Projections of Atka mackerel and Pacific cod catch reductions

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Introduction

New management measures are one potential outcome of the current (2010) Steller sea lion Biological Opinion. A possible suite of measures could include closing all of the western Aleutians (NPFMC area 543), both inside and outside Critical Habitat (CH) to Atka mackerel and Pacific cod fishing; and closing CH in the central Aleutians (area 542) to Atka mackerel and Pacific cod fishing combined with reductions in Total Allowable Catch. The goal of these new measures would be to increase the biomass of Atka mackerel and Pacific cod and thus increase prey abundance for Steller sea lions. The purpose of the analyses described here was to examine how much the biomass of these two species could possibly increase as a result of reductions in commercial catch, and how long it would take to achieve such increases.

The National Research Council (NRC), in its analysis of the factors contributing to the decline of the Steller sea lion, recommended an adaptive management experiment as the most effective way to evaluate management efficacy (NRC 2003). The experiment would require open areas where fishing would take place (i.e., area 541) and closed areas to remove potentially negative impacts of fisheries on sea lions (i.e., area 543). Such an experimental policy could improve management while at the same time facilitating research on the causes of sea lion population decline and the failure to recover. Ideally the experiment would include replicated fished and unfished areas to account for environmental variability among areas and the possibility that different portions of the sea lion population were responding to different stressors. However, this is not feasible at the spatial scale of new management measures being considered here.

The most critical monitoring needs for adaptive management are detailed local sea lion censuses and spatial analysis of fish population changes for each area (NRC 2003). In addition, it may be necessary to maintain monitoring until longer-term recruitment and mortality responses of sea lions are detected (5 to 10 years). Assessment of the management measures cannot be based on a simple comparison between the response of fish and sea lions in fished and unfished areas because the areas likely have different baseline characteristics (e.g., oceanography, habitat type, productivity, etc.). However, the “parallelism hypothesis” asserts that over some number of years, time profiles of fished and unfished areas would diverge (Skalski et al. 2001). The slope of the fish and/or sea lion response metric (abundance, biomass, pup birth rate, etc.) in the unfished area presumably would increase faster than the slope in the fished area. Although statistical tests for parallelism are available, they require replicated “control” (unfished) and “experimental” (fished) sites which are not feasible in the present case.

Methods

The projection model used for north Pacific groundfish stock status determinations in NMFS stock assessments was run to simulate total (Aleutian-wide) Atka mackerel and (Bering Sea-Aleutian Islands) Pacific cod biomass under different scenarios of reduced catch. For the purposes of this work, we assume that the population dynamics within NPFMC management areas (541, 542, 543) are equal to the region-wide values and that the initial relative biomass among areas is estimated without uncertainty and that migrations between management areas is zero.

Model simulations consisted of 100 Monte Carlo replicates projected 100 years into the future for 21 different F_{ABC} multipliers. The multipliers ranged from the "maximum permissible ABC" (a value of 1.0) down to no fishing with decrements 0.05. For reference, the initial biomass was designated as 500,000 mt for Atka mackerel and 1.5 million t for BSAI Pacific cod. These values approximate the current total Atka mackerel biomass (505,200 mt, Lowe et al. 2009) and Pacific cod for the EBS stock (1.510 million t; Thompson et al. 2009). Total Atka mackerel biomass refers to fish age 1+ years, and total Pacific cod biomass is age 0+. For illustration, comparisons of spawning biomass relative to total biomass are shown since maturity and selectivity schedules can lead to differences in relative biomass trends. Results are tabulated to show the frequency of simulations that achieved target biomass levels and to show the year that the mean biomass from the simulations achieved different targets (if the target was attained).

Results

Since total biomass is considered most appropriate for forage considerations and Atka mackerel spawning biomass is commonly used for conservation reference points, it is useful to compare the mean values for these quantities. For the maximum permissible ABC level and under the "no fishing" scenario, spawning biomass (relative to the "current" stock size) increases more, on a proportional basis, for Atka mackerel than for Pacific cod (Fig. 1). In both cases, the increases in spawning biomass under the no fishing scenario is large (in relative terms) compared to the increases in total biomass, possibly because the total biomass includes immature fish.

Table 1 shows the year in which a given total Atka mackerel biomass would be expected to be attained by reducing catch, based on the mean biomass from the 100 simulations. For example, if the total target biomass was 600,000 mt, the expectation is that this would be achieved in 2019 if catch was reduced to 45% of maximum permissible ABC. The same target would be expected to be achieved sooner, in 2016, if catch was reduced even further, to 30% of ABC.

