Appendix C: PIBKC 2019 Status Determination

true

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Introduction

This is an appendix to the 2019 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for status determination (is overfishing occurring?, is the stock overfished?) for the current year using the "rPIBKC"" R package developed by the assessment author. The rPIBKC package (source code and R package) is available under version control at https://github.com/wStockhausen/rPIBKC.git.

Status Determination and OFL calculations

For all crab stocks managed by the NPFMC, overfishing is evaluated by comparing the previous year's catch mortality (retained + discard mortality) to the previous year's OFL: if the former is greater than the latter, then overfishing is occurring. Overfished status is assessed with respect to MSST, the Minimum Stock Size Threshold. If stock biomass drops below the MSST, the stock is considered to be overfished. For crab stocks, MSST is one-half B_{MSY}, where B_{MSY} is the longterm spawning stock biomass 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"" spawning stock biomass. 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. Furthermore, if $B/B_{MSY} < \beta(= 0.25)$, directed fishing on the stock is prohibited. For PIBKC, the OFL is based on average historic catch mortality over a specified time period (a Tier 5 approach) and is consequently fixed at 1.16 t.

PIBKC falls into Tier 4 for status determination. For Tier 4 stocks, it is not possible to determine B_{MSY} and MSST directly. Instead, average mature male biomass (MMB) at the time of mating ("MMB at mating"") is used as a proxy for B_{MSY}, where the averaging is over some time period assumed to be representative of the stock being fished at an average rate near F_{MSY} and is thus fluctuating around B_{MSY}. For PIBKC, the NPFMC's Science and Statistical Committee (SSC) has endorsed using the disjoint time periods [1980-84, 1990-97] to calculate $B_{MSY_{proxy}}$ to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected. Once $B_{MSY_{proxy}}$ has been calculated, 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.

MMB-at-mating

MMB-at-mating (MMB_m) 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. MMB at the time of the survey in year y is calculated from survey data using:

$$MMB_{s_y} = \sum_z w_z \cdot P_z \cdot n_{z,y}$$

where w_z is male weight at size z (mm CL), P_z is the probability of maturity at size z, and $n_{z,y}$ is survey-estimated male abundance at size z in year y.

For a year y prior to the assessment year, MMB_{m_y} is given by

1. $MMB_{f_y} = MMB_{s_y} \cdot e^{-M \cdot t_{sf}}$
2. $MMB_{m_y} = \left[MMB_{f_y} - RM_y - DM_y \right] \cdot e^{-M \cdot t_{fm}}$

where MMB_{f_y} is the MMB in year y just prior to the fishery, M is natural mortality, RM_y is retained mortality on MMB in the directed fishery in year y, DM_y is discard mortality on MMB (**not** on all crab) in all fisheries in year y, t_{sf} is the time between the survey and the fishery, and t_{fm} is the time between the fishery and mating.

For the assessment year, the fishery has not yet occurred so RM and DM are unknown. The amount of fishing mortality presumably depends on the (as yet-to-be-determined) overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the 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} using the following equations:
   - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$

- $RM_{OFL} = \left(1 - e^{-F_{OFL}}\right) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
- $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
- $OFL = RM_{OFL} + DM_{OFL}$

3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = \left[MMB_{f_y} - \left(RM_{OFL} + p_{male} \cdot DM_{OFL}\right)\right] \cdot e^{-M \cdot t_{fm}}$
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.

where p_{male} is the assumed fraction of discard mortality on males. Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating. 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 $\frac{\theta}{p_{male}}$. The constant θ is determined by the average ratio of discard mortality on MMB (DM_{MMB}) to MMB at the time of the fishery (MMB_f) over a recent time interval:

$$\theta = \frac{1}{N} \sum_y \frac{DM_{MMB_y}}{MMB_{f_y}}$$

where the sum is over the last N years. In addition, DM_{MMB} is assumed to be proprtional to total discard mortality, with that proportionality given by the percenatge of males in the stock.

Data

Data from the following files were used in this assessment:

- fishery data: ./Data2019AM.Fisheries.csv
- survey data : ./Data2019AM.Surveys.csv

The following figures illustrate the time series of retained PIBKC in the directed fishery and PIBKC incidentally taken in the crab and groundfish fisheries (i.e., bycatch):

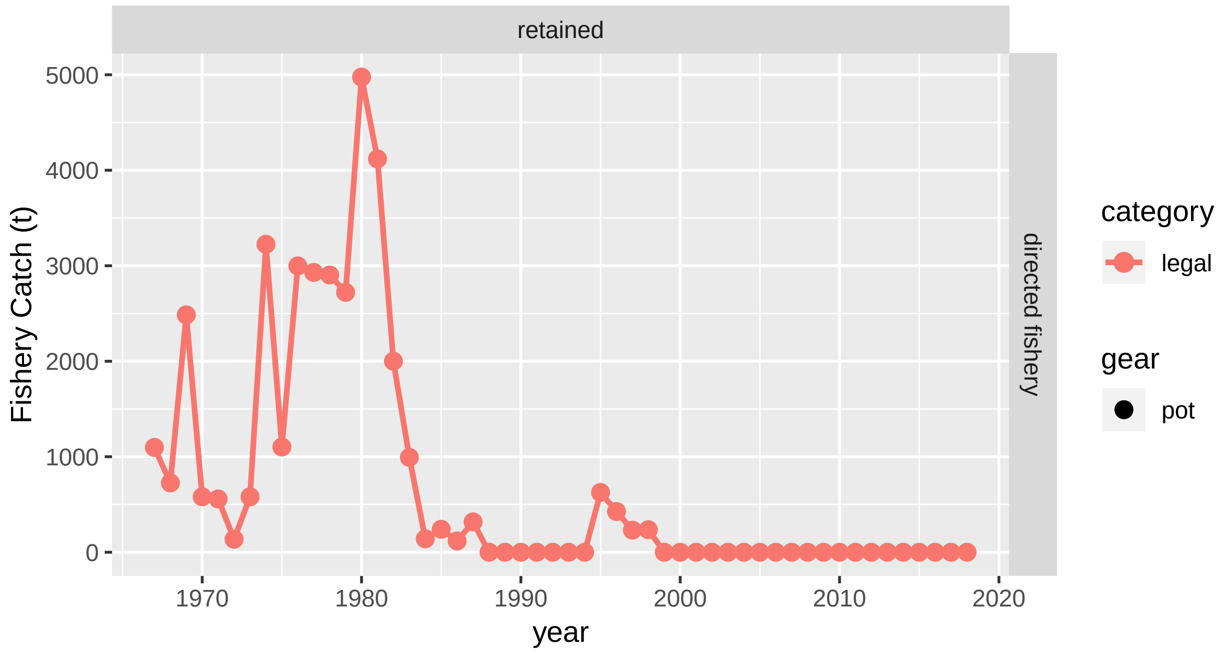

Figure 1: Time series of retained PIBKC catch in the directed fishery.

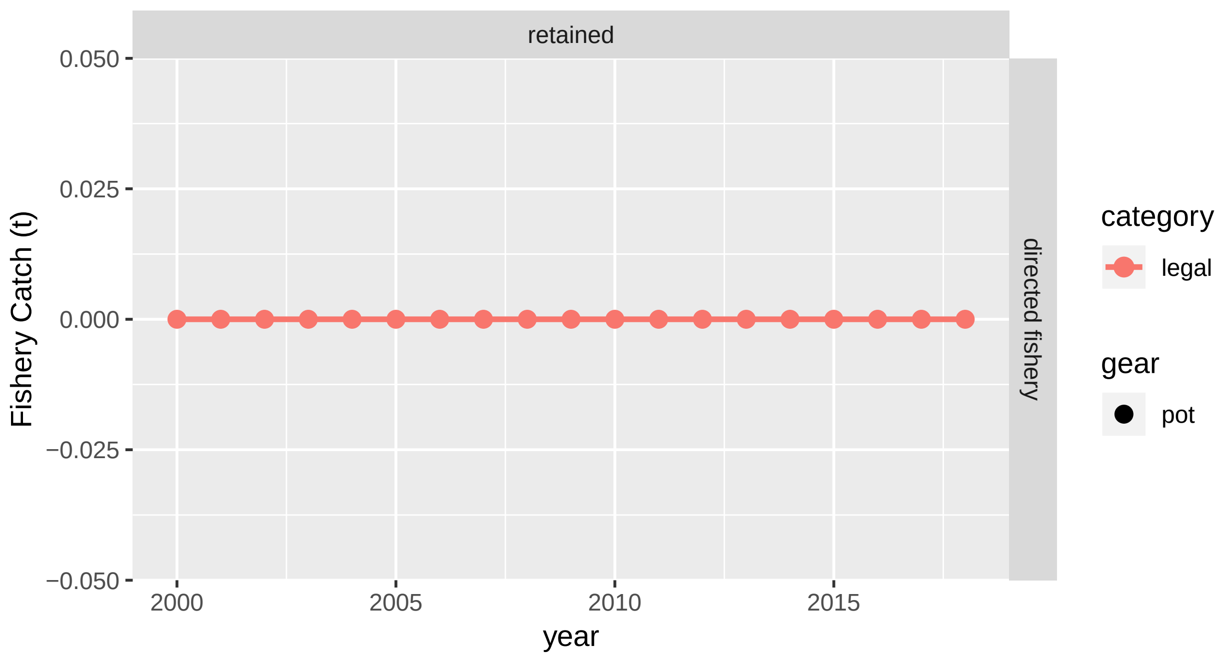

Figure 2: Time series of retained PIBKC catch in the directed fishery (recent time period).

