Example Tier 4 Status Determination for The Tanner Crab Stock

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1 Introduction

For crab stocks managed by the NPFMC, *overfished* status is assessed with respect to the Minimum Stock Size Threshold (MSST; NPFMC 2022). If stock biomass drops below the MSST, the stock is considered to be overfished. For crab stocks, MSST is one-half of B_{MSY}, where B_{MSY} is the long-term mature male biomass (MMB, assumed to reflect the reproductive potential for the stock) when the stock is fished at maximum sustainable yield (MSY). Thus, the stock is overfished if $B/B_{MSY} < 0.5$, where B is the "current"" MMB. In general, the overfishing limit (OFL) for the subsequent year is based on B/B_{MSY} and an F_{OFL} harvest control rule, where F_{OFL} is the fishing mortality rate that yields the OFL and $F_{OFL} \leq F_{MSY}$, the fishing mortality that yields the long-term maximum sustainable yield (MSY). Furthermore, if $B/B_{MSY} < \beta(= 0.25)$, directed fishing on the stock is prohibited. Tanner crab has been considered a "Tier 3" stock for status determination and fishery management since 2012/13 (SSC, 2012) because the available biological and fishery information have been deemed sufficiently informative that Tier 3 proxies for B_{MSY} and F_{MSY} (i.e., spawner-per-recruit proxies $B_{35\%}$ and $F_{35\%}$) can be reliably estimated.

However, both the the SSC and CPT have expressed concerns regarding the complexity of the current Tier 3 model for Tanner crab and have requested that a simpler "Tier 4" model be developed as a fallback in the event that a candidate Tier 3 model is deemed unreliable. For Tier 4 stocks, the $B_{MSY_{proxy}}$ is taken to be the mean mature male biomass ($\overline{MMB}$) of the stock at the time of mating, where the averaging is over a period during which the stock was assumed to be fished at an average rate near F_{MSY} and thus the stock was fluctuating around B_{MSY}. For determining a Tier 4 OFL, F_{MSY} is taken to be $\gamma \cdot M$, where M is the assumed rate of natural mortality and γ is a constant taken as 1 by default. Once the $B_{MSY_{proxy}}$ has been calculated, the overfished status is then determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating. The ratio also determines F_{OFL} relative to F_{MSY}:

1. if $B/B_{MSY_{proxy}} \geq 1$ then $F_{OFL} = F_{MSY}$;
2. if $0.25 < B/B_{MSY_{proxy}} < 1$, then $F_{OFL} < F_{MSY}$ as determined by a sloping F_{OFL} control rule (NPFMC, 2022); or
3. $F_{OFL} = 0$ if $B/B_{MSY_{proxy}} < 0.25$.

In this report, I develop a Tier 4 model for Tanner crab based on the one used to determine status for PIBKC, a Tier 4 stock for status determination (Stockhausen, 2021).

2 Tier 4 modeling

2.1 MMB-at-mating

Following the PIBKC assessment, MMB-at-mating (MMB^{am}) is calculated from MMB at the time of the annual NMFS EBS bottom trawl survey (MMB^{s}) by accounting for natural and fishing mortality from the time of the survey to mating. On a per-haul basis, MMB at the time of the survey in year y was calculated from survey data using:

$$MMB^{s}_{y,h} = \sum_{z} w_z \cdot P_z \cdot n_{z,y,h} \tag{1}$$

where $MMB^{s}_{y,h}$ is the observed MMB in haul h in year y, w_z is male weight at size z (mm CL), P_z is the probability of maturity at size z, and $n_{z,y,h}$ is the haul-level (h) male abundance at size z in year y. Survey MMB for year y, MMB^{s}_{y}, was then calculated using the standard design-based approach for the EBS shelf survey (e.g., Wakabayashi et al., 1985). Here, as a simplification, the cutline used by the AFSC Shellfish Assessment Program for the EBS (113 mm CW; e.g., Daly, 2015) was used to define P_z for mature male Tanner crab. Following the design-based estimation of survey MMB, a random walk model (see Section 3) was applied to the survey MMB time series to reduce the observed variance, allow estimation of missing years (the survey was not conducted in 2020), and better estimate the stock trend.

For a year y prior to the assessment year, MMB^{am}_{y} was related to MMB^{s}_{y}, MMB^{bf}_{y} (MMB just before the fisheries), MMB^{af}_{y} (MMB just after the fisheries, which are assumed to occur instantaneously as a simplification), and MMB^{am}_{y} (MMB just before mating) by:

$$MMB^{bf}_{y} = MMB^{s}_{y} \cdot e^{-M \cdot t_{sf}} \tag{2}$$

$$MMB^{af}_{y} = MMB^{bf}_{y} - RM_y - DM^{MM}_{y} \tag{3}$$

$$MMB^{bm}_{y} = MMB^{af}_{y} \cdot e^{-M \cdot t_{fm}} \tag{4}$$

$$MMB^{am}_{y} = MMB^{bm}_{y} + R^{M}MB_y \tag{5}$$

where M is natural mortality, RM_y is retained catch mortality on MMB in the directed fishery in year y, DM^{MM}_{y} is discard mortality on mature males (**not** on all crab) in all fisheries in year y, t_{sf} is the time between the survey and the fishery, t_{fm} is the time between the fishery and mating, and R^{MMB}_{y} is recruitment to the mature male component of the stock at the time of mating. The latter quantity is given by:

$$R^{MMB}_{y} = MMB^{s}_{y+1} \cdot e^{1-(t_{sf}+t_{fm})} - MMB^{bm}_{y} \tag{6}$$

The Tier 4 $B_{MSY_{proxy}}$, $\overline{MMB}$, is then calculated as the average MMB^{am} over some time frame:

$$\overline{MMB} = \frac{1}{N} \sum_{y} MMB^{am}_{y} \tag{7}$$

2.2 Stock status

For the assessment year, the fishery has not yet occurred so RM and DM are unknown, as are current B and stock status. The amount of fishing mortality depends on the (as yet-to-be-determined) stock status and overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the upcoming fishery year. This procedure involves:

1. "guess" a value for F_{OFL}, the directed fishing mortality rate that yields OFL ($F_{OFL_{max}} = \gamma \cdot M$ is used)
2. determine the OFL corresponding to fishing at F_{OFL} starting with MMB^s, the estimated survey MMB at the start of the assessment year, and using:

$$MMB^{bf} = MMB^s \cdot e^{-M \cdot t_{sf}} \tag{8}$$

$$RM_{OFL} = \left(1 - e^{-F_{OFL}}\right) \cdot MMB_s \cdot e^{-M \cdot t_{sf}} \tag{9}$$

$$DM_{OFL} = \left(\theta / p_{MM}\right) \cdot MMB_f \tag{10}$$

$$OFL = RM_{OFL} + DM_{OFL} \tag{11}$$

3. project MMB-at-mating from the "current" survey MMB assuming the OFL will be taken and recruitment to the mature male stage will be $\bar{R}_{MMB}$ (the average recruitment over some time interval):

$$MMB^{am} = \left[MMB_y^{bf} - \left(RM_{OFL} + p_{MM} \cdot DM_{OFL}\right)\right] \cdot e^{-M \cdot t_{fm}} + \bar{R}_{MMB} \tag{12}$$

4. use the harvest control rule to determine the F_{OFL} corresponding to the projected MMB-at-mating.
5. update the "guess" in 1. for the result in 4.
6. repeat steps 2-5 until the process has converged, yielding self-consistent values for F_{OFL} and MMB-at-mating.

Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating and stock status. Also note that, while the retained mortality RM_{OFL} is based on the F_{OFL}, the discard mortality DM_{OFL} is assumed to be proportional to the MMB at the time of the fishery, with proportionality constant $\frac{\theta}{p_{MM}}$. The constant θ is determined by the ratio of the average discard mortality on MMB (DM^{MM}) to MMB at the time of the fishery (MMB^{bf}) over a recent time interval:

$$\theta = \frac{\sum_y DM_y^{MM}}{\sum_y MMB_y^{bf}} \tag{13}$$

The constant p_{MM} is estimated as the fraction of discard mortality on mature males, and is calculated similarly to θ as a ratio of averages over a recent time interval:

$$p_{MM} = \frac{\sum_y DM_y^{MM}}{\sum_y DM_y} \tag{14}$$

where DM_y is the estimated discard mortality on all crab.

The estimation of DM_y and DM_y^{MM} in the crab fisheries and in the groundfish fisheries is discussed separately in Sections 4 and 5.

3 Survey MMB

3.1 NMFS EBS shelf survey data

Design-based estimates of mature male Tanner crab biomass from the NMFS EBS shelf survey were calculated applying a cutline at 113 mm CW for the transition to maturity to observed males for 1982-2022 (Daly et al., 2015). The resulting time series for mature and immature male, as well as female, survey biomass are shown in Figure 1 by state management area and in Figure 2 for the EBS. The survey was not conducted in 2020.

3.2 *rema* state-space model and results

The design-based mature male survey biomass time series for 1982-2022 was fit with the state-space/random effects R modeling package "**rema**" (version 0.1.0; Sullivan, 2022) using a ln-scale random walk model to reduce sampling variance, estimate survey MMB in 2020, and better capture the time series trend. The state-space/random effects model is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$p(< ln(MMB_s) >_y \mid < ln(MMB_s) >_{y-1}) \sim N(0, \phi^2) \tag{15}$$

as the state equation, where $p(x|y)$ denotes the probability of x conditional on y, $N(\mu, v)$ indicates the normal distribution with mean μ and variance v, and

$$ln(MMB_{s_y}) =< ln(MMB_s) >_y + \eta_y, \text{ where } \eta_y \sim N(0, \sigma^2_{s_y}) \tag{16}$$

as the observation equation. $< ln(MMB_s) >_y$ in equations 15 and 16 is the estimated "true" ln-scale survey MMB in year y, while ϕ^2 in Equation 15 represents the estimated (ln-scale) process error variance. MMB_{s_y} in equation 16 is the observed survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and $\sigma^2_{s_y}$ is the ln-scale survey MMB variance in year y. The MMB_s's and σ_s's are observed quantities, while the $< ln(MMB_s) >$'s are estimated parameters regarded as random effects in the likelihood function. The process error variance ϕ^2 is parameterized on the ln-scale using $\phi^2 = exp(2 \cdot \lambda)$, where λ is an estimated fixed effect parameter.

Parameter estimates are obtained by minimizing the joint negative log-likelihood objective function

$$\Lambda = \sum_y \left[ln(2\pi\phi) + \left(\frac{< ln(MMB_s) >_y - < ln(MMB_s) >_{y-1}}{\phi} \right)^2 \right] + \sum_y \left(\frac{ln(MMB_{s_y}) - < ln(MMB_s) >_y}{\sigma_{s_y}} \right)^2 \tag{17}$$

and integrating out the random effects using the Laplace approximation.

The estimated process error, ϕ, was 0.3984 (Table 1). The model fits the data well (Table 2; Figures 3 and 4) and provides an estimate for mature male survey biomass in 2020.

4 Tanner crab mortality in the crab fisheries

In order to account for mortality related to fishing in a Tier 4 assessment model, the mortality associated with retention and discarding of mature male Tanner crab in the EBS crab and groundfish fisheries needs to be accounted for. For the purposes of this model, the transition from immature to mature male crab is assumed to occur as a cutline at 113mm CW, which is much smaller than the industry-preferred size (125 mm CW).

Tanner crab mortality in the crab fisheries is comprised of retained catch mortality of legal-size male crab in primarily, but not exclusively, the directed Tanner crab fisheries as well as mortality associated with on-deck handling and discarding of immature and sublegal male crab and all female crab taken as bycatch in the directed fisheries and in the snow crab and BBRKC fisheries. Incidental retention of legal males also occurs in the latter two fisheries.

Because all retained crab can be considered to be mature, it is not necessary to separate retained catch biomass into immature and mature components–all retained catch is mature male mortality. In contrast, discard mortality occurs on both immature and mature males, as well as females. It is thus necessary to estimate the mature male portion of discard mortality from the available data, but this is not straightforward because Tanner crab are not categorized by maturity state in the available data on discards. Furthermore, discards are not an explicit data stream but are estimated as the difference between total catch and retained catch. To estimate mature male mortality due to discarding from data on total and retained catch, it is necessary to 1) estimate the total catch biomass of males by size; 2) apply a maturity cutline and sum across all sizes larger than the cutline to obtain the estimated total catch biomass of mature males; 3) subtract the retained catch from 2) to get the estimated discard biomass of mature males; and 4) to apply an assumed handling mortality associated with the process of discarding crab to the discards.

Details of these steps are discussed in the following sections. Details of similar steps associated with determining mortality due to the groundfish fisheries is addressed in Section 5.

4.1 Retained catch abundance and biomass

Data on retained catch abundance and biomass of legal males is available from fish ticket data. ADFG provided annual retained catch abundance and biomass data for the directed fisheries aggregated to the EBS from 1982 to 1996 and by management area from 2005 to present (the fisheries were closed from 1997/98-2004/05, ; Table 3, Figure 5). ADFG also provided data for incidentally-retained catch in the snow crab and BBRKC fisheries for 2004/05 to the present (Table 3, Figure 5). Prior to 2004/05, incidental retention in the snow crab and BBRKC fisheries (if any occurred) was "lumped in" with retained catch in the directed fisheries as a simplification.

Additionally, ADFG provided size composition data for retained catch in the directed fisheries aggregated to the EBS for 1982-1996/97 and by state management area from 2005/06, as well as for incidentally-retained catch in the snow crab (2004/05-2021/22) and BBRKC (2006/07-2020/21) fisheries (Table 4). Although it is not strictly necessary to consider this data in order to estimate discard mortality of mature males because the assumption is that all retained (i.e., industry-preferred) crab are mature, examining the retained catch size compositions provides a check on this assumption. The retained catch size compositions consist of the counts of retained males sampled by dockside fishery observers by 1-mm CW size increment. To expand size compositions for retained catch biomass, the size compositions using individual crab counts were: 1) multiplied by the expected weight of an individual crab in each size bin (from standard size-weight regressions developed using NMFS EBS shelf survey data, Daly et al. 2015); 2) normalized by the total observed catch biomass to get the fraction of observed biomass within each size bin; 3) and scaled by the total observed biomass to get the estimated catch biomass-at-size. Results for retained catch biomass are shown in Figure 6.

4.2 Total catch abundance and biomass

Data on total catch abundance and biomass of all Tanner crab is available by fishery and sex from at-sea observer sampling data, scaled from sampled abundance/biomass by sex to total catch using the ratio of observed effort to total effort for each crab fishery. ADFG has provided the author with estimates of annual total catch abundance and biomass data for the directed fisheries by state management area from 1991 to present (the fisheries were both closed from 1997/98-2012/13, and in 2016/17 and 2019/20; Table 5, Figure 7) and for the snow crab and BBRKC fisheries from 1990.