For Pacific cod, due to large year classes spawned in 2006 and 2008, increases in stock size are anticipated to occur sooner (Table 2). However, these trends are somewhat dampened due to recent high recruitment levels, as indicated by future proportions of Monte Carlo simulations that decline after the first 4 years (Fig. 1).

If we assume that the region-wide population dynamics of Atka mackerel apply within each NMFS management area and that the initial biomass among areas is well estimated, one can also use Table 1 to examine expectations for individual statistical areas. For example, if the target is

to increase the biomass of Atka mackerel in area 542 to 150% of the current value, the expectation is that this would achieved only if catch were reduced to virtually nothing (ABC multiplier 0.05) and it would take until 2019 before that target was reached (see the row for 740 kt, which is approximately 150% of 500 kt). In other words, the target biomass shown in the first column can also be regarded as increasing percentages of the starting biomass, beginning with 100% (500 kt) and ending with 160% (800 kt).

Table 2 shows that if the target is to increase the biomass of Pacific cod by 150% in any given statistical area, the expectation is that this would be achieved in 2013 if catch is reduced to 80% of maximum permissible ABC. The target could be reached sooner, in 2012, if the catch is reduced to 60% of ABC.

An alternative way to view the results is to evaluate the proportion of simulations that exceed a given target biomass, as opposed to examining when the mean biomass from the simulations exceeds the target. For example, if the target Atka mackerel biomass is 600,000 mt then there is about a 50% chance of achieving this target in 2019 if the catch is reduced to 45% of maximum permissible ABC (Table 3). The probability of achieving the target in 2019 increases to nearly 60% if the catch is reduced to 30% of ABC, and the probability is as high as 84% if catch is set to zero. Table 3 provides results for Atka mackerel biomass targets of 500, 550, 600, 650, 700 and 750 kt.

If the target Pacific cod biomass is 2,100,000 mt then there is a 51% chance of achieving this target in 2017 if catch is reduced to 75% of maximum permissible ABC (Table 4). The probability of achieving the target in 2017 increases to 61% if the catch is reduced to 65% of ABC, and increases to 91% if the catch is set a 35% of ABC. Table 4 provides results for Pacific cod biomass targets of 1,500, 1,650, 1,800, 1,950, 2,100, and 2,250 kt.

Discussion

The intention of these simulations was to provide a sense for how much fish biomass could increase as a result of reductions in commercial catch. The projection models do not explicitly account for variability in recruitment or in distribution of biomass among areas. The models also assume that the population dynamics in each area are identical and that there is no movement of adults or recruits from one area to another. Thus the simulations do not account for the possibility that an area under full protection from fishing (i.e., area 543) could be the source of recruits for other areas. When considering these results, decisions may arise from expected values from Monte Carlo simulations or some other appropriate summary statistic (e.g., the proportion of runs that achieved a specified goal by a specified date). However, it is important to understand that what happens in the future will be a single realization of an infinite variety of outcomes (Fig. 2).

Adaptive management involves monitoring and assessing changes that result from existing management measures, and revising those measures accordingly. New management measures could provide a contrast between an area managed under the status quo (area 541), an area subjected to moderate restrictions of catch (542) and an area with extreme restrictions (543).

Although the areas have different baseline biomass levels, comparing the rate of change of fish biomass over time could be used as an indication of the effect of the management measures on fish (Skalski et al. 2001). However, given the inherent interannual variability in survey biomass estimates and in actual recruitment, particularly for Atka mackerel (Lowe et al. 2009), it may be difficult to ascribe changes in fish biomass to changes in area-specific harvest rates.

References

Lowe, S., Ianelli, J., Wilkins, M., Aydin, K., Lauth, R., and Spies, I. 2009. Stock assessment of Bering Sea/Aleutian Islands Atka mackerel. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. Pages 979-1054. North Pacific Fishery Management Council. 605 West 4th Ave., Suite 306, Anchorage, AK 99501. 1334 pp.

National Research Council (NRC). 2003. Decline of the Steller sea lion: untangling food webs and fishing nets. The National Academies Press. Washington, D.C. 204 pp.

