual discards (±SE) in **(A)** number and **(B)** weight expressed as percentage of total catch (kept + discards) for 2000-2018. Minimum size and IFQ management regimes are denoted in (A).

(A) Discards in Number



(B) Discards in Weight, Percentage of Total Catch

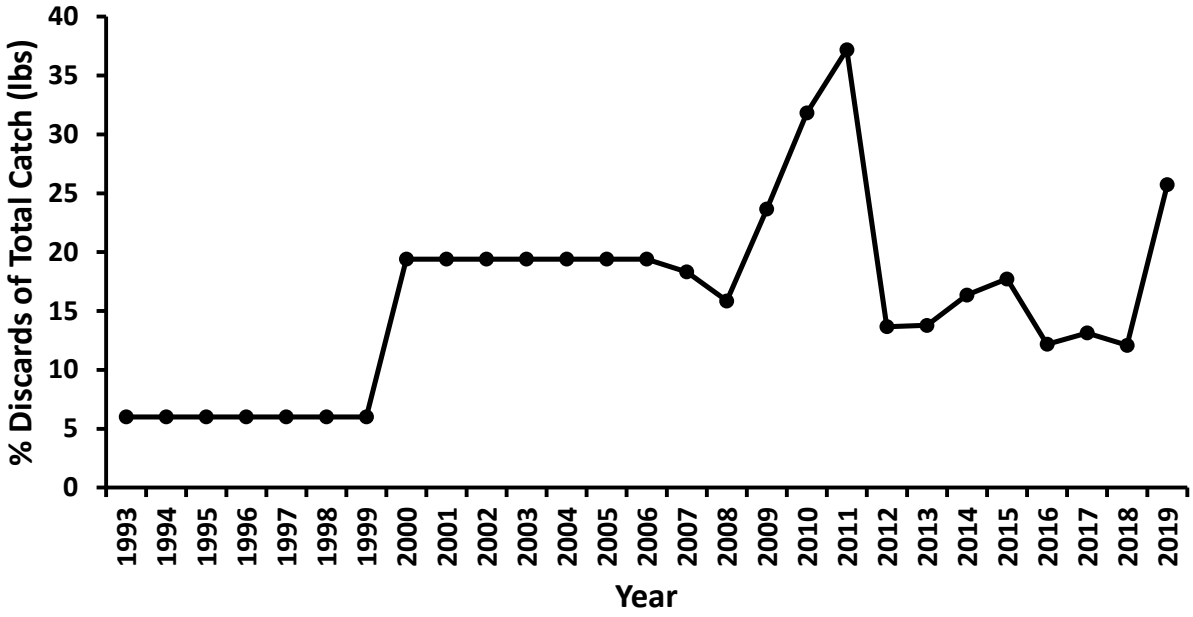


Figure 5. Length-frequency plots of observer bottom longline GOM Gag for **(A)** kept and **(B)** discarded fish by management time period. For discards (**B**), left panels show trips with no kept fish, right panels show trips with kept fish. Vertical dashed lines denote the minimum size limit; n is the number of measured fish.