ADFG also provided sex-specific size compositions from at-sea observer data on total catch in the directed fisheries by state management area (when the fisheries were prosecuted), as well as for bycatch in the snow crab and BBRKC (1990+) fisheries. As with the retained catch, the total catch size composition data was expanded from sampled counts to total catch biomass within each size bin using individual crab counts (by sex) multiplied by the expected weight of an individual crab in each size bin (from size-weight regressions developed using survey data), then normalized by the total observed male biomass to get the fraction of observed male biomass within each size bin, then scaled by the estimated total male biomass to get the estimated catch biomass-at-size. Results are shown in Figure 8.

4.3 Discard mortality estimation

4.3.1 1990-present

The total annual catch biomass of mature males for 1990-present was calculated from the expanded total catch biomass-at-sex/size by summing the latter for males across all size bins larger than the assumed male maturity cutline (113 mm CW). Annual discard biomass of mature male Tanner crab in the crab fisheries was then estimated by subtracting annual retained catch biomass from the estimated mature male total catch biomass. Finally, annual discard mortality of mature males in the crab fisheries during this time period was then calculated by applying the assumed handling mortality (0.321) to the discard biomass.

4.3.2 Extrapolation for missing years

The State's at-sea crab fishery observer program started in 1989, so data on total catch or discards of Tanner crab in the crab fisheries does not exist prior to 1989, requiring that it be extrapolated in some fashion for the 1982-1989 time period. Furthermore, the 1990 data for the directed fisheries appears to be unreliable (sampling effort was low), so total catch/discards also needs to be extrapolated for this case. For the directed fisheries, annual retained catch and effort (total potlifts), both aggregated over the state management areas, are available in this time period. For the snow crab and BBRKC fisheries, annual effort is available.

4.3.2.1 Tanner crab fisheries

In the Tier 3 model, fitting retained catch (aggregated over the state management areas) in the directed fishery prior to 1990 provides the basis for estimating the total catch that was consistent with that retained catch. Here, linear regressions of estimated total and mature male catch biomass on retained catch in the directed fishery in the period 1991-1995 were used to extrapolate the former back to 1982 (Figure 9). It was assumed that fleet behavior was substantially different pre- and post-rationalization (2005), so the regression was limited to the pre-rationalization period when the directed fisheries were prosecuted (as previously noted, the fisheries were closed from 1997/98-2004/05). Also, estimated total catches from 1996/97 were excluded because the associated discard mortality estimates were less than zero.

4.3.2.2 Snow crab and BBRKC fisheries

In the Tier 3 model, the mean ratio of total catch to effort in the snow crab and BBRKC fisheries is used to extrapolate total catch into the past. Here, fishery-specific linear regressions of estimated mature male discard mortality on effort during 1990-2004 are used for the extrapolation (Figure 10, Figure 11).

5 Tanner crab bycatch in the groundfish fisheries

Tanner crab are taken as bycatch in groundfish fisheries in the Bering Sea targeting a number of different groundfish stocks and by several different gear types. All must be discarded, and it is assumed that some will survive and the remainder will experience handling mortality. The NMFS Alaska Regional Office's Catch Accounting System (CAS) provides estimates of total Tanner crab bycatch abundance and biomass (Table 7) based on sampling data taken by groundfish observers onboard fishing vessels and at dockside. Gear-specific estimates of total bycatch are available starting in 1991; prior to this, all bycatch is assumed to be taken in the trawl fisheries.

Both male and female crab are taken as bycatch across a fairly wide size range (Figures 13 and 14). Thus, for the Tier 4 model discussed here, it was also necessary to estimate the fraction of the total catch mortality that pertains to the mature male component of the stock. To do so, annual gear- and sex-specific size compositions from observer sampling were used to determine the mature male fraction of the total catch biomass by gear type (Table 8, Figure 13). As with the crab fisheries data, a size cutpoint (113) was used to divide the male size composition data into immature and mature components (Figure 13) prior to determining the annual fraction of catch biomass accounted for by mature males (and other stock components; Table 8, Figure 14). These were subsequently applied to the total catch biomass estimates to partition the total catch into component-specific annual estimates (Table 7, Figure 15). Mature males are by far the dominant stock biomass component in the fixed gear fisheries (Figure 14) and tend to dominate in the trawl gear fisheries, although in some years the largest biomass component in the trawl gear fisheries is immature males. The fraction of females taken by either gear type is small compared to males.

After determining the annual fraction of mature male bycatch biomass, gear-specific mortality rates were then applied to the total and mature male-specific catch biomass by gear type (trawl gear:0.8, fixed gear: 0.321) to account for general differences in fishing operations by gear type (Table 9, Figure 16). However, the estimates of total catch abundance and biomass from CAS include all Tanner crab and are not separated out by sex and life stage. Bycatch mortality in the groundfish fisheries peaked in the early 1970s at almost 20,000 t, then rapidly declined to less than 1,000 t by 1982. It rose somewhat in the early 1990s to 1,000-2,000 t then declined again after 1996. It has remained below 200 t since 2009.

6 Tier 4 management quantities

Functions in the R package rPIBKC package (version 2023.4.14) were used to calculate example Tier 4 management quantities as described in Section 2 based on the survey and fishery results presented in the previous two sections (summarized in Table 10). Survey MMB (Figure 17) was projected forward under an assumed mortality rate ($M = 0.23$) from the time of the survey to the time just prior to the prosecution of the fisheries (7.5 months by convention) to obtain MMB immediately before fishing, which was represented as a pulse. Fishing mortality on MMB was then subtracted to obtain MMB immediately after fishing (Figure 17). MMB just before mating was then determined by decrementing MMB after fishing for natural mortality during the interval from the fisheries to mating (Figure 18). Here, mating was assumed to occur just after the fishery, so no adjustment for M was made. Finally, the estimated recruitment to the mature male component of the stock at mating was added to MMB just before mating to obtain the MMB at mating (Figure 18). The resulting time series was averaged over 1982-2021 to determine a Tier 4 B_{MSY} (42,320) and $MSST$ (21,160).

To project MMB from the survey in the assessment year to the time of mating, the scalars θ (the average ratio between mature male discard mortality and MMB at the time of fishing) and p_{MM} (the average fraction of mature male discard mortality relative to that for all crab), were estimated from annual ratios derived from the respective time series(Table 10, Figures 20-21). Because fishing practices in the crab fisheries changed substantially when the fisheries were rationalized in 2005, the averaging period to determine these scalars was taken to start with the 2005/06 crab year. The estimated value for θ was found to be 0.016 while that for p_{MM} was 0.79. The mean recruitment used to project MMB for the assessment year was estimated using the 1982-2021, the same period as used to calculate B_{MSY} (the estimated value was 12,079 t). Using these values, M, and MMB from the survey in 2022 (17,322 t), the F_{OFL} was determined to be 0.126, less than F_{MSY} (0.23) because the stock status ratio $\frac{B}{B_{MSY}}$ was 0.5923. Because this ratio is greater than 0.5, the stock would be found to be **not overfished** from a Tier 4 perspective. The resulting Tier 4 OFL for 2022/23 would be 2,076 t and the projected MMB-at-mating would be 25,068 t (Figure 22).

These example Tier 4 results are summarized in the following table (and Table 11):

Quantity	Value	Units
assessment year	2022/23	–
MMB-at-mating	25,068	t
$MSST$	21,160	t
status ratio	0.592	–
status	not overfished	–
F_{MSY}	0.23	–
F_{OFL}	0.126	–
OFL	2,076	t
retained OFL	1,774	t
discard OFL	303	t

7 Discussion

Based on the Tier 4 model presented here, the Tanner crab stock was below B_{MSY} but above MSST, putting it on the sloping portion of the F_{OFL} control rule. The resulting Tier 4 OFL, 2,076 t, is about twice as large as the 2022/23 TAC (913 t).

The Tier 4 management quantities presented in the previous section are for example purposes only and depend on the value chosen for M and the time frames chosen for: 1) averaging estimated MMB-at-mating to determine B_{MSY}; 2) determining θ and p_{MM}; and 3) determining average recruitment $\bar{R}_{MMB}$. While reasonable, the values chosen are not the only "reasonable" choices that could be made. The author looks forward to feedback from the CPT and SSC on these aspects of the model presented here, as well as on the model itself.

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Table 1. Estimated process error variance (and standard error and lower and upper confidence intervals) from the rema model fit to male survey biomass.

parameter	estimate	std. error	lci	uci
process error	0.3984	0.0518	0.3373	0.4707

Table 2. rema model results for mature male survey biomass.

year	observed value	lci	uci	rema value	lci	uci
1982	45.3	37.4	54.8	42.9	35.8	51.4
1983	28.3	23.1	34.6	29.1	24.3	34.8
1984	25.0	21.0	29.8	23.7	20.2	27.9
1985	11.5	9.4	14.1	12.6	10.5	15.1
1986	9.7	7.5	12.5	11.4	9.2	14.1
1987	19.3	15.8	23.6	20.0	16.7	24.0
1988	50.0	33.6	74.3	44.8	34.0	59.0
1989	88.8	74.7	105.7	83.6	71.2	98.2
1990	92.5	76.1	112.5	92.5	77.7	110.2
1991	107.5	83.1	139.1	102.5	82.6	127.2
1992	105.0	77.6	142.1	93.8	73.8	119.3
1993	62.0	51.1	75.3	62.4	52.5	74.3
1994	43.4	36.9	51.1	43.6	37.6	50.7
1995	32.2	25.7	40.4	32.0	26.4	39.0
1996	26.4	19.4	35.9	22.8	17.9	29.0
1997	10.2	8.7	11.9	10.8	9.3	12.6
1998	9.9	8.6	11.4	10.0	8.8	11.4
1999	10.4	8.5	12.8	10.8	9.0	13.0
2000	15.7	11.8	21.0	14.8	11.8	18.7
2001	17.3	14.3	20.9	17.0	14.3	20.2
2002	17.4	14.3	21.1	17.7	14.9	21.1
2003	21.3	17.5	26.1	21.2	17.8	25.4
2004	23.5	19.3	28.5	24.7	20.8	29.5
2005	42.3	35.5	50.4	41.2	35.1	48.4
2006	57.9	46.3	72.5	54.9	45.2	66.7
2007	55.9	42.1	74.2	55.1	43.7	69.5
2008	60.7	42.8	86.3	53.1	40.8	69.0
2009	36.9	30.9	44.1	38.4	32.6	45.2
2010	38.6	30.1	49.5	38.5	31.2	47.4
2011	39.9	29.9	53.2	37.9	30.1	47.8
2012	29.2	24.4	34.9	31.8	27.0	37.5
2013	59.3	44.1	79.7	54.3	43.0	68.6
2014	73.4	64.2	83.9	71.4	62.9	81.0
2015	62.3	55.1	70.5	62.6	55.7	70.4
2016	59.9	53.6	67.0	59.5	53.5	66.2
2017	49.5	43.0	56.9	49.2	43.1	56.1
2018	38.4	33.5	44.0	37.2	32.8	42.3
2019	17.8	15.5	20.5	18.6	16.3	21.2
2020	NA	NA	NA	15.9	11.0	23.2
2021	13.2	11.4	15.3	13.7	11.9	15.7
2022	17.7	15.2	20.6	17.3	15.0	20.0

Table 3. Retained catch biomass (t) in the directed Tanner crab fisheries (1982+) and incidental retention in the snow crab and BBRKC fisheries (2005+). Percents relative to the total retained catch are also listed. The author does not have retained catch split by management area before 2005/06. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

year	TCF (total)	TCF West 166W	TCF East 166W	SCF	RKF	% TCF (total)	% East 166W	% West 166W	% SCF	% RKF
1982	2,390	0	0	0	0	100	0	0	0	0
1983	549	0	0	0	0	100	0	0	0	0
1984	1,429	0	0	0	0	100	0	0	0	0
1987	998	0	0	0	0	100	0	0	0	0
1988	3,180	0	0	0	0	100	0	0	0	0
1989	11,113	0	0	0	0	100	0	0	0	0
1990	18,189	0	0	0	0	100	0	0	0	0
1991	14,424	0	0	0	0	100	0	0	0	0
1992	15,921	0	0	0	0	100	0	0	0	0
1993	7,666	0	0	0	0	100	0	0	0	0
1994	3,538	0	0	0	0	100	0	0	0	0
1995	1,919	0	0	0	0	100	0	0	0	0
1996	821	0	0	0	0	100	0	0	0	0
2005	245	245	0	188	0	57	0	57	43	0
2006	787	156	631	171	5	82	66	16	18	0
2007	861	151	710	86	8	90	74	16	9	1
2008	854	47	807	3	23	97	92	5	0	3
2009	592	0	592	2	8	98	98	0	0	1
2010	0	0	0	1	0	0	0	0	100	0
2011	0	0	0	2	0	0	0	0	100	0
2012	0	0	0	1	0	0	0	0	100	0
2013	1,248	594	654	10	6	99	52	47	1	1
2014	6,198	2,369	3,829	14	4	100	62	38	0	0
2015	8,878	3,770	5,108	30	1	100	57	42	0	0
2016	0	0	0	1	0	0	0	0	98	2
2017	1,118	1,117	0	15	0	99	0	99	1	0
2018	1,104	1,104	0	3	0	100	0	100	0	0

(continued)

year	TCF (total)	TCF West 166W	TCF East 166W	SCF	RKF	% TCF (total)	% East 166W	% West 166W	% SCF	% RKF
2019	0	0	0	0	0	0	0	0	100	0
2020	655	655	0	2	0	100	0	100	0	0
2021	494	494	0	1	0	100	0	100	0	0

Table 4. Sample sizes for retained crab size compositions in the crab fisheries. Percents relative to the area-aggregated directed fishery are also listed. The directed fisheries were both closed 1997/98-2004/05, 2010/11-2012/13, 2016/17, and 2019/20. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

year	TCF (total)	TCF West 166W	TCF East 166W	SCF	RKF
1989	35,956	0	0	0	0
1990	83,590	0	0	0	0
1991	127,227	0	0	0	0
1992	125,395	0	0	0	0
1993	71,622	0	0	0	0
1994	27,658	0	0	0	0
1995	19,276	0	0	0	0
1996	4,430	0	0	0	0
2004	0	0	0	16	0
2005	705	705	0	2,826	0
2006	2,940	581	2,359	2,520	847
2007	5,827	1,658	4,169	1,231	303
2008	3,490	521	2,969	125	699
2009	2,417	0	2,417	64	141
2010	0	0	0	42	0
2011	0	0	0	54	1
2012	0	0	0	36	1
2013	4,761	2,237	2,524	171	66
2014	14,371	6,819	7,552	270	82
2015	24,320	9,095	15,225	292	1
2016	0	0	0	43	0
2017	3,470	3,470	0	97	0
2018	3,306	3,306	0	68	0
2019	0	0	0	12	0
2020	3,323	3,323	0	115	0
2021	2,344	2,344	0	7	0