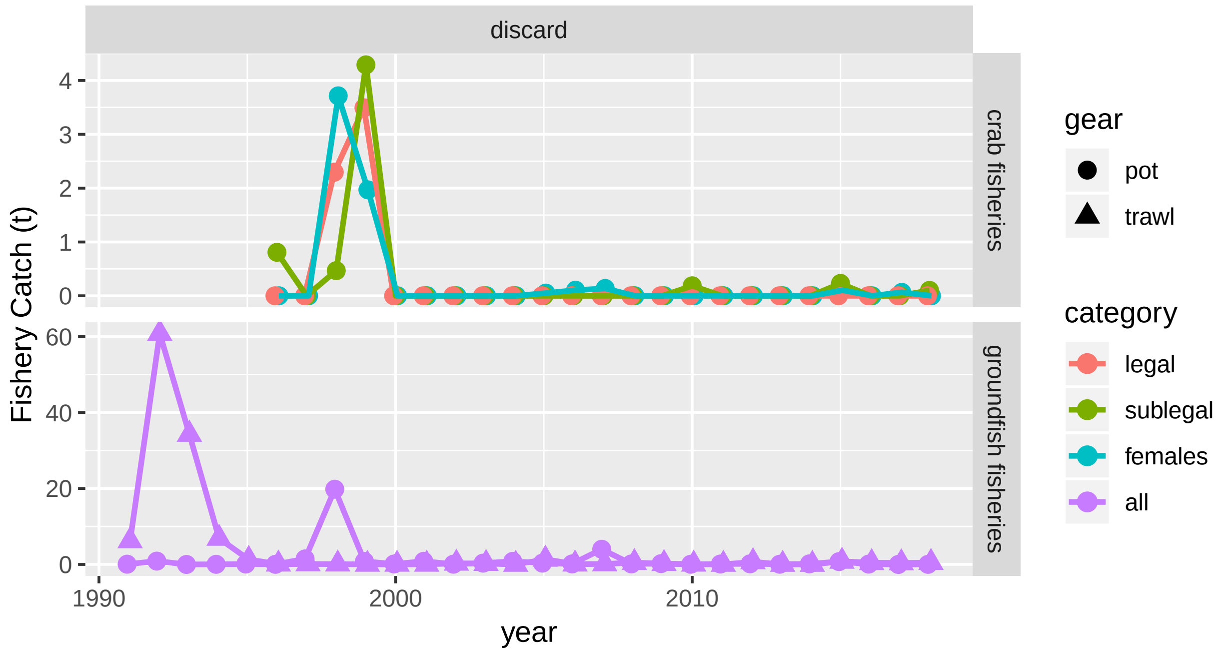

Figure 3: Time series of PIBKC bycatch in the crab and groundfish fisheries.