(A) Kept

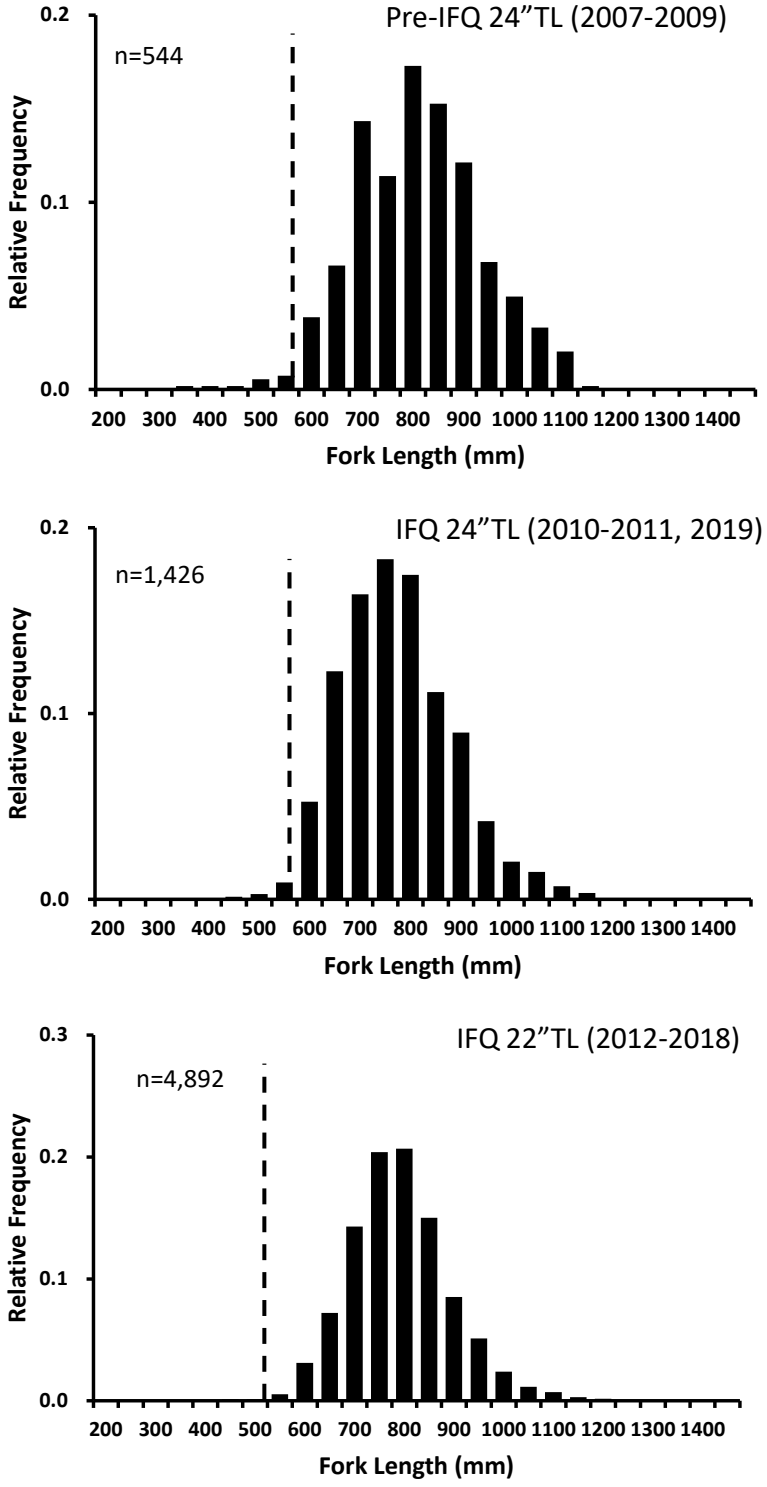


Figure 5. (cont.)