Table 5. Estimated annual total catch biomass (t) in the directed Tanner crab fisheries (1991+) and the snow crab and BBRKC fisheries (1990+). Percents relative to the total catch are also listed. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

year	TCF (total)	TCF West 166W	TCF East 166W	SCF	RKF	% TCF (total)	% East 166W	% West 166W	% SCF	% RKF
1990	0	0	0	7,187	3,758	0	0	0	66	34
1991	27,703	6,661	21,042	8,504	1,997	73	55	17	22	5
1992	38,711	7,947	30,764	2,650	1,336	91	72	19	6	3
1993	12,850	1,780	11,070	3,275	3,280	66	57	9	17	17
1994	8,157	470	7,687	1,539	0	84	79	5	16	0
1995	6,130	791	5,339	1,142	0	84	73	11	16	0
1996	357	72	285	2,080	272	13	11	3	77	10
1997	0	0	0	2,056	162	0	0	0	93	7
1998	0	0	0	736	117	0	0	0	86	14
1999	0	0	0	143	77	0	0	0	65	35
2000	0	0	0	319	68	0	0	0	82	18
2001	0	0	0	566	43	0	0	0	93	7
2002	0	0	0	181	63	0	0	0	74	26
2003	0	0	0	72	57	0	0	0	56	44
2004	0	0	0	175	51	0	0	0	77	23
2005	708	708	0	1,179	42	37	0	37	61	2
2006	1,832	652	1,181	1,613	31	53	34	19	46	1
2007	2,503	695	1,808	1,914	62	56	40	16	43	1
2008	1,305	121	1,184	1,125	282	48	44	4	41	10
2009	667	0	667	1,575	188	27	27	0	65	8
2010	0	0	0	1,462	32	0	0	0	98	2
2011	0	0	0	2,155	18	0	0	0	99	1
2012	0	0	0	1,575	43	0	0	0	97	3
2013	1,703	944	758	1,857	130	46	21	26	50	4
2014	8,403	3,087	5,315	5,381	306	60	38	22	38	2
2015	12,287	5,497	6,790	3,936	211	75	41	33	24	1
2016	0	0	0	2,592	180	0	0	0	94	6
2017	1,401	1,401	0	1,089	185	52	0	52	41	7

(continued)

year	TCF (total)	TCF West 166W	TCF East 166W	SCF	RKF	% TCF (total)	% East 166W	% West 166W	% SCF	% RKF
2018	1,633	1,633	0	889	74	63	0	63	34	3
2019	0	0	0	1,018	18	0	0	0	98	2
2020	1,581	1,581	0	132	6	92	0	92	8	0
2021	842	842	0	84	0	91	0	91	9	0

Table 6. Annual retained catch biomass and estimated discard mortality (t) in the crab fisheries for all Tanner crab and mature males only.

	TCF (total)			SCF			RKF		
year	all crab	discarded mature males	retained mature males	all crab	discarded mature males	retained mature males	all crab	discarded mature males	retained mature males
1982	885	732	2,390	144	49	0	251	242	0
1983	203	168	549	0	0	0	0	0	0
1984	529	438	1,429	278	160	0	72	69	0
1985	0	0	0	556	392	0	0	0	0
1986	0	0	0	675	491	0	442	427	0
1987	369	306	998	887	668	0	687	663	0
1988	1,177	974	3,180	754	558	0	282	272	0
1989	4,113	3,403	11,113	1,154	891	0	603	582	0
1990	6,732	5,571	18,189	2,307	2,018	0	1,206	1,186	0
1991	4,263	3,476	14,424	2,730	2,301	0	641	627	0
1992	7,316	6,199	15,921	851	485	0	429	411	0
1993	1,664	1,235	7,666	1,051	563	0	1,053	991	0
1994	1,483	1,162	3,538	494	198	0	0	0	0
1995	1,352	991	1,919	367	199	0	0	0	0
1996	0	0	821	668	454	0	87	86	0
1997	0	0	0	660	480	0	52	51	0
1998	0	0	0	236	158	0	38	36	0
1999	0	0	0	46	25	0	25	23	0
2000	0	0	0	102	67	0	22	20	0
2001	0	0	0	182	123	0	14	13	0
2002	0	0	0	58	29	0	20	19	0
2003	0	0	0	23	11	0	18	16	0
2004	0	0	0	56	14	0	17	15	0
2005	149	134	245	318	238	188	14	12	0
2006	336	274	787	463	365	171	8	7	5
2007	527	456	861	587	437	86	17	16	8
2008	145	136	854	360	244	3	83	81	23
2009	24	22	592	505	398	2	58	56	8
2010	0	0	0	469	402	1	10	10	0
2011	0	0	0	691	621	2	6	5	0
2012	0	0	0	505	432	1	14	13	0
2013	146	123	1,248	593	463	10	40	39	6

(continued)

year	all crab	discarded mature males	TCF (total) retained mature males	all crab	discarded mature males	SCF retained mature males	all crab	discarded mature males	RKF retained mature males
2014	708	576	6,198	1,723	1,295	14	97	96	4
2015	1,094	828	8,878	1,254	1,058	30	67	64	1
2016	0	0	0	832	694	1	58	55	0
2017	91	59	1,118	345	286	15	59	57	0
2018	170	125	1,104	284	240	3	24	24	0
2019	0	0	0	327	251	0	6	6	0
2020	297	203	655	41	26	2	2	2	0
2021	112	57	494	27	15	1	0	0	0

Table 7. Bycatch of Tanner crab (1,000s t; expanded to total catch biomass) in the groundfish fisheries by gear type for mature males and all crab.

year	fixed mature males	fixed total	trawl mature males	trawl total	all gear mature males	all gear total
1973	–	–	–	–	7.5856	17.7355
1974	–	–	–	–	14.9077	24.4486
1975	–	–	–	–	5.5407	9.4075
1976	–	–	–	–	2.7143	4.6992
1977	–	–	–	–	1.5415	2.7760
1978	–	–	–	–	0.4377	1.8688
1979	–	–	–	–	1.0319	3.3974
1980	–	–	–	–	0.8936	2.1137
1981	–	–	–	–	0.5501	1.4742
1982	–	–	–	–	0.1876	0.4491
1983	–	–	–	–	0.4603	0.6713
1984	–	–	–	–	0.3745	0.6441
1985	–	–	–	–	0.1665	0.3992
1986	–	–	–	–	0.2878	0.6486
1987	–	–	–	–	0.3577	0.6396
1988	–	–	–	–	0.2555	0.4627
1989	–	–	–	–	0.3341	0.6713
1990	–	–	–	–	0.4256	0.9435
1991	0.1118	0.1483	1.1603	2.3949	–	–
1992	0.0806	0.1027	1.2750	2.6569	–	–
1993	0.0217	0.0235	1.0474	1.7345	–	–
1994	0.0216	0.0239	1.5036	2.0721	–	–
1995	0.0630	0.1279	0.7552	1.3970	–	–
1996	0.0948	0.1180	0.8108	1.4765	–	–
1997	0.0501	0.0639	0.3855	1.1160	–	–
1998	0.0445	0.0880	0.3096	0.8471	–	–
1999	0.0533	0.0848	0.2097	0.5459	–	–
2000	0.0451	0.0531	0.3588	0.6884	–	–
2001	0.1122	0.1247	0.6542	1.0605	–	–
2002	0.0837	0.0955	0.4205	0.6236	–	–
2003	0.0139	0.0204	0.2211	0.4034	–	–
2004	0.0446	0.0649	0.3588	0.6102	–	–
2005	0.1034	0.1331	0.2617	0.4881	–	–
2006	0.2788	0.3459	0.1963	0.3712	–	–
2007	0.3580	0.4744	0.1017	0.2206	–	–
2008	0.2264	0.2876	0.1481	0.2453	–	–
2009	0.1849	0.2253	0.0955	0.1488	–	–
2010	0.1015	0.1179	0.0684	0.1135	–	–

(continued)

		fixed		trawl		all gear
year	mature males	total	mature males	total	mature males	total
2011	0.0699	0.0764	0.0462	0.1276	–	–
2012	0.0403	0.0461	0.0478	0.1072	–	–
2013	0.1478	0.1816	0.0650	0.1668	–	–
2014	0.2234	0.2613	0.0698	0.1744	–	–
2015	0.2180	0.2760	0.0456	0.0853	–	–
2016	0.1364	0.1611	0.0836	0.1451	–	–
2017	0.0937	0.1144	0.0321	0.0497	–	–
2018	0.1050	0.1224	0.0290	0.0565	–	–
2019	0.0311	0.0448	0.0500	0.1031	–	–
2020	0.0153	0.0234	0.0237	0.1017	–	–
2021	0.0272	0.0569	0.0340	0.1124	–	–

Table 8. Fraction of Tanner crab bycatch in the groundfish fisheries by gear type for mature males.

year	fixed	trawl	all gear
1973	–	–	0.428
1974	–	–	0.610
1975	–	–	0.589
1976	–	–	0.578
1977	–	–	0.555
1978	–	–	0.234
1979	–	–	0.304
1980	–	–	0.423
1981	–	–	0.373
1982	–	–	0.418
1983	–	–	0.686
1984	–	–	0.581
1985	–	–	0.417
1986	–	–	0.444
1987	–	–	0.559
1988	–	–	0.552
1989	–	–	0.498
1990	–	–	0.451
1991	0.754	0.484	–
1992	0.785	0.480	–
1993	0.925	0.604	–
1994	0.905	0.726	–
1995	0.493	0.541	–
1996	0.804	0.549	–
1997	0.783	0.345	–
1998	0.506	0.366	–
1999	0.628	0.384	–
2000	0.848	0.521	–
2001	0.900	0.617	–
2002	0.876	0.674	–
2003	0.679	0.548	–
2004	0.688	0.588	–
2005	0.777	0.536	–
2006	0.806	0.529	–
2007	0.755	0.461	–
2008	0.787	0.604	–
2009	0.820	0.642	–
2010	0.861	0.602	–
2011	0.916	0.362	–

(continued)

year	fixed	trawl	all gear
2012	0.874	0.446	–
2013	0.814	0.389	–
2014	0.855	0.400	–
2015	0.790	0.535	–
2016	0.846	0.576	–
2017	0.819	0.646	–
2018	0.858	0.513	–
2019	0.695	0.485	–
2020	0.655	0.233	–
2021	0.478	0.302	–

Table 9. Estimated bycatch mortality of Tanner crab in the groundfish fisheries by gear type for mature males and all crab (1,000s t).

	fixed		trawl		all gear	
year	mature males	total	mature males	total	mature males	total
1973	–	–	–	–	6.06847	14.18837
1974	–	–	–	–	11.92620	19.55890
1975	–	–	–	–	4.43257	7.52600
1976	–	–	–	–	2.17143	3.75937
1977	–	–	–	–	1.23323	2.22079
1978	–	–	–	–	0.35019	1.49504
1979	–	–	–	–	0.82554	2.71793
1980	–	–	–	–	0.71486	1.69099
1981	–	–	–	–	0.44007	1.17934
1982	–	–	–	–	0.15005	0.35925
1983	–	–	–	–	0.36827	0.53705
1984	–	–	–	–	0.29960	0.51528
1985	–	–	–	–	0.13321	0.31933
1986	–	–	–	–	0.23021	0.51891
1987	–	–	–	–	0.28618	0.51165
1988	–	–	–	–	0.20437	0.37013
1989	–	–	–	–	0.26731	0.53705
1990	–	–	–	–	0.34050	0.75478
1991	0.05589	0.07413	0.92823	1.91593	–	–
1992	0.04029	0.05136	1.01996	2.12554	–	–
1993	0.01086	0.01175	0.83794	1.38761	–	–
1994	0.01081	0.01194	1.20287	1.65769	–	–
1995	0.03149	0.06393	0.60415	1.11761	–	–
1996	0.04741	0.05898	0.64860	1.18122	–	–
1997	0.02504	0.03197	0.30837	0.89282	–	–
1998	0.02224	0.04398	0.24770	0.67766	–	–
1999	0.02663	0.04238	0.16773	0.43668	–	–
2000	0.02253	0.02657	0.28703	0.55072	–	–
2001	0.05612	0.06234	0.52338	0.84841	–	–
2002	0.04186	0.04776	0.33643	0.49884	–	–
2003	0.00693	0.01021	0.17691	0.32271	–	–
2004	0.02230	0.03243	0.28704	0.48816	–	–
2005	0.05170	0.06653	0.20939	0.39049	–	–
2006	0.13940	0.17297	0.15704	0.29696	–	–
2007	0.17900	0.23718	0.08137	0.17645	–	–
2008	0.11319	0.14378	0.11848	0.19625	–	–
2009	0.09243	0.11267	0.07642	0.11907	–	–
2010	0.05073	0.05895	0.05469	0.09078	–	–

(continued)

year	mature males	fixed total	mature males	trawl total	mature males	all gear total
2011	0.03497	0.03818	0.03694	0.10210	–	–
2012	0.02013	0.02304	0.03821	0.08574	–	–
2013	0.07390	0.09078	0.05198	0.13345	–	–
2014	0.11169	0.13066	0.05585	0.13952	–	–
2015	0.10901	0.13798	0.03647	0.06820	–	–
2016	0.06818	0.08055	0.06685	0.11612	–	–
2017	0.04685	0.05721	0.02567	0.03977	–	–
2018	0.05252	0.06119	0.02318	0.04521	–	–
2019	0.01556	0.02238	0.03999	0.08245	–	–
2020	0.00766	0.01168	0.01895	0.08133	–	–
2021	0.01360	0.02845	0.02718	0.08989	–	–

Table 10. Time series associated with calculating the Tier 4 management quantities for Tanner crab. All all quantities are in metric tons.