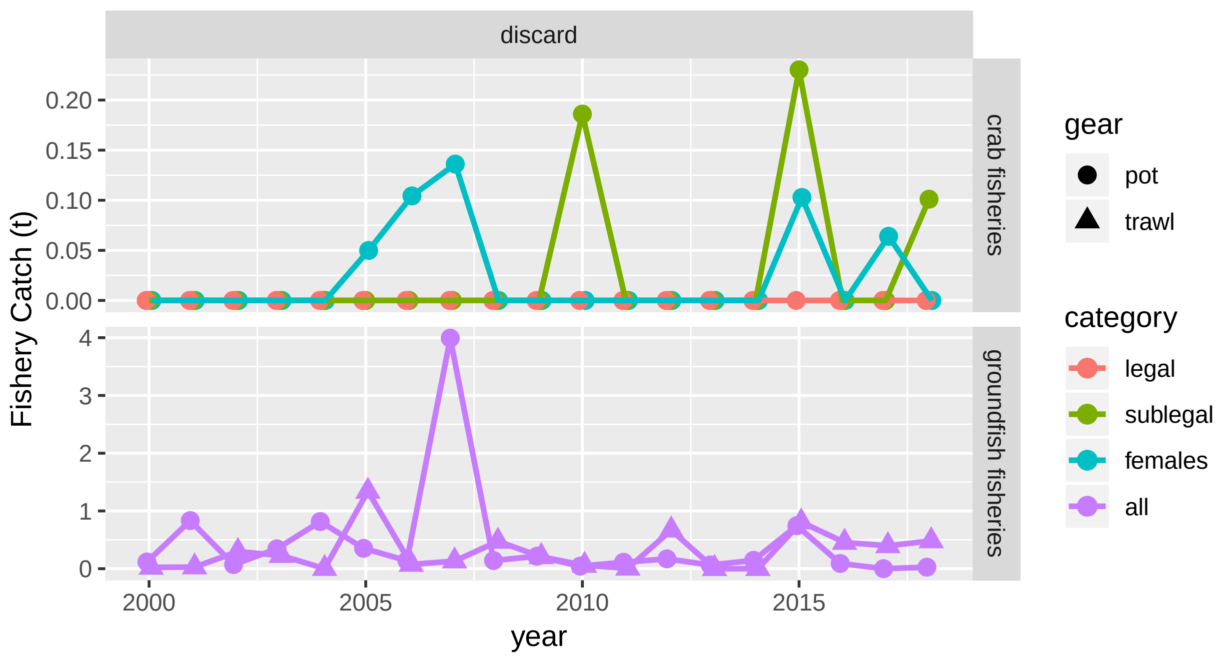

Figure 4: Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

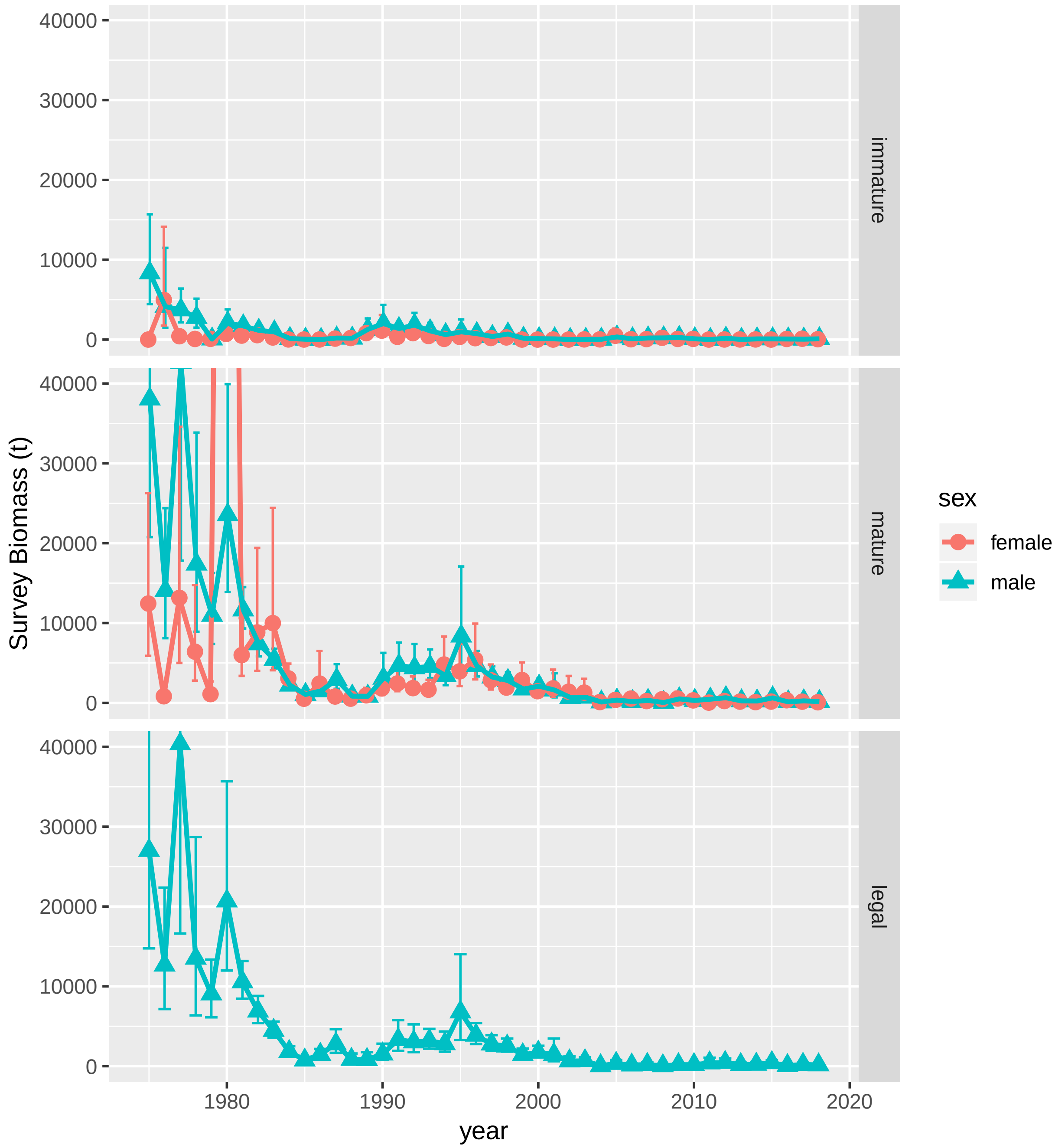

Figure 5: Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

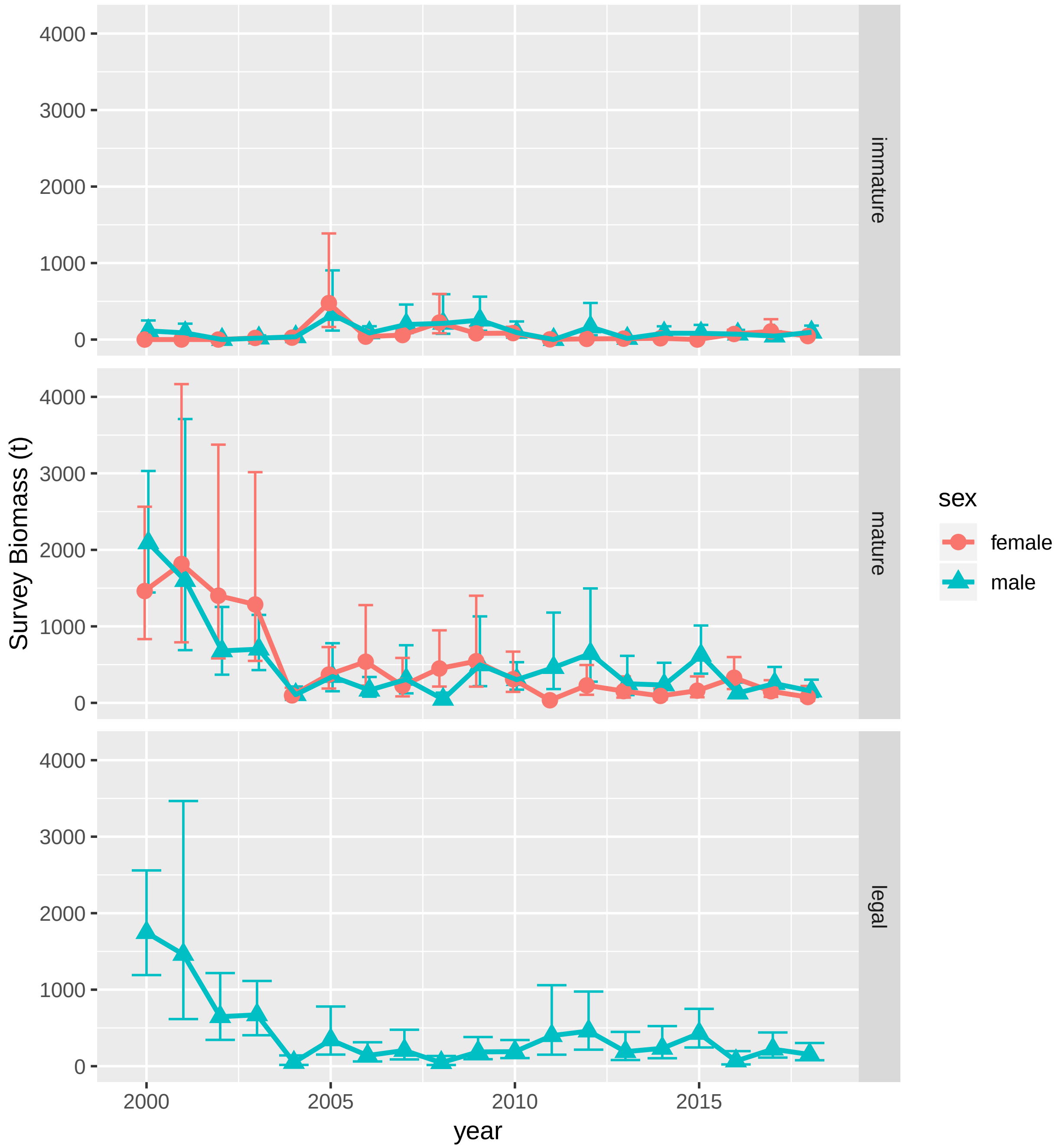

Figure 6: Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time period). Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