(B) Discarded

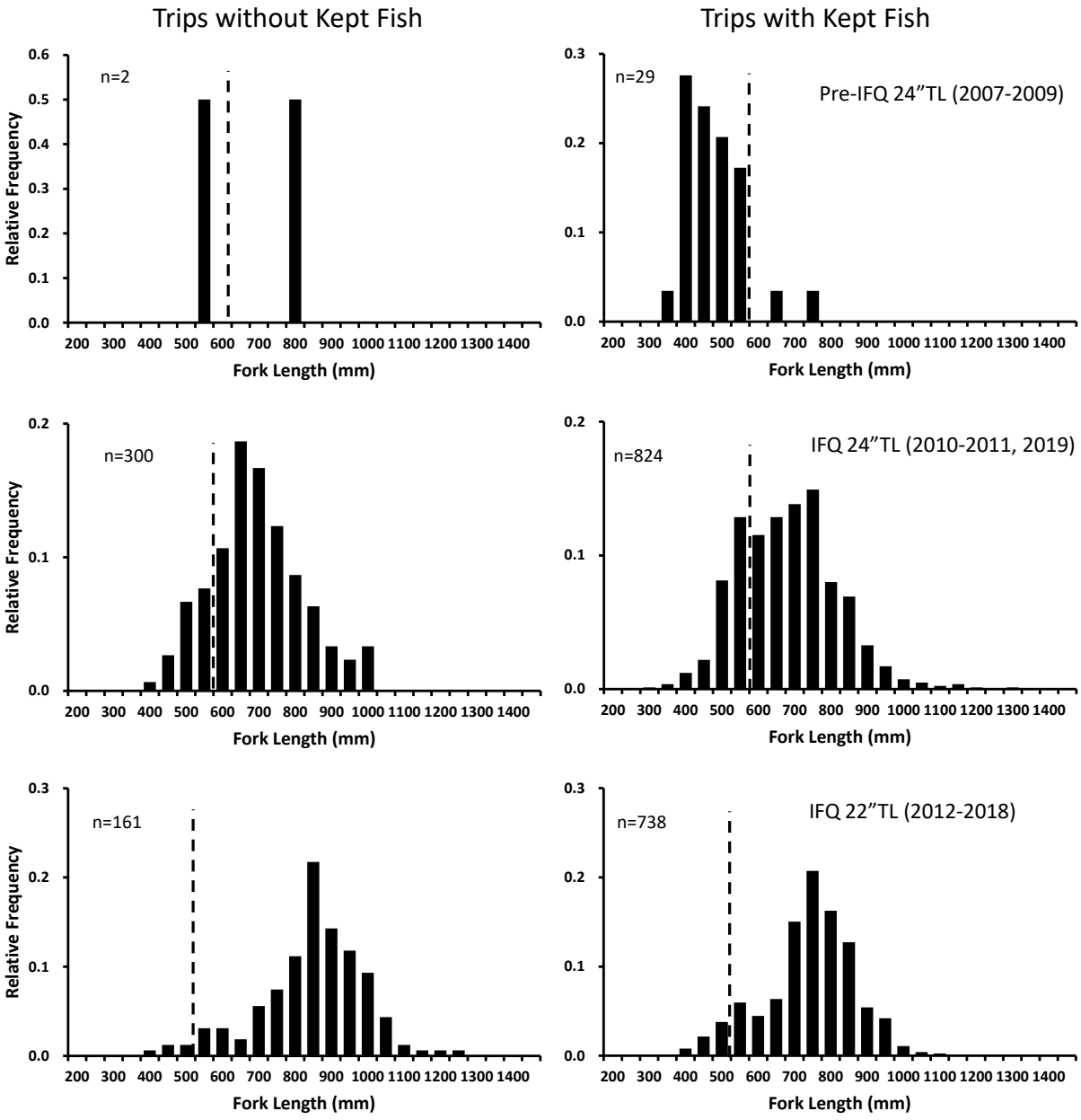


Figure 6. Comparison of bottom longline reported annual logbook landings of GOM Gag (solid dots and black line) with CPUE expansion estimates from observer data (open squares). Error bars (SE) are shown for observer estimates.