	Survey	Fishing Mortality			Derived Quantities			
		retained	discards		MMB			
year	MMB	all crab	all crab	mature males	before fishery	after fishery	at mating	recruitment
1982	42,921	2,390	1,280	1,023	37,174	33,761	31,720	-2,041
1983	29,099	549	204	168	25,202	24,485	25,884	1,399
1984	23,745	1,429	879	667	20,566	18,470	13,688	-4,782
1985	12,557	0	556	392	10,875	10,483	12,409	1,926
1986	11,384	0	1,118	918	9,860	8,941	21,849	12,907
1987	20,043	998	1,944	1,637	17,359	14,724	48,858	34,134
1988	44,820	3,180	2,213	1,803	38,819	33,836	91,150	57,314
1989	83,618	11,113	5,870	4,877	72,422	56,432	100,873	44,441
1990	92,538	18,189	10,246	8,776	80,147	53,183	111,704	58,522
1991	102,474	14,424	7,636	6,405	88,753	67,924	102,303	34,379
1992	93,849	15,921	8,597	7,096	81,283	58,266	68,061	9,796
1993	62,437	7,666	3,770	2,789	54,077	43,623	47,578	3,956
1994	43,647	3,538	1,979	1,361	37,803	32,904	34,929	2,025
1995	32,042	1,919	1,720	1,191	27,752	24,642	24,836	194
1996	22,783	821	756	541	19,733	18,370	11,812	-6,558
1997	10,836	0	713	531	9,385	8,854	10,933	2,079
1998	10,030	0	275	194	8,687	8,493	11,791	3,298
1999	10,817	0	71	48	9,368	9,320	16,168	6,848
2000	14,832	0	125	87	12,846	12,759	18,558	5,798
2001	17,024	0	196	137	14,745	14,608	19,323	4,715
2002	17,727	0	79	49	15,353	15,304	23,161	7,857
2003	21,247	0	42	27	18,402	18,375	26,974	8,599
2004	24,745	0	73	29	21,432	21,403	44,933	23,529
2005	41,220	432	481	384	35,700	34,884	59,843	24,958
2006	54,897	963	807	647	47,547	45,937	60,104	14,166
2007	55,137	956	1,131	908	47,754	45,890	57,853	11,963
2008	53,072	880	589	461	45,966	44,626	41,871	-2,754
2009	38,411	603	587	477	33,268	32,188	41,925	9,736
2010	38,460	1	480	412	33,311	32,898	41,324	8,426
2011	37,909	2	697	627	32,833	32,204	34,671	2,467
2012	31,806	1	519	445	27,547	27,101	59,226	32,125
2013	54,332	1,264	779	625	47,057	45,168	77,797	32,629
2014	71,368	6,216	2,528	1,967	61,813	53,629	68,264	14,636
2015	62,623	8,910	2,415	1,949	54,238	43,380	64,859	21,480
2016	59,500	1	890	749	51,533	50,783	53,608	2,825
2017	49,178	1,133	495	401	42,593	41,059	40,592	-467
2018	37,238	1,107	478	388	32,252	30,756	20,236	-10,520
2019	18,564	0	333	257	16,078	15,821	17,364	1,542
2020	15,929	658	341	230	13,796	12,908	14,899	1,991
2021	13,668	494	139	72	11,838	11,271	18,882	7,611
2022	17,322	1,774	303	239	15,002	12,989	25,068	12,079

Table 11. Example Tier 4 management quantities for Tanner crab. M was set to 0.23. The period to determine B_{MSY} was 1982-2021; the same period was used to calculate average recruitment used in the projection. The period 2005-2021 was used to determine \theta and p_{MM}.

Quantity	Value	Units
assessment year	2022/23	–
MMB-at-mating	25,068	t
$MSST$	21,160	t
status ratio	0.592	–
status	not overfished	–
F_{MSY}	0.23	–
F_{OFL}	0.126	–
OFL	2,076	t
retained OFL	1,774	t
discard OFL	303	t

Figures

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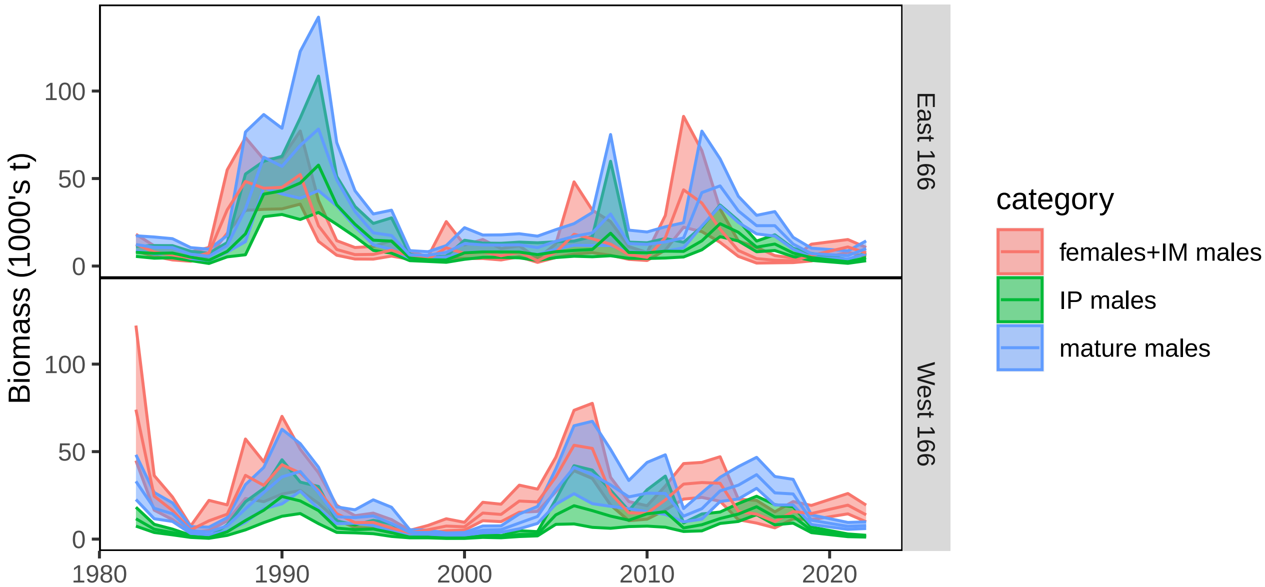

Figure 1. Tanner crab biomass estimates from the NMFS EBS shelf survey, by State management area.

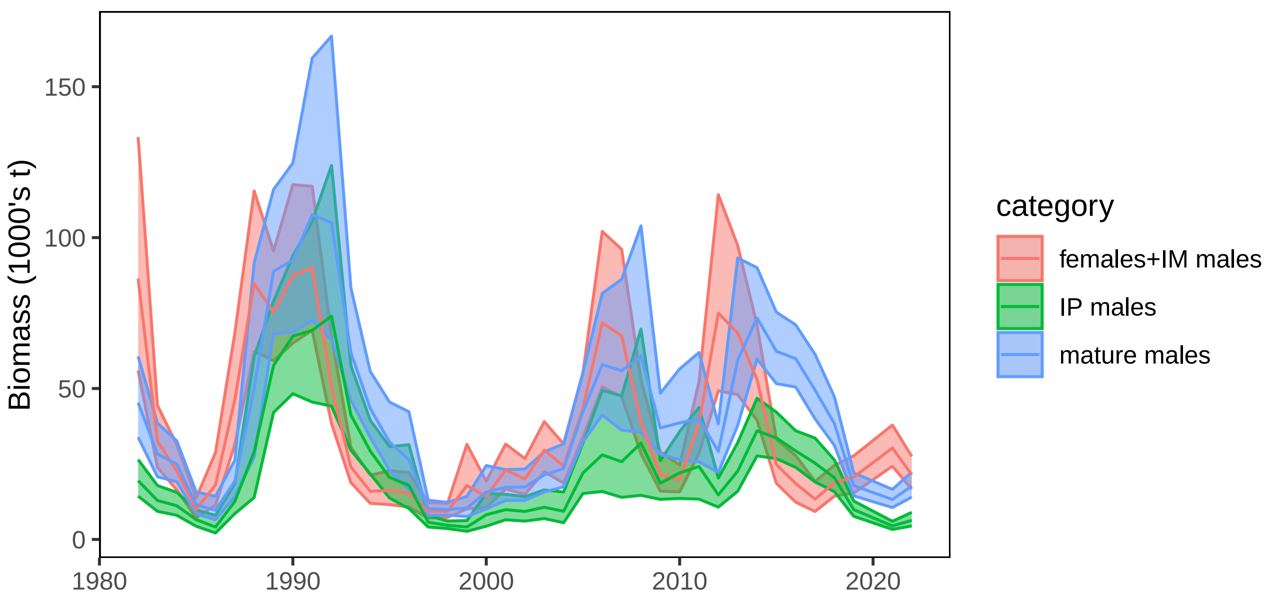

Figure 2. Tanner crab biomass estimates from the NMFS EBS shelf survey.

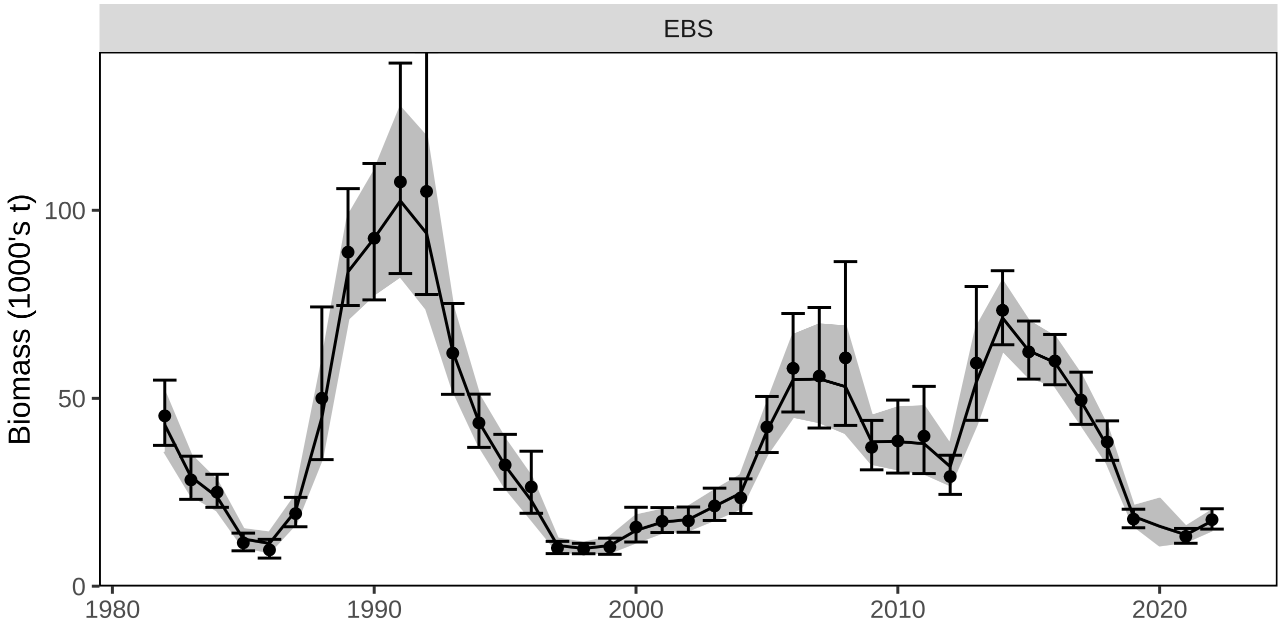

Figure 3. Results for the **rema** model fit to mature survey biomass.

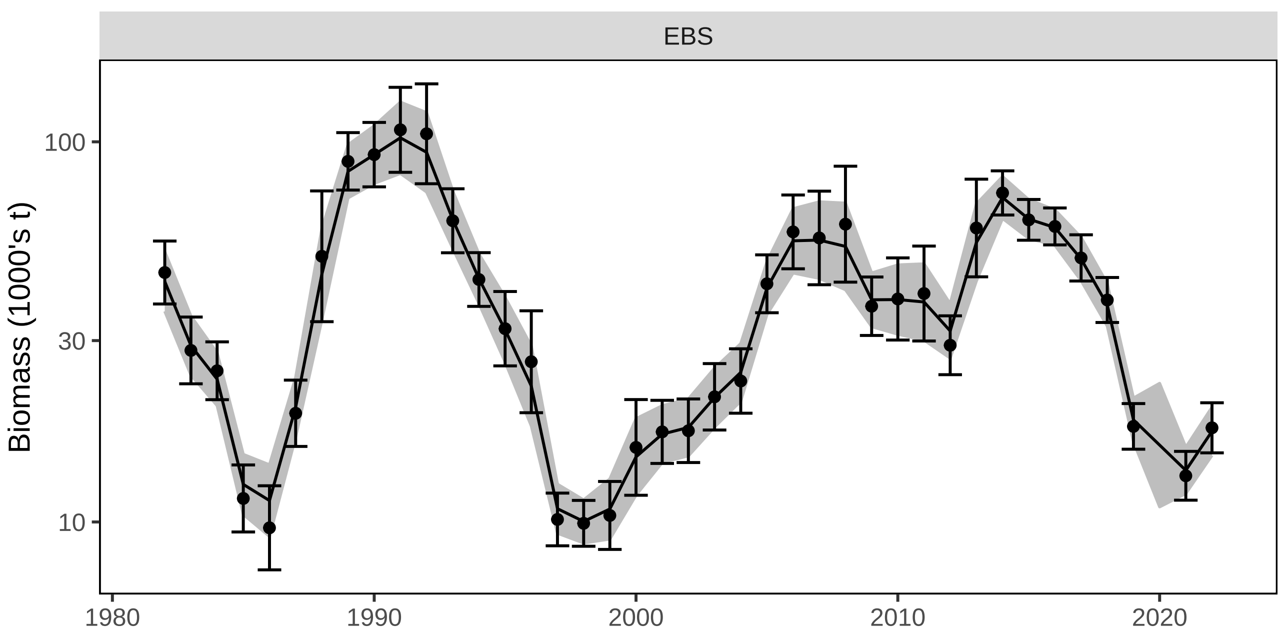

Figure 4. Results for the **rema** model fit to mature male survey biomass.