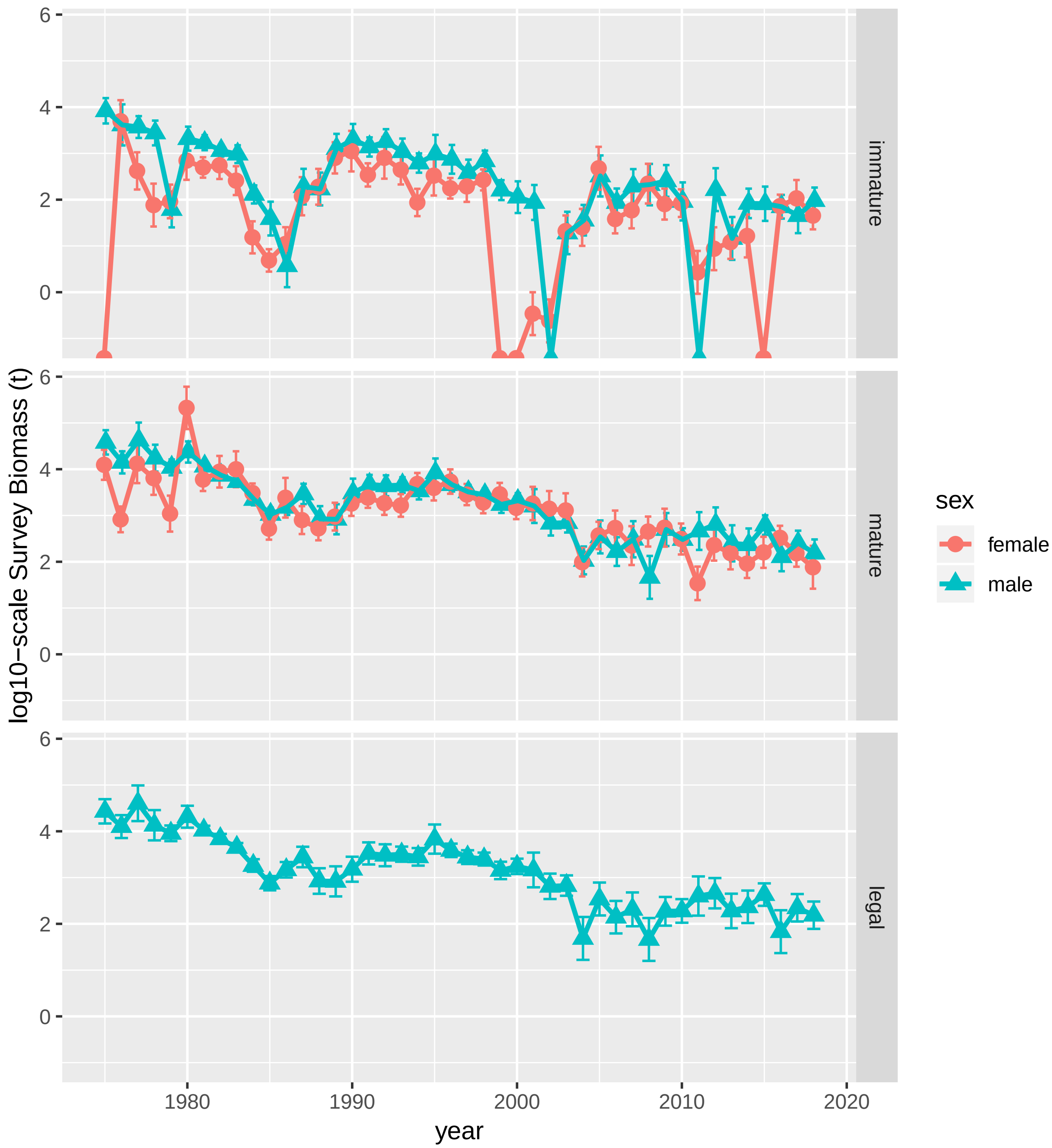

Figure 7: Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estimating B_{MSY} and "current" MMB-at-mating, the survey MMB time series is first smoothed to reduce overall variability. Starting with the 2015 assessment (Stockhausen, 2015), a random effects (RE) model based on code developed by Jim Ianelli (NOAA/NMFS/AFSC) has been used to perform the smoothing. This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$< ln(MMB_s) >_y = < ln(MMB_s) >_{y-1} + \epsilon_y, \text{ where } \epsilon_y \sim N(0, \phi^2)$$

as the state equation and

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

as the observation equation, where $< ln(MMB_s) >_y$ is the estimated "true" log-scale survey MMB in year y, ϵ_y represents normally-distributed process error in year y with standard deviation ϕ, MMB_{s_y} is the observed survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and σ_{s_y} is the log-scale survey MMB standard deviation in year y. The MMB_s's and σ_s's are observed quantities, the $< ln(MMB_s) >$'s and ϕ are estimated parameters, and the ϵ's are random effects (essentially nuisance parameters) that are integrated out in the solution.

Parameter estimates are obtained by minimizing the objective function

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

The model is coded in C++ and uses AD Model Builder C++ libraries (Fournier et al., 2012) to minimize the objective function.

Calculating the OFL for the upcoming 2019/20 fishing year requires a value of survey biomass for 2019. The NMFS EBS Bottom Trawl Survey is conducted June-August but the timing of the 2019 assessment was moved from September (after the 2019 NMFS EBS Bottom Trawl Survey) to May (before the survey) so the value for the 2019 survey biomass is based on a 1-step prediction from the RE-smoothed time series. For the random-walk model used here, the best 1-step prediction for the 2019 survey biomass is simply the estimated 2018 survey biomass (the uncertainty of the predicted 2019 value is larger, though, than that for the 2018 estimate).

Smoothing results

For comparison, the raw and RE-smoothed survey MMB time series are shown below in Figures 8-10, on both arithmetic and natural log scales:

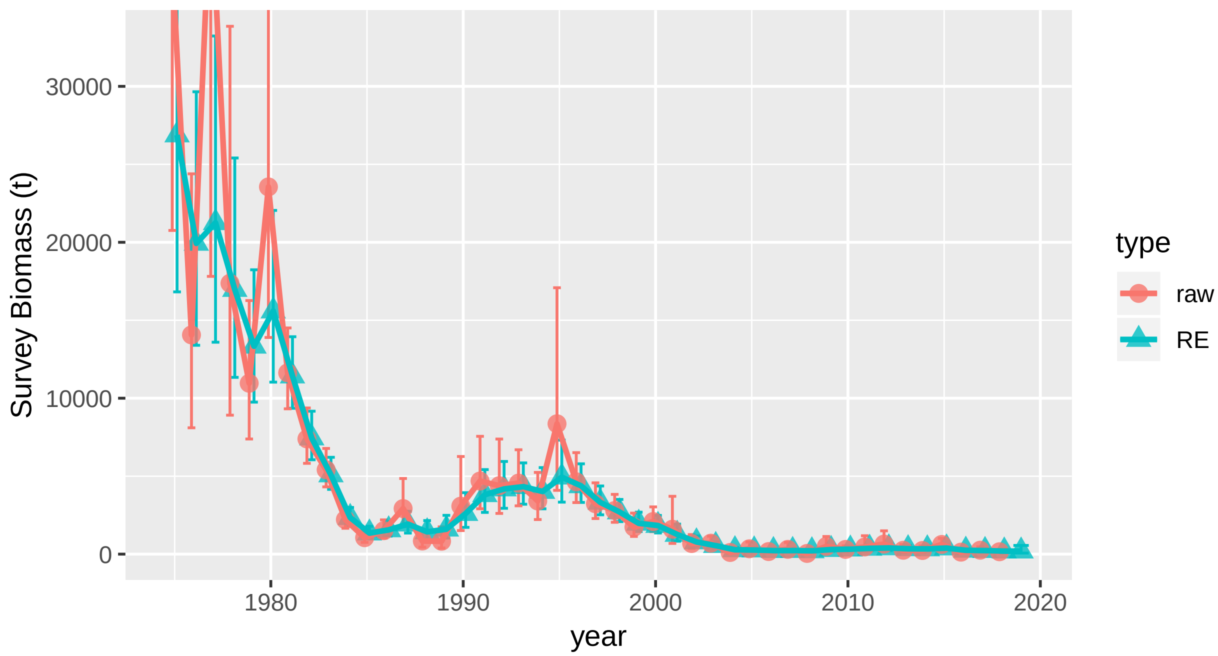

Figure 8: Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

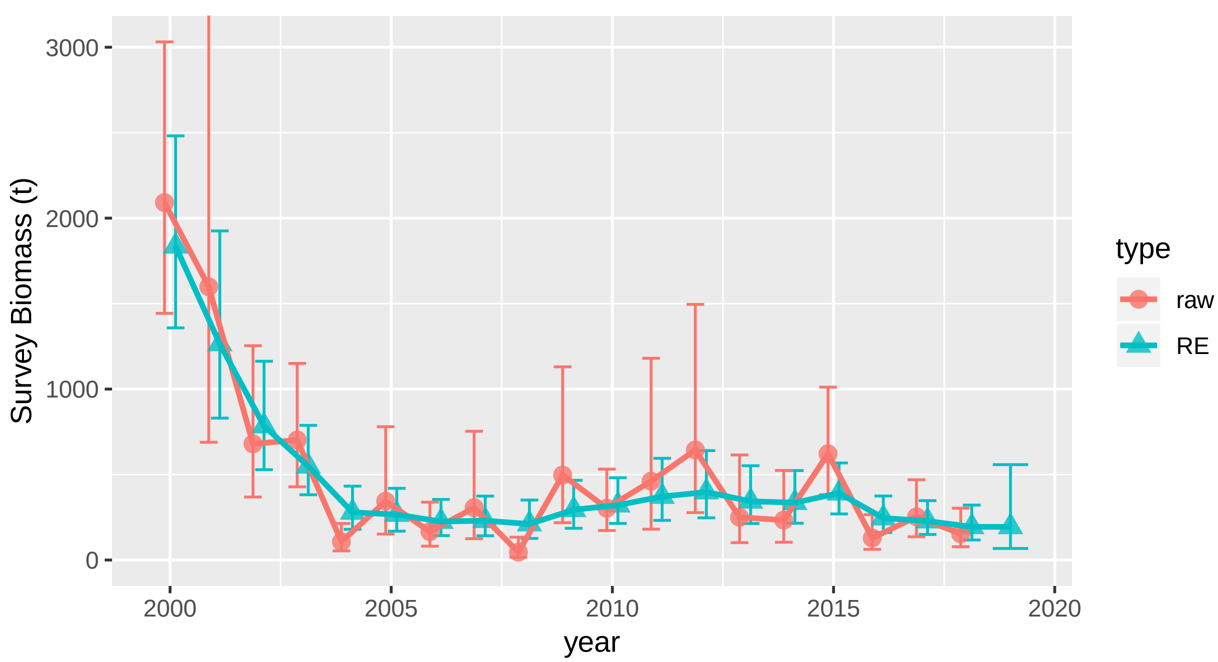

Figure 9: Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

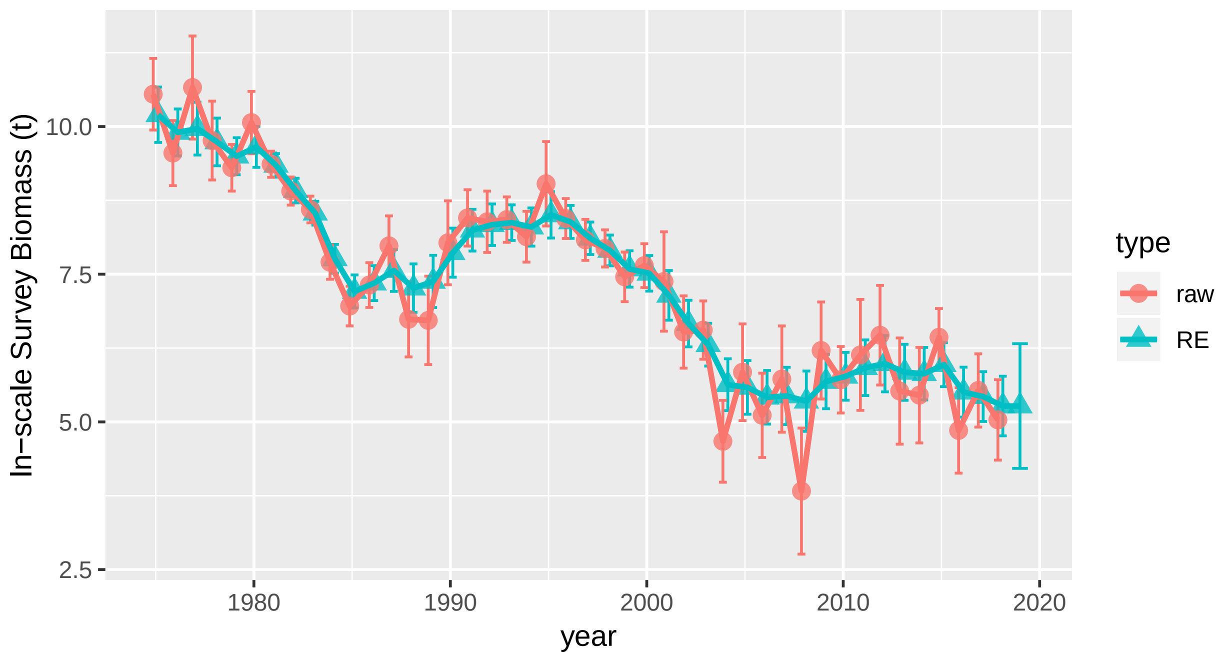

Figure 10: Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

Status determination

Overfishing status

For PIBKC, the total fishing mortality in 2018/19 was 0.4107838 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2018/19.

Overfished status

As discussed previously, overfished status is 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. For PIBKC, $B_{MSY_{proxy}}$ is obtained by averaging estimated MMB-at-mating over the period [1980/81-1984/85,1990/91-1997/98]. Following recommendations made by the CPT and SSC in 2015 (CPT, 2015; SSC, 2015), B and $B_{MSY_{proxy}}$ are based on MMB-at-mating calculated using the RE-smoothed time series of survey biomass projected forward to mating time.

MMB-at-mating

The time series for MMB-at-mating using the RE-smoothed survey MMB time series is shown in the following figure. Note that because the fishery will not yet have been conducted in the year of the assessment, values for MMB at the time of the fishery and the time of mating are unavailable (a predicted value for MMB-at-mating in the assessment year will be determined as part of the OFL calculation).

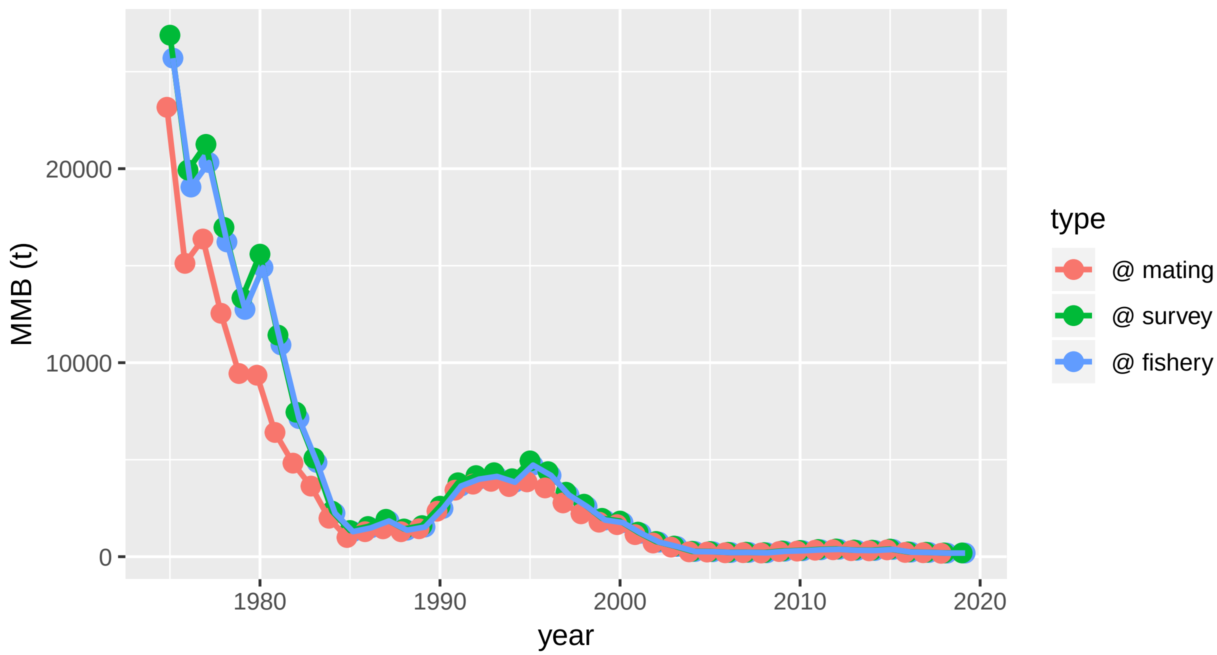

Figure 11: Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating. The value for MMB at the time of the survey in the assessment year is a 1-step ahead prediction because the survey has not yet been conducted while values for MMB at the time of the fishery and the time of mating are unavailable (a predicted value for MMB-at-mating in the assessment year will be determined as part of the OFL calculation).

The value for $B_{MSY_{proxy}}$ and the estimated current (2019) MMB *at the time of the survey* from the RE-smoothed results are:

Table 1: Estimated $B_{MSY_{proxy}}$ and current MMB at the time of the survey using the RE-smoothed survey data.

	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
RE-smoothed	194	$4,106$

Values for θ, used in the projected MMB calculations, based on averaging over the last three years, are:

Table 2: Estimated value for the θ coefficient.

	Estimation Type	theta
1	RE-smoothed	0.0008647

Results from the calculations for B ("current" MMB), overfished status, and an illustrative Tier

4-based OFL for 2019/20 (not used for PIBKC) are:

Table 3: More results from the OFL determination.

	quantity	units	RE.smoothed
1	B ("current" MMB)	t	174.67
2	B_{MSY}	t	4,106.40
3	stock status	–	overfished
4	F_{OFL}	$year^{-1}$	0.00
5	RM_{OFL}	t	0.00
6	DM_{OFL}	t	0.32
7	OFL	t	0.32

Because B/B_{MSY} using RE-smoothed MMB-at-mating from the Table above is 0.0425, the stock is overfished. Furthermore, because $B/B_{MSY} < \beta(= 0.25)$, directed fishing on PIBKC is prohibited.