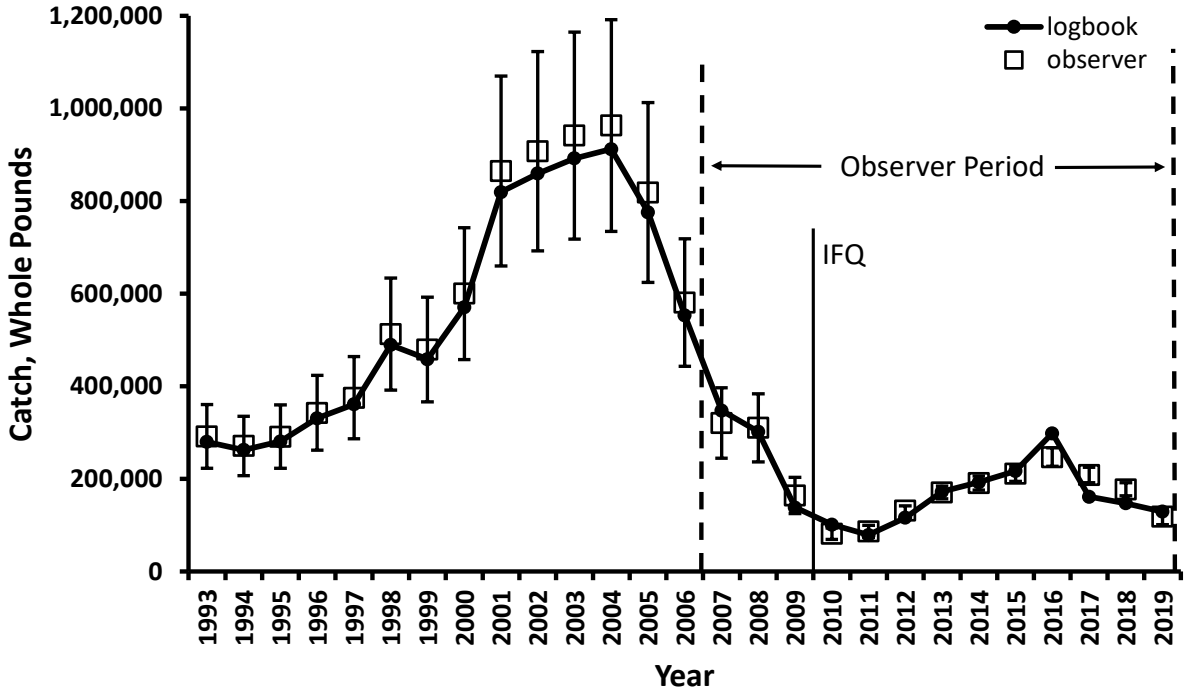
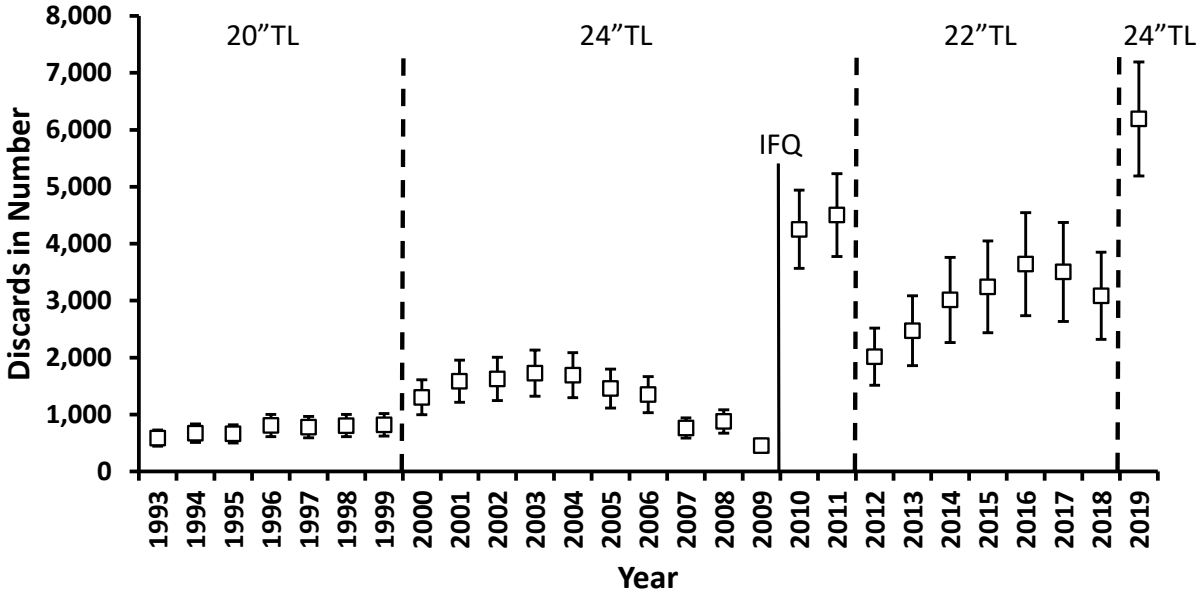


Figure 7. Observer CPUE expansion estimates of GOM Gag bottom longline annual discards (±SE) in **(A)** number and **(B)** weight expressed as percentage of total catch (kept + discards) for 2000-2018. Minimum size and IFQ management regimes are denoted in (A).

(A) Discards in Number



(B) Discards in Weight, Percentage of Total Catch