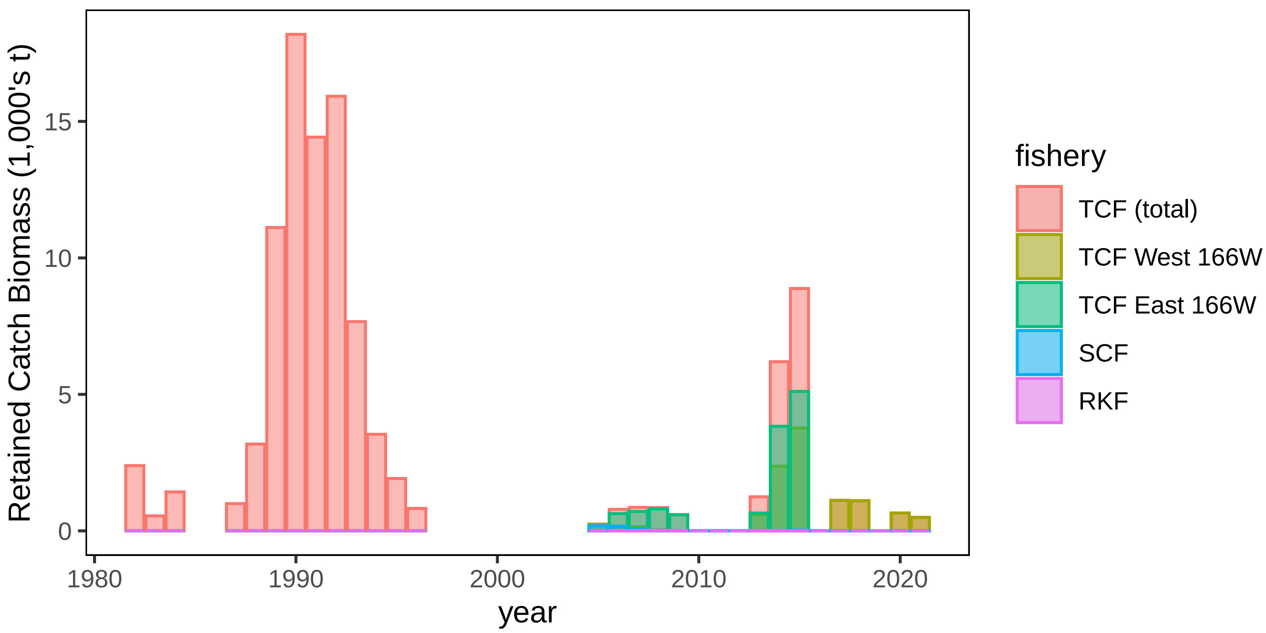

Figure 5. Annual retained catch biomass (1000's t) in the directed Tanner crab fisheries (TCF) by total and state management area (when available) for 1982-2021/22, as well as incidental retention in the snow crab and BBRKC fisheries (since 2005). TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

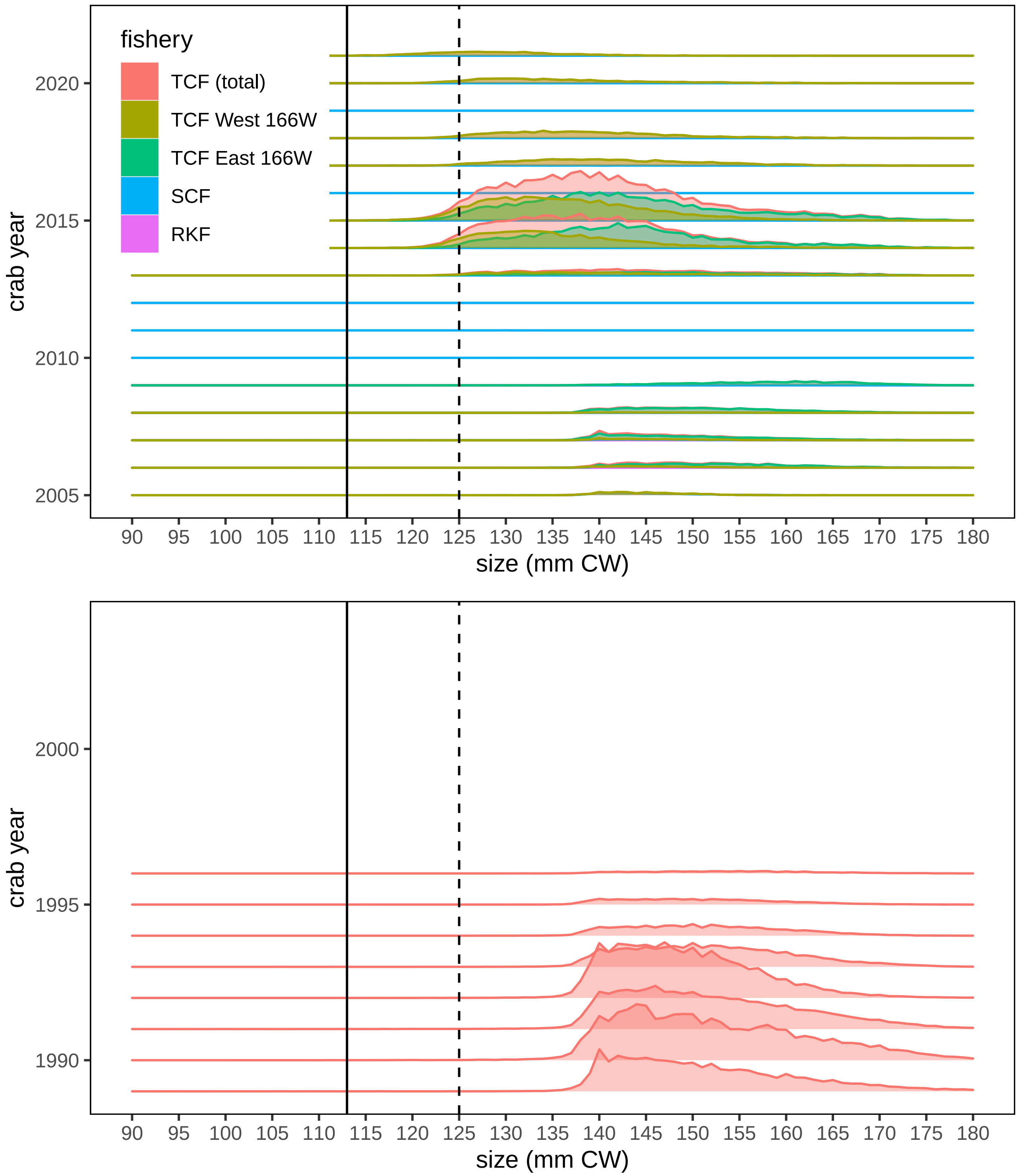

Figure 6. Retained catch size compositions with size bin counts scaled by individual crab biomass, then expanded to total retained catch biomass. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

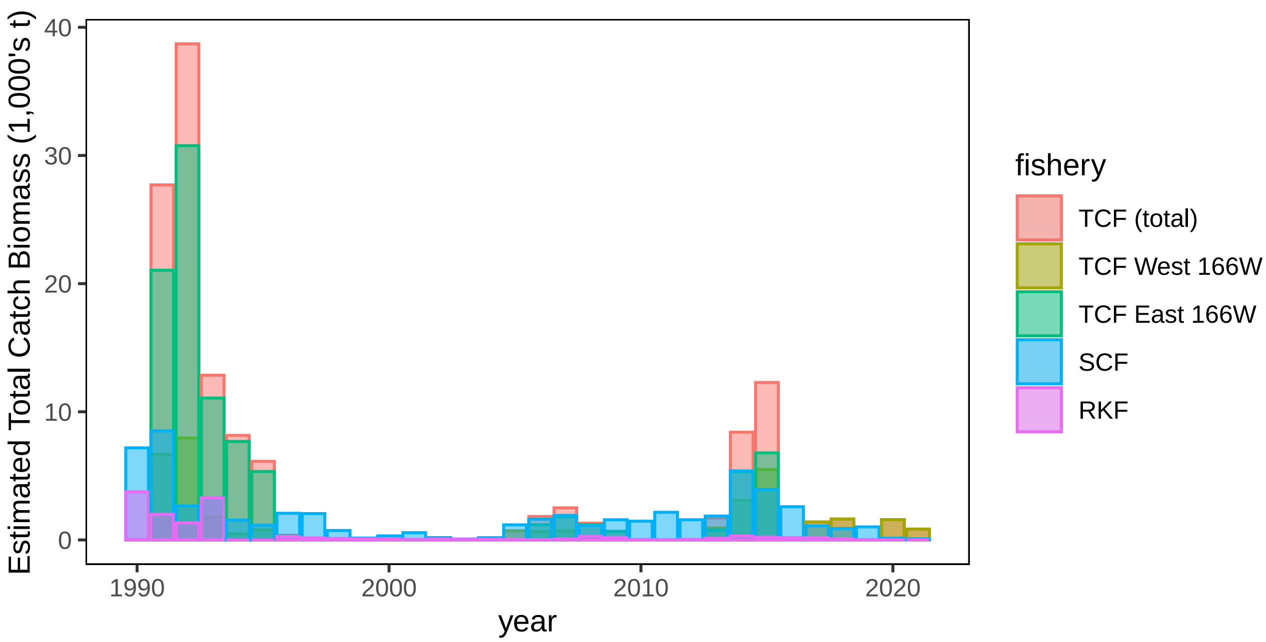

Figure 7. Estimated annual total catch biomass (1000's t) in the directed Tanner crab fisheries (TCF) by total and state management area (1991+) as well as bycatch in the snow crab and BBRKC fisheries (since 1990). TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

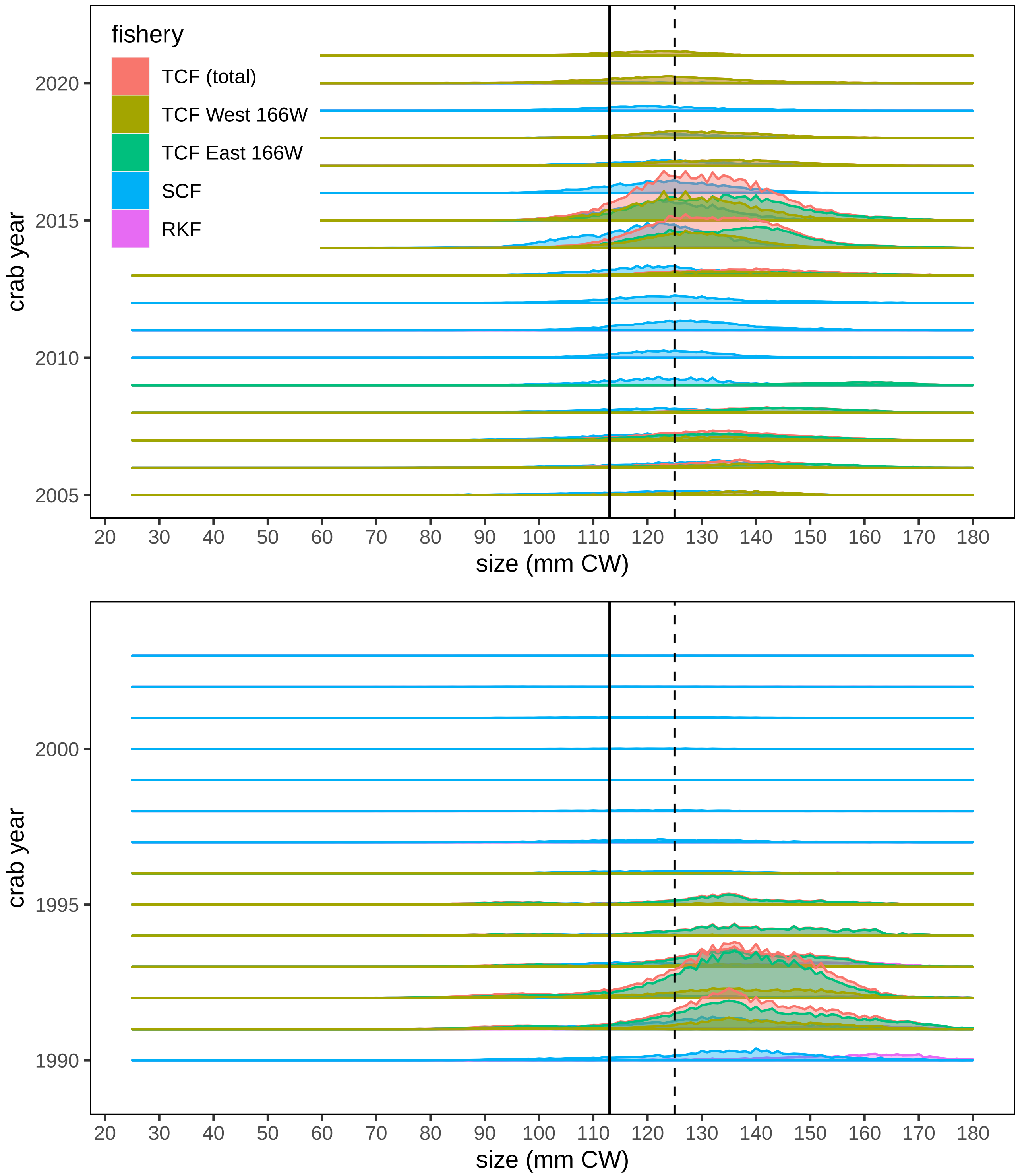

Figure 8. Total catch size compositions for all crab, with sex-specific size bin counts scaled by individual crab biomass, then expanded to total catch biomass. Solid line: assumed sie at male maturity; dashed line: industry-preferred size. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

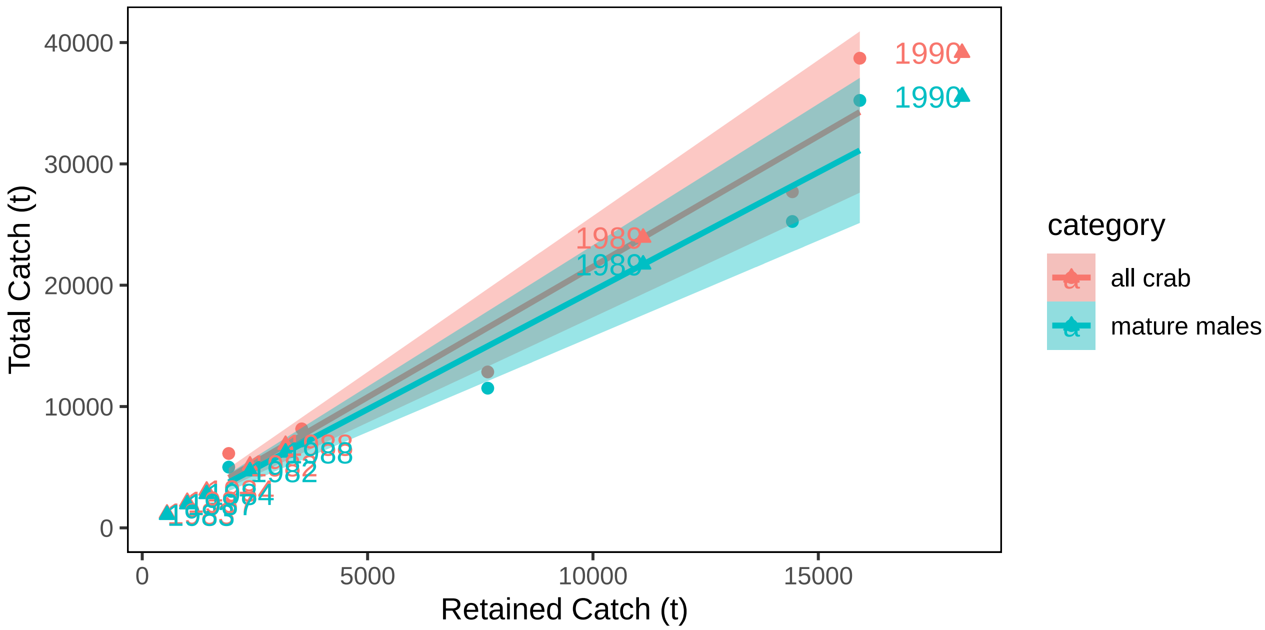

Figure 9. Linear regressions of all crab and mature male catch biomass on retained catch in the (area-aggregated) directed fishery (circles, line) and values extrapolated for 1982-1990 (triangles). The adjusted R^2 for the regressions 0.976 for all crab and 0.976 for mature males.