Tables

Fishery data

Table 4: Annual retained catch biomass and bycatch (not mortality; in t), as available, in the directed fishery, the other crab fisheries, and the groundfish fisheries.

		crab fisheries		directed fishery	groundfish fisheries	
		pot		pot	pot	trawl
		discard		retained	discard	discard
	females	legal	sublegal	legal	all	all
year	t	t	t	t	t	t
1966	0.00000	NA	NA	0.00000	0.00000	NA
1967	NA	NA	NA	1,097.69285	NA	NA
1968	NA	NA	NA	725.74734	NA	NA
1969	NA	NA	NA	2,485.68463	NA	NA
1970	NA	NA	NA	580.59787	NA	NA
1971	NA	NA	NA	557.91827	NA	NA
1972	NA	NA	NA	136.07763	NA	NA
1973	NA	NA	NA	580.59787	NA	NA
1974	NA	NA	NA	3,225.03973	NA	NA
1975	NA	NA	NA	1,102.22877	NA	NA
1976	NA	NA	NA	2,998.24369	NA	NA
1977	NA	NA	NA	2,930.20488	NA	NA
1978	NA	NA	NA	2,902.98935	NA	NA
1979	NA	NA	NA	2,721.55252	NA	NA
1980	NA	NA	NA	4,975.90519	NA	NA
1981	NA	NA	NA	4,118.61614	NA	NA
1982	NA	NA	NA	2,000.34110	NA	NA
1983	NA	NA	NA	993.36667	NA	NA
1984	NA	NA	NA	140.61355	NA	NA
1985	NA	NA	NA	240.40381	NA	NA
1986	NA	NA	NA	117.93394	NA	NA
1987	NA	NA	NA	317.51446	NA	NA
1988	NA	NA	NA	0.00000	NA	NA
1989	NA	NA	NA	0.00000	NA	NA
1990	NA	NA	NA	0.00000	NA	NA
1991	NA	NA	NA	0.00000	0.06700	6.19900
1992	NA	NA	NA	0.00000	0.87900	60.79100
1993	NA	NA	NA	0.00000	0.00000	34.23200
1994	NA	NA	NA	0.00000	0.03500	6.85600
1995	NA	NA	NA	625.95708	0.10800	1.28400
1996	0.00000	0.00000	0.80739	426.37656	0.03100	0.06700
1997	0.00000	0.00000	0.00000	231.33196	1.46200	0.13000
1998	3.71492	2.29518	0.46720	235.86788	19.80000	0.07900
1999	1.96859	3.49266	4.29098	0.00000	0.79500	0.02000
2000	0.00000	0.00000	0.00000	0.00000	0.11600	0.02300
2001	0.00000	0.00000	0.00000	0.00000	0.83300	0.02900
2002	0.00000	0.00000	0.00000	0.00000	0.07100	0.29700
2003	0.00000	0.00000	0.00000	0.00000	0.34500	0.22700
2004	0.00000	0.00000	0.00000	0.00000	0.81600	0.00200
2005	0.04990	0.00000	0.00000	0.00000	0.35300	1.33900
2006	0.10433	0.00000	0.00000	0.00000	0.13800	0.07400
2007	0.13608	0.00000	0.00000	0.00000	3.99300	0.13200
2008	0.00000	0.00000	0.00000	0.00000	0.14100	0.47300
2009	0.00000	0.00000	0.00000	0.00000	0.21563	0.20677
2010	0.00000	0.00000	0.18597	0.00000	0.04434	0.05629
2011	0.00000	0.00000	0.00000	0.00000	0.11175	0.00710
2012	0.00000	0.00000	0.00000	0.00000	0.16994	0.66875
2013	0.00000	0.00000	0.00000	0.00000	0.06464	0.00000
2014	0.00000	0.00000	0.00000	0.00000	0.14430	0.00010
2015	0.10281	0.00000	0.23013	0.00000	0.74427	0.80776
2016	0.00000	0.00000	0.00000	0.00000	0.09043	0.45500
2017	0.06400	0.00000	0.00000	0.00000	0.00025	0.39664
2018	0.00000	0.00000	0.10104	0.00000	0.02613	0.48169

Survey data

Table 5: Input ('raw') male survey abundance data (numbers of crab).

	immature		legal		mature		total	
year	value	cv	value	cv	value	cv	value	cv
1975	8, 475, 780.89	0.57	9, 051, 485.73	0.50	28, 435, 755.89	1.11	36, 911, 536.79	1.07
1976	12, 328, 947.42	1.92	4, 012, 289.16	0.47	5, 551, 254.42	0.96	17, 880, 201.84	1.50
1977	5, 067, 465.88	1.28	11, 768, 927.37	0.77	26, 924, 033.45	1.60	31, 991, 499.33	1.48
1978	2, 482, 381.42	1.50	3, 922, 873.85	0.62	12, 067, 151.89	1.16	14, 549, 533.30	1.08
1979	221, 771.00	1.42	3, 017, 118.91	0.31	5, 276, 802.27	1.14	5, 498, 573.27	1.09
1980	3, 513, 951.44	1.24	6, 244, 057.67	0.42	190, 745, 260.90	1.39	194, 259, 212.34	1.38
1981	2, 925, 999.23	0.73	3, 245, 951.07	0.18	9, 267, 921.40	0.62	12, 193, 920.63	0.63
1982	2, 247, 538.58	0.80	2, 071, 467.90	0.19	10, 190, 817.25	0.83	12, 438, 355.84	0.80
1983	1, 494, 458.75	0.90	1, 321, 394.69	0.17	11, 159, 269.86	0.97	12, 653, 728.61	0.98
1984	983, 046.34	0.91	558, 226.46	0.25	3, 539, 833.29	0.60	4, 522, 879.63	0.58
1985	327, 846.69	1.14	270, 241.72	0.29	914, 260.33	0.72	1, 242, 107.02	0.63
1986	55, 588.48	1.70	460, 310.63	0.31	2, 582, 129.95	1.20	2, 637, 718.43	1.18
1987	1, 023, 070.70	1.58	830, 150.65	0.42	1, 573, 658.67	1.00	2, 596, 729.37	0.91
1988	2, 135, 682.52	1.71	237, 867.82	0.51	703, 331.18	0.99	2, 839, 013.70	1.35
1989	6, 150, 862.84	1.33	239, 947.52	0.62	1, 381, 703.37	1.28	7, 532, 566.21	1.16
1990	4, 627, 193.67	1.51	571, 708.33	0.54	3, 516, 258.12	1.17	8, 143, 451.79	1.13
1991	2, 725, 893.73	0.84	1, 237, 558.37	0.44	4, 781, 533.72	0.78	7, 507, 427.45	0.70
1992	4, 233, 139.11	1.51	1, 154, 465.28	0.45	4, 084, 797.20	0.91	8, 317, 936.31	1.00
1993	2, 364, 196.25	1.13	1, 114, 300.52	0.30	3, 658, 157.09	0.76	6, 022, 353.33	0.72
1994	783, 283.02	0.95	935, 268.63	0.34	6, 341, 478.39	0.78	7, 124, 761.41	0.77
1995	1, 805, 281.89	1.81	2, 186, 408.91	0.62	7, 140, 267.33	1.12	8, 945, 549.23	1.17
1996	995, 165.22	1.04	1, 269, 274.66	0.26	6, 757, 837.30	0.77	7, 753, 002.53	0.80
1997	787, 577.26	1.19	932, 852.28	0.28	3, 815, 669.55	0.72	4, 603, 246.80	0.73
1998	1, 449, 688.57	0.89	797, 187.26	0.25	2, 796, 606.53	0.69	4, 246, 295.10	0.67
1999	159, 535.74	0.37	452, 740.30	0.34	3, 373, 234.05	0.82	3, 532, 769.79	0.82
2000	163, 834.62	0.56	527, 589.35	0.30	2, 088, 120.40	0.76	2, 251, 955.02	0.77
2001	111, 434.07	1.65	445, 863.41	0.74	2, 219, 704.16	1.46	2, 331, 138.23	1.43
2002	18, 729.46	1.00	207, 145.98	0.49	1, 447, 328.02	1.27	1, 466, 057.48	1.25
2003	112, 599.69	1.20	213, 572.37	0.40	1, 349, 151.10	1.15	1, 461, 750.78	1.06
2004	185, 710.36	1.22	15, 583.88	1.00	117, 939.32	1.17	303, 649.68	0.93
2005	4, 249, 450.99	1.96	91, 932.30	0.71	381, 129.58	1.28	4, 630, 580.58	1.81
2006	251, 165.41	1.04	38, 242.00	0.70	485, 119.46	1.33	736, 284.87	1.04
2007	368, 647.45	1.45	54, 402.91	0.75	275, 842.91	1.75	644, 490.36	1.23
2008	576, 037.92	1.83	18, 255.62	1.00	455, 624.48	1.66	1, 031, 662.41	1.61
2009	420, 006.90	1.24	68, 117.04	0.59	725, 721.22	1.55	1, 145, 728.13	1.43
2010	266, 783.19	1.40	64, 702.83	0.48	379, 492.70	1.18	646, 275.89	1.23
2011	18, 089.34	1.00	129, 097.71	0.87	202, 037.20	1.49	220, 126.54	1.36
2012	229, 204.82	2.00	164, 164.90	0.68	584, 327.37	1.56	813, 532.19	1.57
2013	121, 694.76	1.70	68, 726.09	0.80	254, 660.86	1.49	376, 355.62	1.18
2014	118, 710.86	1.59	91, 855.85	0.71	166, 223.38	1.31	284, 934.24	1.07
2015	75, 575.44	0.77	124, 591.54	0.45	436, 094.37	1.02	511, 669.81	1.06
2016	225, 711.04	1.02	19, 344.90	1.00	378, 612.24	1.08	604, 323.27	0.99
2017	256, 098.21	1.52	71, 937.24	0.59	252, 444.72	1.04	508, 542.93	0.99
2018	186, 266.58	1.17	55, 775.69	0.56	113, 648.88	1.56	299, 915.46	1.06