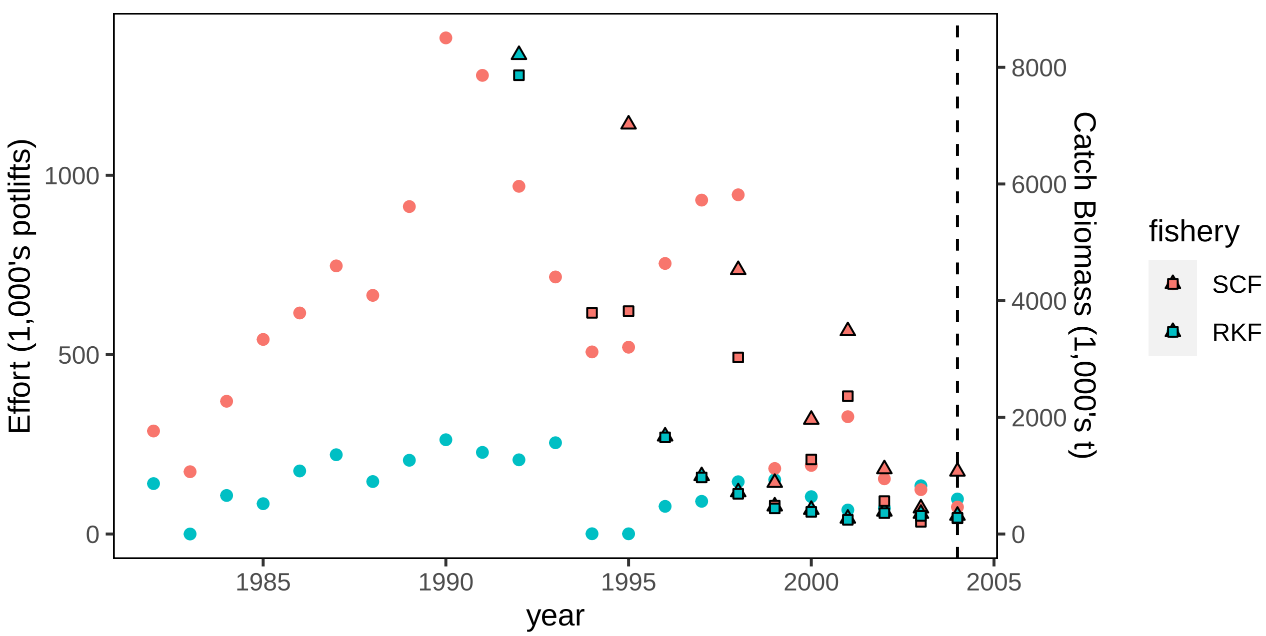

Figure 10. Annual effort (potlifts, filled circles) and previously-estimated total catch biomass for all Tanner crab (filled triangles) and just mature males (filled squares)in the snow crab and BBRKC fisheries, 1982-2004.

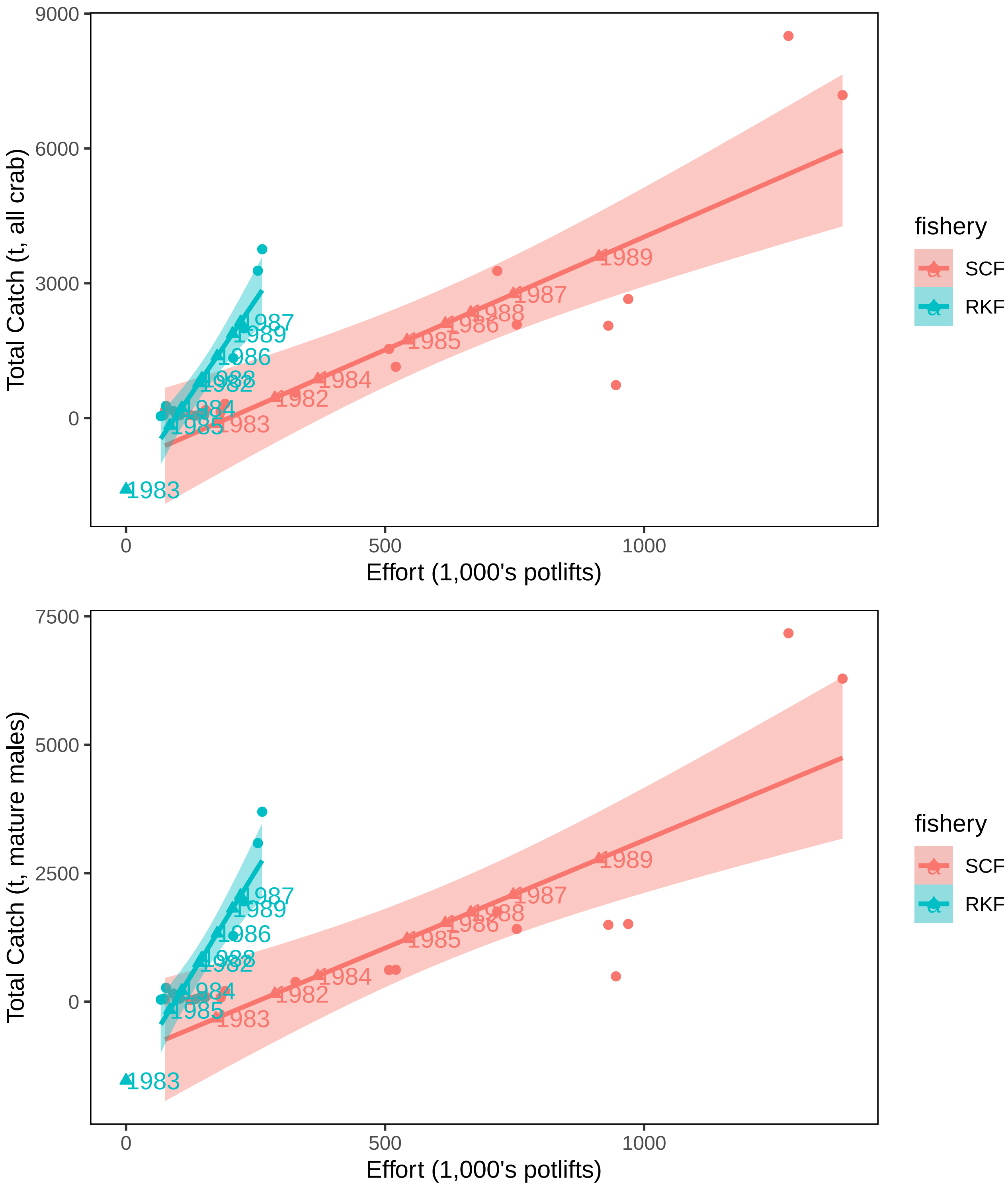

Figure 11. Linear regressions of mature male and all crab total catch on fishery effort (potlifts) and extrapolated values (1982-1989) for the snow crab and BBRKC fisheries. Adjusted R^2 for the snow crab fishery regressions: 1) all crab = 0.690, 2) mature males = 0.640; for the BBRKC fishery: 1) all crab = 0.787, 2) mature males = 0.785.

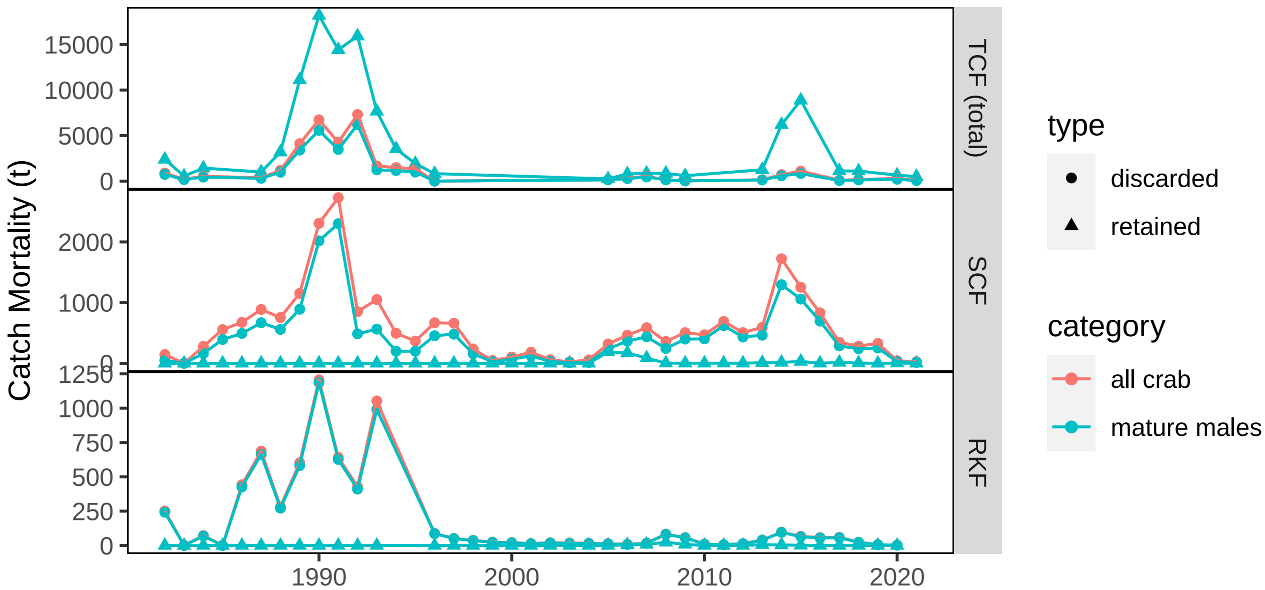

Figure 12. Annual retained catch biomass and estimated discard mortality (t) in the crab fisheries for all Tanner crab and for mature males only.

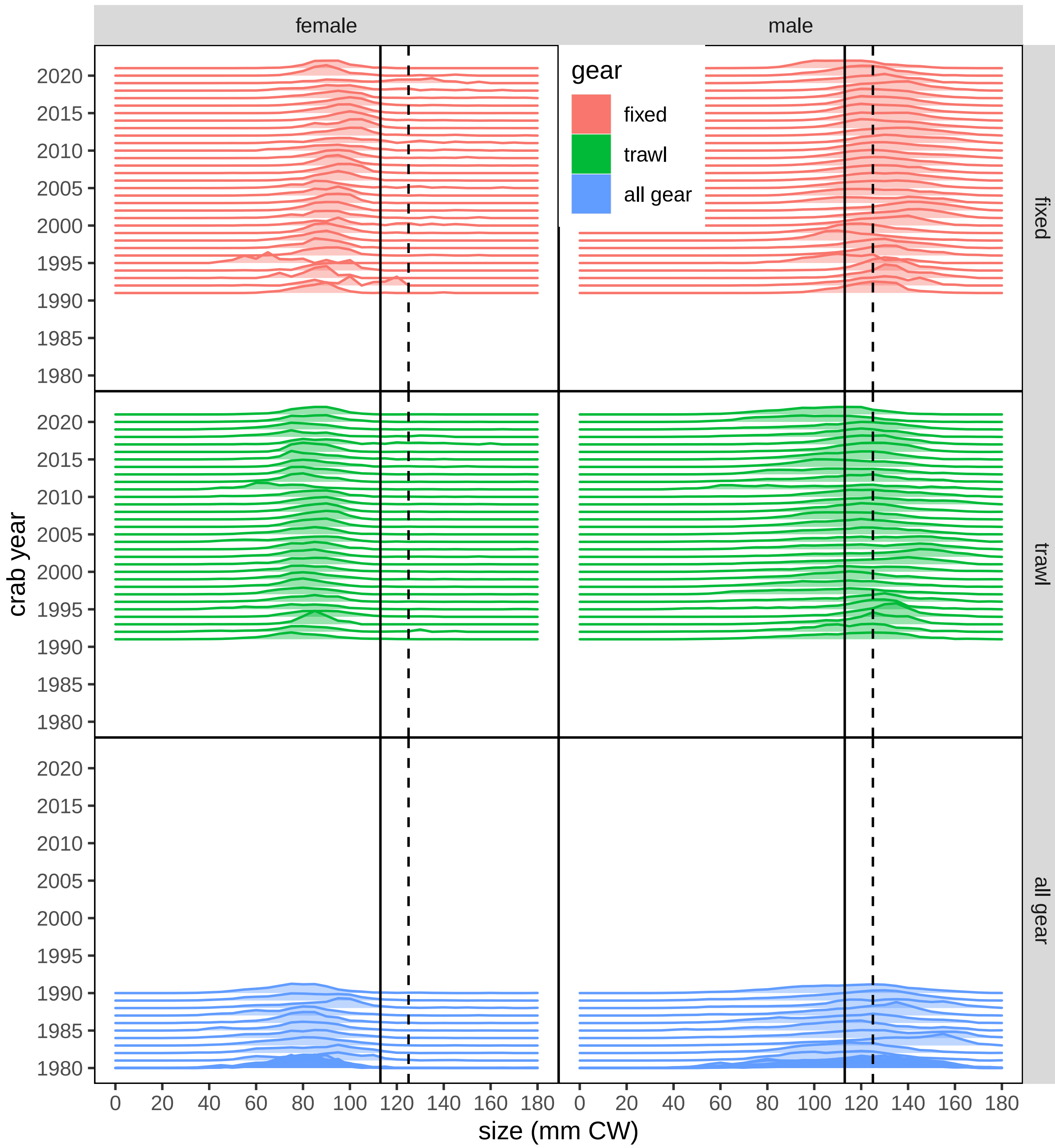

Figure 13. Tanner crab bycatch (as fractions of annual biomass by year/gear/sex) in the groundfish fisheries. The vertical scales differ between

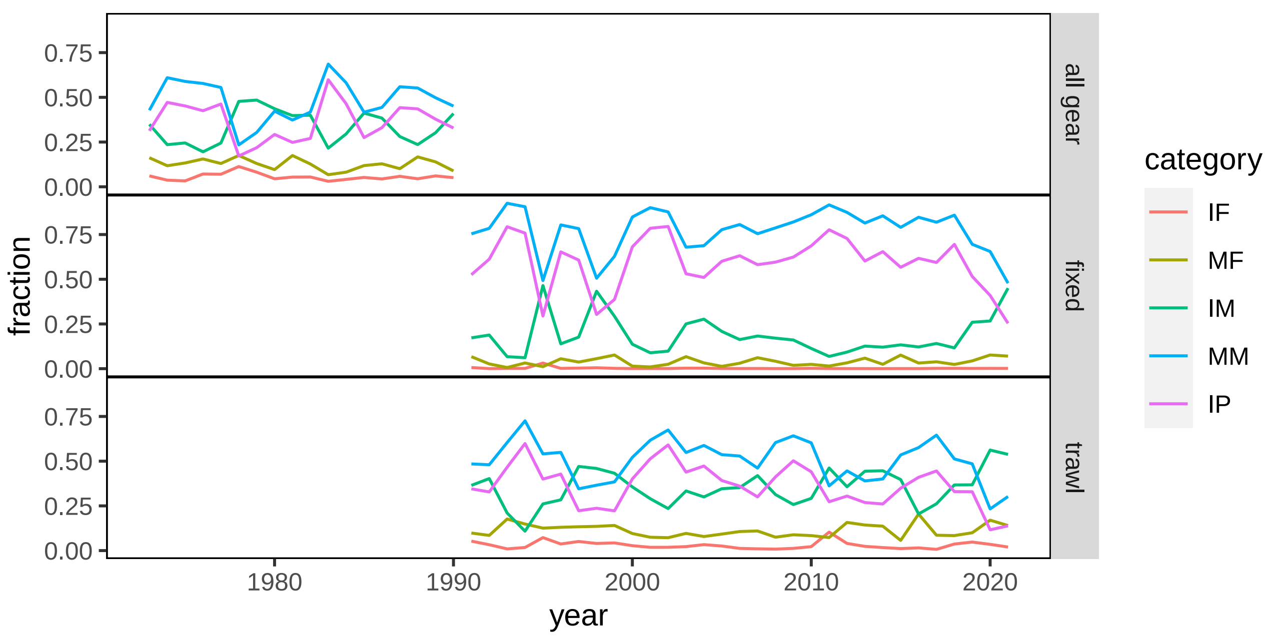

Figure 14. Fraction of bycatch of Tanner crab in the groundfish fisheries by gear type and life stage. IF: immature females; MF: mature females; IM: immature males; MM: mature males; IP: industry-preferred males.

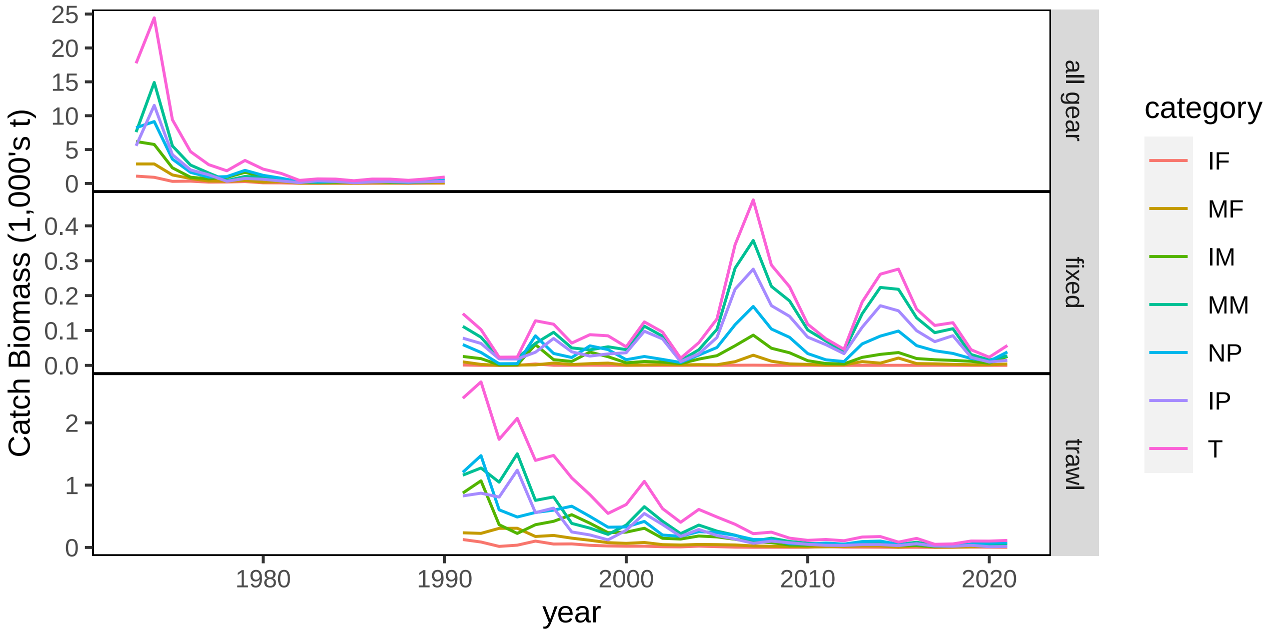

Figure 15. Bycatch of Tanner crab (expanded to total biomass) in the groundfish fisheries by gear type and life stage. IF: immature females; MF: mature females; IM: immature males; MM: mature males; IP: industry-preferred males; T: total biomass.

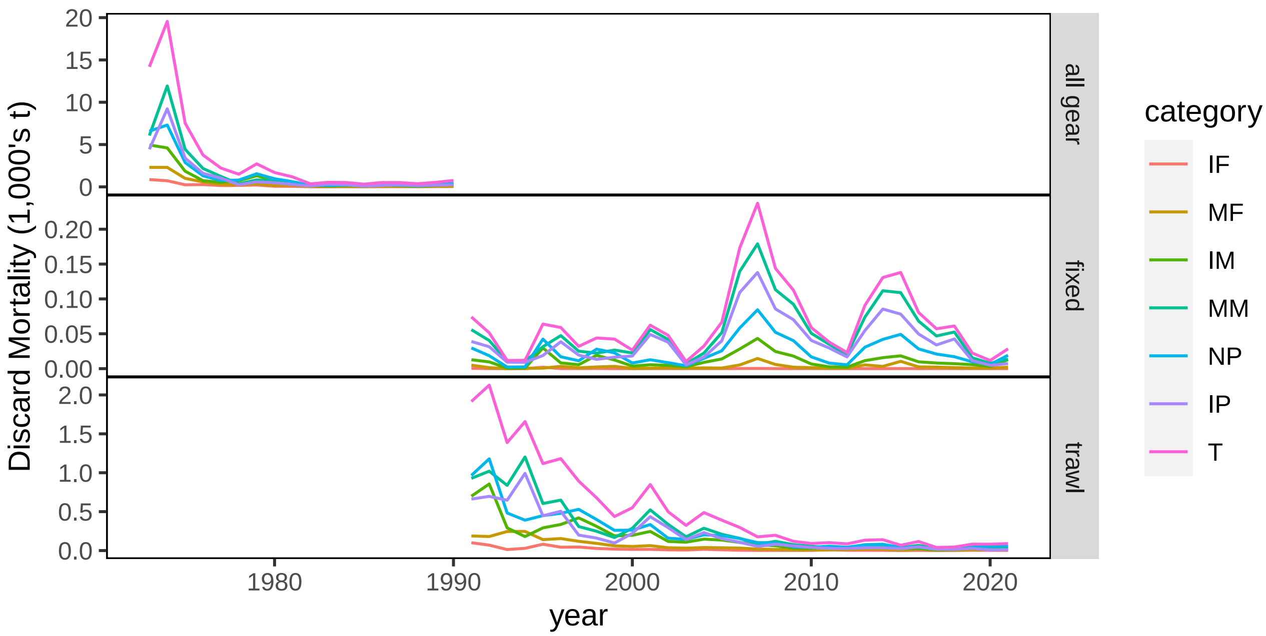

Figure 16. Estimated bycatch mortality of Tanner crab in the groundfish fisheries by gear type and life stage. IF: immature females; MF: mature females; IM: immature males; MM: mature males; IP: industry-preferred males; T: total.

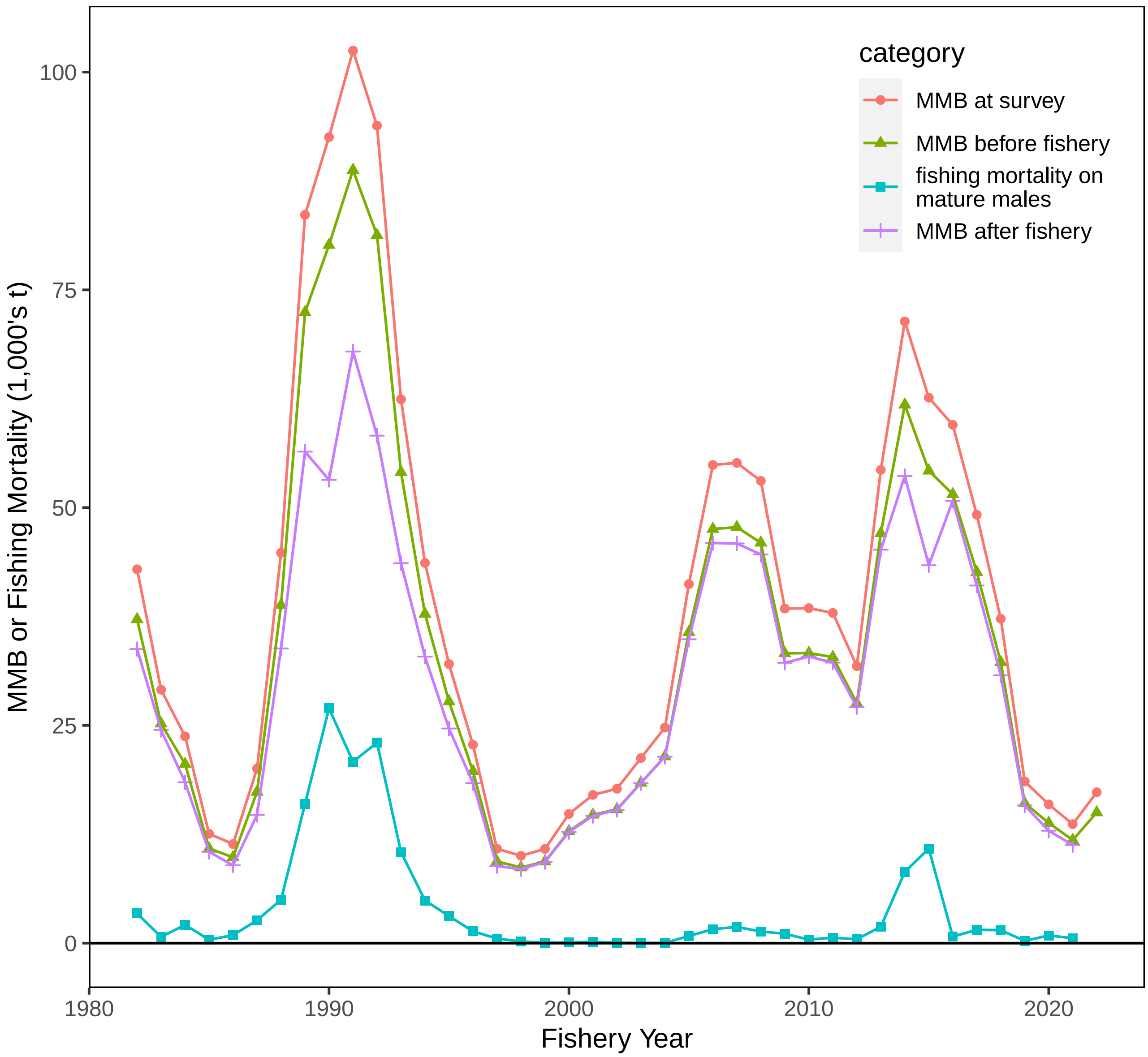

Figure 17. Progression from MMB at the time of the survey (red line) to just before the fishery (decremented for natural mortality, blue line), to just after the fishery (purple line), taking into account fishing mortality on mature males (blue line).

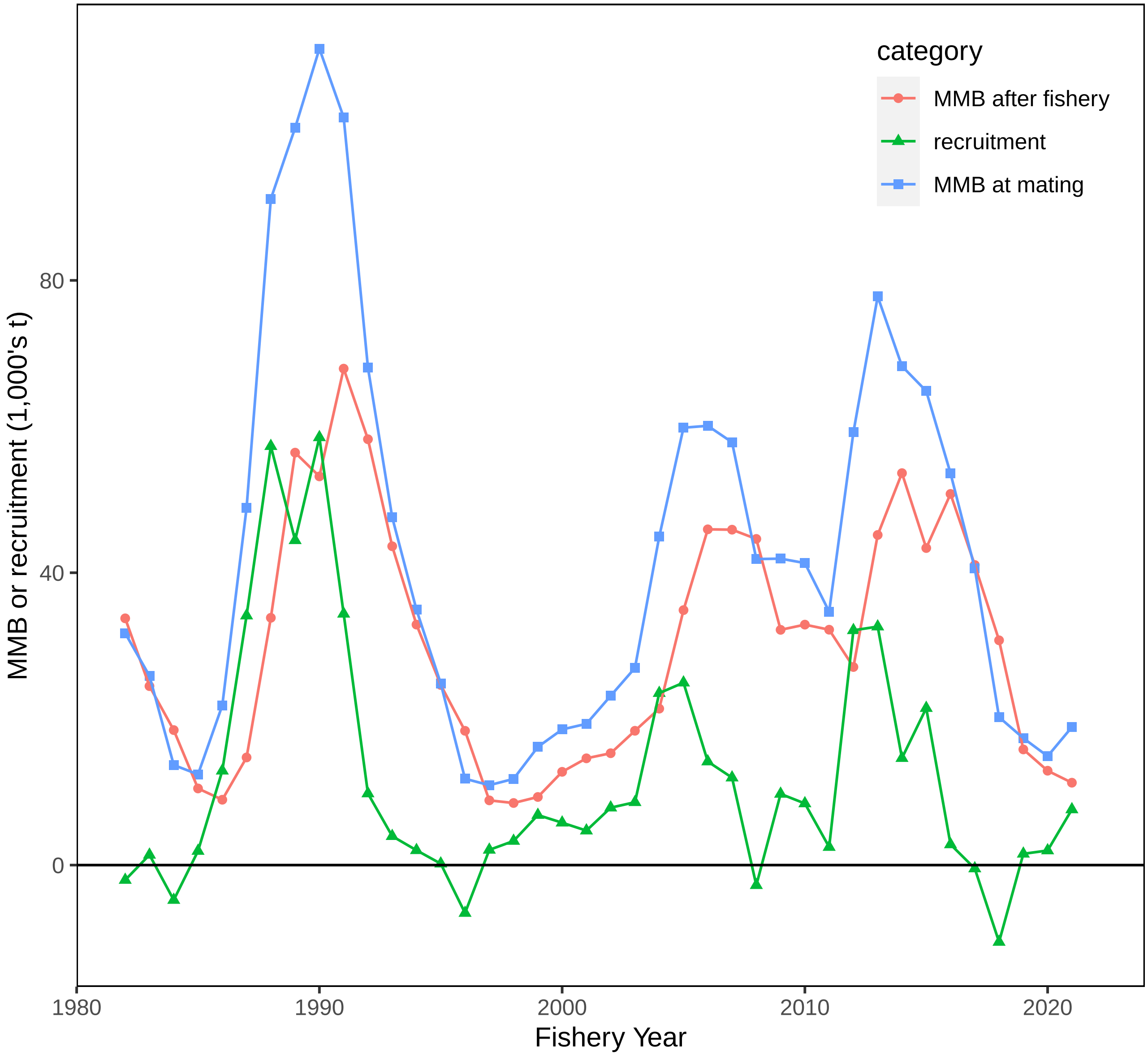

Figure 18. Progression from MMB just after the fishery (red line) to MMB at mating (blue line), with recriutment into the mature male portion of the stock (green line). The latter is based on the difference between MMB at mating in 'this' year and MMB at the time of the survey in the subsequent year, taking natural mortality into account.