Table 6: Input ('raw') male survey biomass data, in t.

	immature		legal		mature		total	
year	value	cv	value	cv	value	cv	value	cv
1975	8,340.95	0.52	27,016.47	0.50	38,053.59	0.50	46,394.54	0.47
1976	4,128.67	0.94	12,648.94	0.47	14,058.93	0.45	18,187.61	0.45
1977	3,713.34	0.44	40,365.94	0.78	42,618.32	0.77	46,331.66	0.73
1978	2,765.31	0.51	13,516.82	0.64	17,369.71	0.56	20,135.02	0.51
1979	61.27	0.79	9,039.95	0.31	10,959.38	0.32	11,020.66	0.31
1980	2,083.76	0.49	20,678.62	0.45	23,552.92	0.43	25,636.68	0.42
1981	1,704.25	0.30	10,553.54	0.17	11,628.25	0.17	13,332.49	0.18
1982	1,151.96	0.23	6,893.43	0.19	7,388.96	0.19	8,540.92	0.17
1983	962.34	0.36	4,474.40	0.17	5,408.73	0.18	6,371.08	0.19
1984	129.72	0.36	1,824.02	0.25	2,215.66	0.23	2,345.38	0.22
1985	39.02	0.73	755.50	0.28	1,054.79	0.27	1,093.81	0.26
1986	3.73	1.00	1,473.32	0.31	1,504.69	0.30	1,508.43	0.30
1987	191.45	0.78	2,781.34	0.41	2,923.38	0.41	3,114.84	0.40
1988	170.05	0.71	842.43	0.53	842.43	0.53	1,012.48	0.46
1989	1,274.88	0.62	827.50	0.64	827.50	0.64	2,102.37	0.55
1990	2,004.14	0.66	1,514.33	0.52	3,077.51	0.60	5,081.65	0.61
1991	1,377.43	0.39	3,325.77	0.45	4,689.67	0.39	6,067.10	0.37
1992	1,800.51	0.51	3,034.80	0.45	4,391.01	0.42	6,191.52	0.43
1993	1,088.50	0.54	3,202.55	0.30	4,555.60	0.31	5,644.10	0.30
1994	618.98	0.39	2,805.73	0.35	3,410.36	0.34	4,029.34	0.34
1995	967.73	0.86	6,786.93	0.62	8,360.23	0.60	9,327.96	0.63
1996	744.89	0.61	3,873.06	0.27	4,640.62	0.27	5,385.51	0.28
1997	381.39	0.55	2,765.39	0.27	3,232.58	0.28	3,613.97	0.29
1998	692.25	0.41	2,509.92	0.25	2,797.93	0.25	3,490.19	0.25
1999	160.65	0.40	1,426.16	0.35	1,729.24	0.34	1,889.89	0.33
2000	113.32	0.68	1,745.75	0.31	2,091.34	0.30	2,204.66	0.30
2001	87.07	0.76	1,460.92	0.76	1,598.74	0.73	1,685.81	0.73
2002	0.00	0.00	647.07	0.52	679.80	0.51	679.80	0.51
2003	19.06	0.98	671.20	0.41	702.01	0.40	721.07	0.39
2004	36.01	0.65	48.43	1.00	106.88	0.58	142.89	0.46
2005	325.78	0.94	344.06	0.71	344.06	0.71	669.84	0.59
2006	86.89	0.58	139.22	0.70	165.89	0.60	252.77	0.46
2007	196.77	0.74	205.56	0.73	306.46	0.80	503.23	0.66
2008	211.71	0.95	45.98	1.00	45.98	1.00	257.69	0.80
2009	254.30	0.68	186.51	0.60	497.11	0.71	751.41	0.70
2010	91.64	0.85	190.05	0.48	302.93	0.46	394.57	0.52
2011	0.00	0.00	398.98	0.89	461.36	0.84	461.36	0.84
2012	164.71	1.00	458.98	0.64	643.94	0.74	808.65	0.79
2013	14.53	1.00	189.92	0.75	250.14	0.80	264.66	0.75
2014	83.15	0.62	233.39	0.70	233.39	0.70	316.54	0.57
2015	81.69	0.75	428.26	0.46	621.71	0.39	703.40	0.39
2016	70.34	0.49	67.74	1.00	128.55	0.61	198.89	0.52
2017	45.20	0.77	222.52	0.57	252.78	0.51	297.98	0.47
2018	95.57	0.54	153.55	0.57	153.55	0.57	249.12	0.52

Table 7: Input ('raw') female survey abundance data (numbers of crab).

	immature		mature		total	
year	value	cv	value	cv	value	cv
1975	0.00	0.00	13,147,586.68	0.61	13,147,586.68	0.61
1976	7,369,388.06	0.97	769,149.65	0.51	8,138,537.71	0.91
1977	851,600.68	0.82	13,880,050.65	0.86	14,731,651.34	0.86
1978	60,923.05	1.00	5,926,514.32	0.66	5,987,437.37	0.66
1979	142,416.25	0.72	1,168,934.53	0.81	1,311,350.78	0.77
1980	781,223.69	0.77	182,902,918.90	0.98	183,684,142.60	0.98
1981	826,523.82	0.41	5,433,490.77	0.44	6,260,014.59	0.42
1982	876,255.79	0.51	7,837,003.99	0.65	8,713,259.78	0.63
1983	463,726.39	0.54	9,307,968.75	0.78	9,771,695.14	0.76
1984	465,472.58	0.52	2,769,190.35	0.38	3,234,662.94	0.37
1985	260,081.29	0.54	486,184.43	0.44	746,265.72	0.36
1986	36,684.23	0.70	2,101,931.80	0.90	2,138,616.03	0.88
1987	401,529.77	0.74	670,478.72	0.58	1,072,008.49	0.48
1988	897,629.21	0.87	465,463.37	0.48	1,363,092.58	0.64
1989	2,636,098.81	0.74	1,141,755.85	0.66	3,777,854.65	0.58
1990	2,177,329.21	0.91	2,045,839.41	0.55	4,223,168.62	0.56
1991	805,450.59	0.46	2,767,448.02	0.42	3,572,898.61	0.35
1992	1,797,343.33	0.93	2,149,519.20	0.49	3,946,862.54	0.52
1993	880,672.33	0.61	1,782,656.74	0.45	2,663,329.07	0.38
1994	144,763.08	0.57	5,047,215.18	0.44	5,191,978.25	0.44
1995	658,479.28	0.92	4,038,555.59	0.52	4,697,034.87	0.49
1996	275,735.14	0.42	5,045,822.06	0.48	5,321,557.20	0.46
1997	320,343.56	0.67	2,614,373.74	0.42	2,934,717.30	0.39
1998	500,241.34	0.43	1,829,509.02	0.44	2,329,750.36	0.37
1999	0.00	0.00	2,755,975.76	0.49	2,755,975.76	0.49
2000	0.00	0.00	1,363,069.69	0.46	1,363,069.69	0.46
2001	18,516.37	1.00	1,697,465.09	0.75	1,715,981.46	0.74
2002	18,729.46	1.00	1,221,852.43	0.79	1,240,581.89	0.78
2003	67,328.63	0.48	1,120,254.01	0.76	1,187,582.64	0.72
2004	98,059.03	0.63	70,034.56	0.60	168,093.59	0.51
2005	2,268,112.83	1.00	289,197.28	0.56	2,557,310.11	0.89
2006	113,047.12	0.55	429,540.72	0.77	542,587.84	0.62
2007	122,482.70	0.73	165,762.60	0.90	288,245.30	0.59
2008	342,119.25	0.90	437,368.86	0.66	779,488.11	0.75
2009	152,290.08	0.61	477,095.11	0.82	629,385.19	0.76
2010	165,632.29	0.56	249,027.32	0.69	414,659.61	0.62
2011	18,089.34	1.00	36,511.72	0.70	54,601.06	0.56
2012	34,682.61	1.00	312,094.57	0.76	346,777.18	0.70
2013	45,343.64	0.70	150,299.88	0.63	195,643.52	0.53
2014	27,720.50	1.00	74,367.54	0.60	102,088.04	0.51
2015	0.00	0.00	202,464.39	0.65	202,464.39	0.65
2016	131,689.04	0.50	322,760.45	0.52	454,449.50	0.50
2017	187,859.97	0.75	161,799.38	0.53	349,659.35	0.54
2018	75,905.77	0.59	57,873.19	1.00	133,778.96	0.54