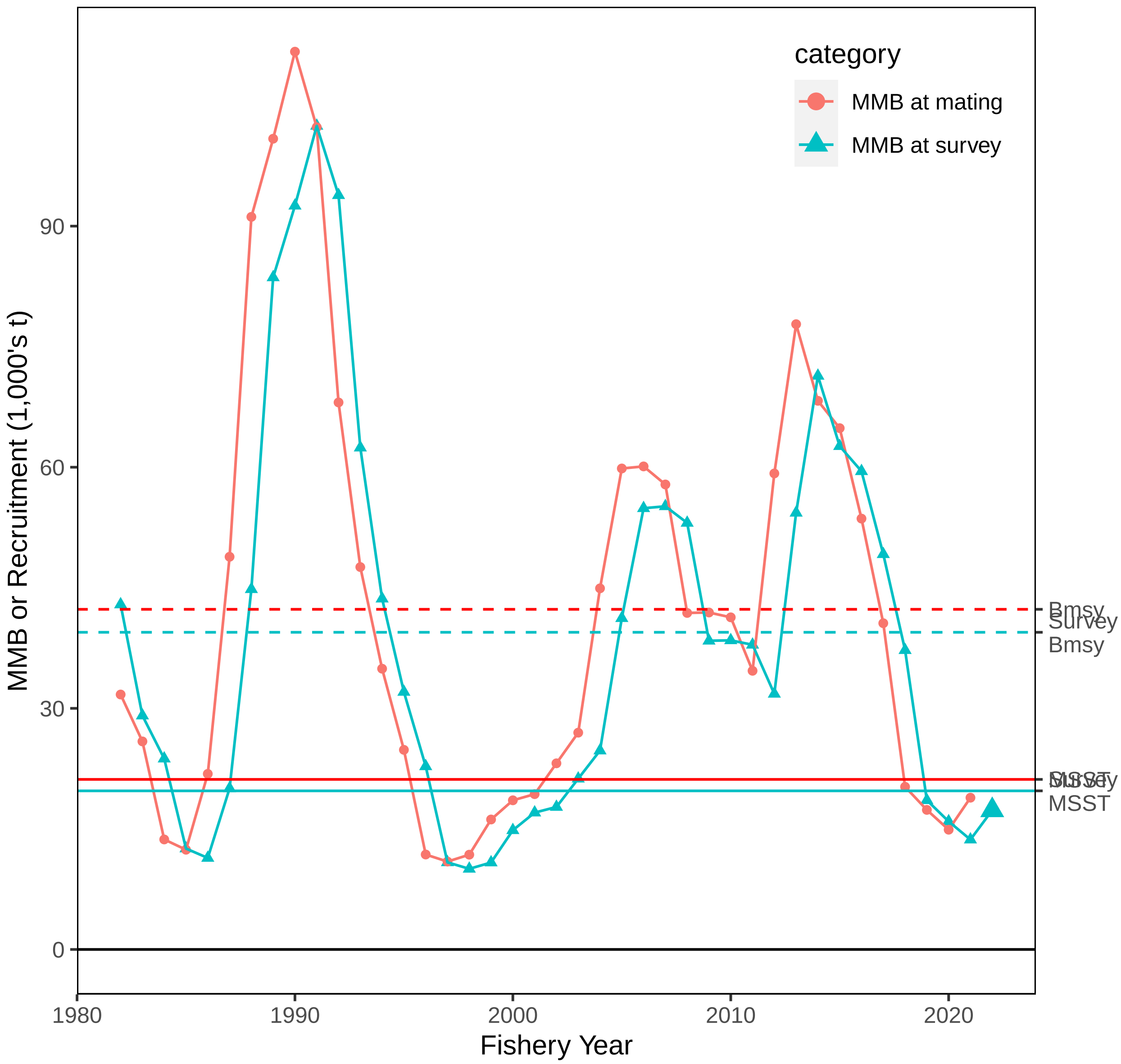

Figure 19. Time series used in the Tier 4 calculations for 2022/23and derived management quantities: B_{MSY}–dashed red line, MSST–solid red line. Also shown (green horizontal lines) are B_{MSY} and MSST calculated using only MMB at the time of the survey (similar to a Tier 5 calculation for groundfish).

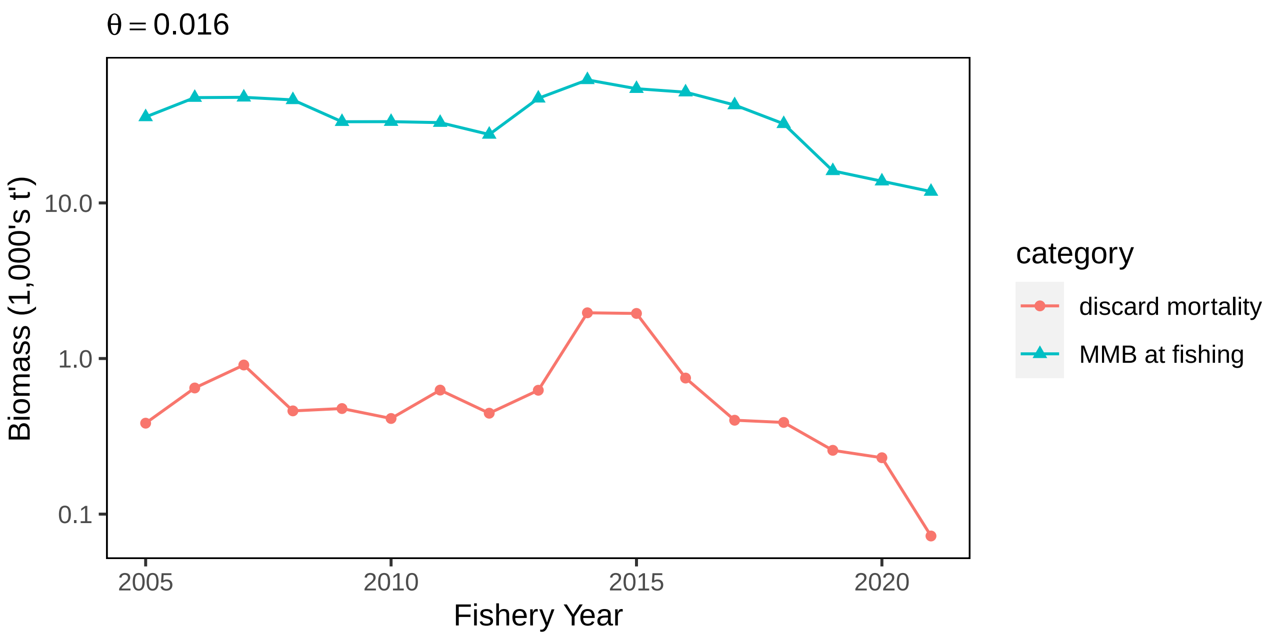

Figure 20. Time series on log scale of discard mortality on mature males and MMB at the assumed time of fishing. The average of the annual ratios over the time frame is taken as θ, a scalar in determining discard mortality.

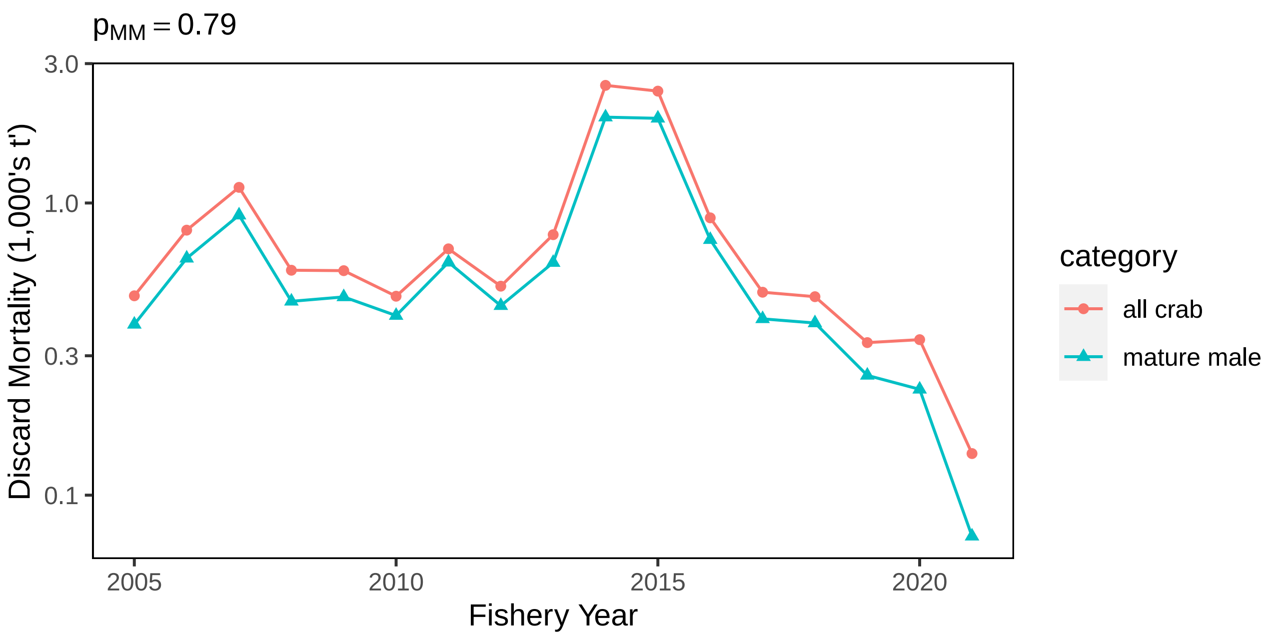

Figure 21. Time series on log scale of discard mortality on mature crab only and on all crab. The average of the annual ratios over the time period shown is taken as p_{mm}, the average fraction of discard mortality on mature males.

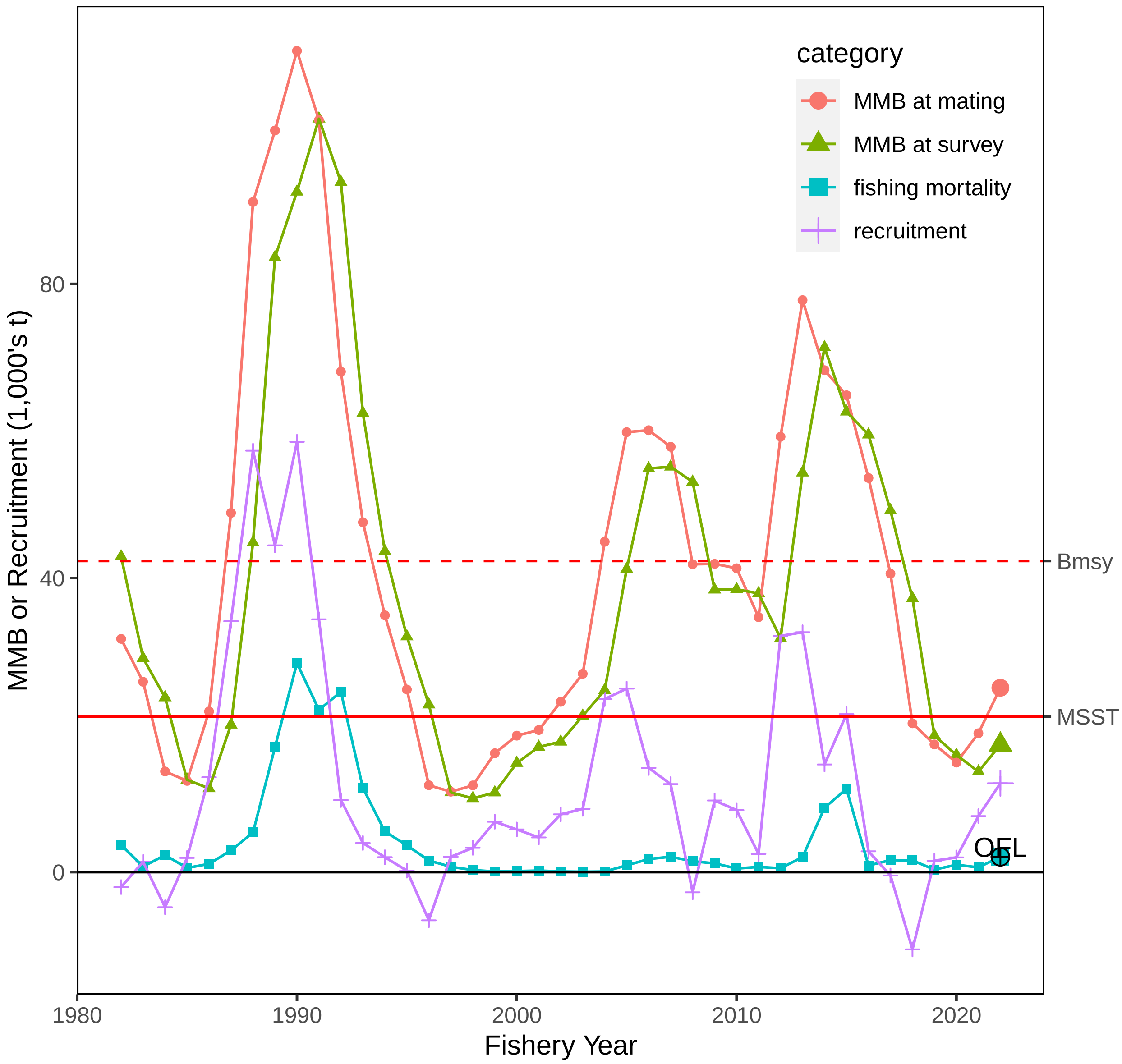

Figure 22. Time series used in the Tier 4 calculations for 2022/23 derived time series (recruitment), and derived management quantities (B_{MSY}, MSST, projected MMB, OFL).