Table 8: Input ('raw') female survey biomass data, in t.

	immature		mature		total	
year	value	cv	value	cv	value	cv
1975	0.00	0.00	12,442.27	0.64	12,442.27	0.64
1976	4,967.70	0.97	823.80	0.53	5,791.50	0.89
1977	418.58	0.83	13,153.87	0.88	13,572.45	0.87
1978	76.40	1.00	6,415.74	0.72	6,492.14	0.72
1979	91.67	0.73	1,097.29	0.79	1,188.96	0.76
1980	699.46	0.86	211,603.71	0.98	212,303.16	0.98
1981	497.16	0.41	5,986.82	0.47	6,483.97	0.46
1982	553.17	0.57	8,823.72	0.68	9,376.89	0.67
1983	258.05	0.61	9,989.87	0.79	10,247.93	0.78
1984	15.35	0.69	3,069.56	0.38	3,084.90	0.38
1985	4.87	0.46	519.81	0.45	524.67	0.44
1986	11.02	0.73	2,419.78	0.90	2,430.80	0.90
1987	118.72	0.86	794.61	0.58	913.33	0.53
1988	190.14	0.79	527.64	0.49	717.78	0.47
1989	800.78	0.67	944.75	0.58	1,745.53	0.50
1990	1,118.45	0.93	1,810.45	0.51	2,928.89	0.49
1991	342.70	0.48	2,433.24	0.41	2,775.93	0.38
1992	801.57	0.96	1,847.65	0.48	2,649.23	0.46
1993	444.39	0.62	1,647.13	0.46	2,091.51	0.40
1994	87.01	0.57	4,805.95	0.45	4,892.96	0.44
1995	331.03	0.90	3,947.94	0.52	4,278.97	0.50
1996	176.52	0.42	5,408.25	0.50	5,584.77	0.49
1997	193.64	0.66	2,834.78	0.43	3,028.42	0.41
1998	267.35	0.42	1,914.46	0.44	2,181.81	0.39
1999	0.00	0.00	2,868.27	0.47	2,868.27	0.47
2000	0.00	0.00	1,461.82	0.46	1,461.82	0.46
2001	0.34	1.00	1,816.35	0.72	1,816.69	0.72
2002	0.24	1.00	1,400.74	0.78	1,400.98	0.78
2003	20.94	0.67	1,286.42	0.75	1,307.36	0.73
2004	25.20	0.82	97.71	0.60	122.91	0.50
2005	477.27	1.00	369.83	0.57	847.10	0.61
2006	38.16	0.60	537.85	0.76	576.01	0.71
2007	58.77	0.79	223.43	0.88	282.19	0.71
2008	222.03	0.90	449.54	0.64	671.57	0.70
2009	80.22	0.66	544.69	0.85	624.91	0.82
2010	84.08	0.58	310.16	0.66	394.24	0.63
2011	2.69	1.00	34.14	0.73	36.83	0.67
2012	8.70	1.00	228.76	0.66	237.46	0.64
2013	12.06	0.72	153.85	0.70	165.91	0.65
2014	16.43	1.00	91.11	0.60	107.54	0.53
2015	0.00	0.00	159.65	0.66	159.65	0.66
2016	72.47	0.47	328.67	0.50	401.14	0.48
2017	106.89	0.81	152.11	0.56	259.01	0.53
2018	45.28	0.58	76.01	1.00	121.29	0.65

Table 9: A comparison of estimates for MMB (in t) at the time of the survey. Note that, for the assessment year, the survey has not yet been conducted so the 'raw' value is unavailable and the smoothed value is a 1-step ahead prediction.

		raw			RE	
year	value	lci	uci	value	lci	uci
1975	38,053.59	20,759.61	69,754.48	26,881.80	16,821.13	42,959.73
1976	14,058.93	8,103.53	24,391.05	19,930.10	13,395.23	29,653.00
1977	42,618.32	17,814.39	101,958.08	21,252.30	13,592.39	33,228.91
1978	17,369.71	8,912.49	33,852.16	16,972.20	11,337.17	25,408.07
1979	10,959.38	7,385.67	16,262.32	13,333.10	9,748.29	18,236.18
1980	23,552.92	13,894.39	39,925.46	15,594.10	11,030.66	22,045.46
1981	11,628.25	9,320.75	14,507.00	11,421.30	9,354.86	13,944.20
1982	7,388.96	5,824.58	9,373.50	7,448.42	6,052.31	9,166.58
1983	5,408.73	4,315.80	6,778.45	5,079.98	4,154.76	6,211.24
1984	2,215.66	1,659.01	2,959.08	2,347.94	1,841.79	2,993.18
1985	1,054.79	753.94	1,475.68	1,350.90	1,021.27	1,786.92
1986	1,504.69	1,029.62	2,198.96	1,555.54	1,157.15	2,091.09
1987	2,923.38	1,761.10	4,852.75	1,926.81	1,351.61	2,746.79
1988	842.43	445.93	1,591.49	1,428.72	947.70	2,153.88
1989	827.50	391.56	1,748.76	1,600.62	1,029.53	2,488.50
1990	3,077.51	1,512.59	6,261.49	2,602.68	1,718.45	3,941.88
1991	4,689.67	2,910.49	7,556.46	3,810.19	2,677.11	5,422.85
1992	4,391.01	2,612.05	7,381.55	4,179.89	2,939.92	5,942.85
1993	4,555.60	3,100.43	6,693.73	4,328.19	3,200.38	5,853.45
1994	3,410.36	2,219.61	5,239.91	4,017.60	2,908.18	5,550.24
1995	8,360.23	4,090.73	17,085.84	4,938.60	3,335.75	7,311.64
1996	4,640.62	3,308.54	6,509.03	4,382.94	3,315.98	5,793.22
1997	3,232.58	2,284.30	4,574.53	3,322.04	2,523.97	4,372.45
1998	2,797.93	2,042.57	3,832.65	2,704.77	2,085.68	3,507.62
1999	1,729.24	1,136.48	2,631.17	1,976.51	1,451.63	2,691.17
2000	2,091.34	1,442.89	3,031.19	1,835.78	1,358.03	2,481.61
2001	1,598.74	688.93	3,710.05	1,264.25	830.09	1,925.49
2002	679.80	368.60	1,253.75	784.09	528.68	1,162.87
2003	702.01	428.47	1,150.19	548.53	381.99	787.67
2004	106.88	53.46	213.67	278.66	179.67	432.19
2005	344.06	151.76	780.00	266.14	168.86	419.48
2006	165.89	81.25	338.67	225.18	143.05	354.47
2007	306.46	124.64	753.49	230.31	141.81	374.03
2008	45.98	15.82	133.66	210.68	126.46	350.98
2009	497.11	218.63	1,130.34	294.11	185.61	466.03
2010	302.93	172.57	531.78	321.07	214.15	481.35
2011	461.36	180.34	1,180.27	371.44	231.84	595.10
2012	643.94	277.26	1,495.58	397.61	246.94	640.21
2013	250.14	101.79	614.66	343.39	213.72	551.75
2014	233.39	103.97	523.89	335.70	215.28	523.48
2015	621.71	382.23	1,011.25	391.25	269.61	567.77
2016	128.55	62.34	265.09	245.61	160.99	374.71

2017	252.78	135.99	469.85	227.90	149.47	347.47
2018	153.55	77.73	303.35	194.18	117.29	321.48
2019	0.00	0.00	0.00	194.18	67.56	558.12

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