Skalski, J.R., Coats, D.A., Fukuyama, A.K. 2001. Criteria for oil spill recovery: a case study of the intertidal community of Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. Environmental Management 28: 9-18

Thompson, G.G., Ianelli, J.N. and Lauth, R.R. 2009. Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands area. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. Pages 235-440. North Pacific Fishery Management Council. 605 West 4th Ave., Suite 306, Anchorage, AK 99501. 1334 pp.

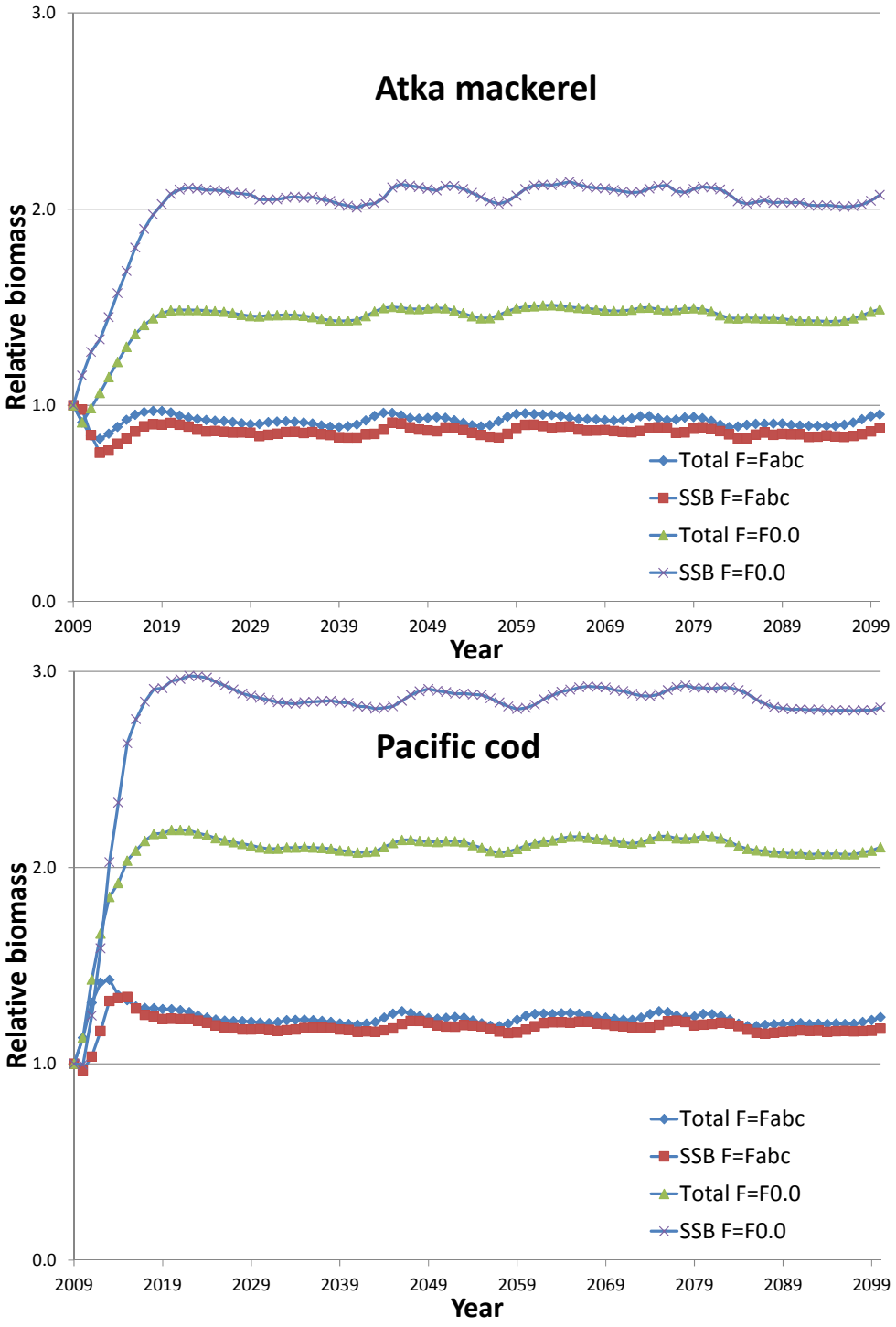

Figure 1. Mean biomass relative to 2009 estimates for Atka mackerel (top) and Pacific cod (bottom) under no fishing (F=F0.0) and fishing at maximum permissible levels (F=F_{ABC}).

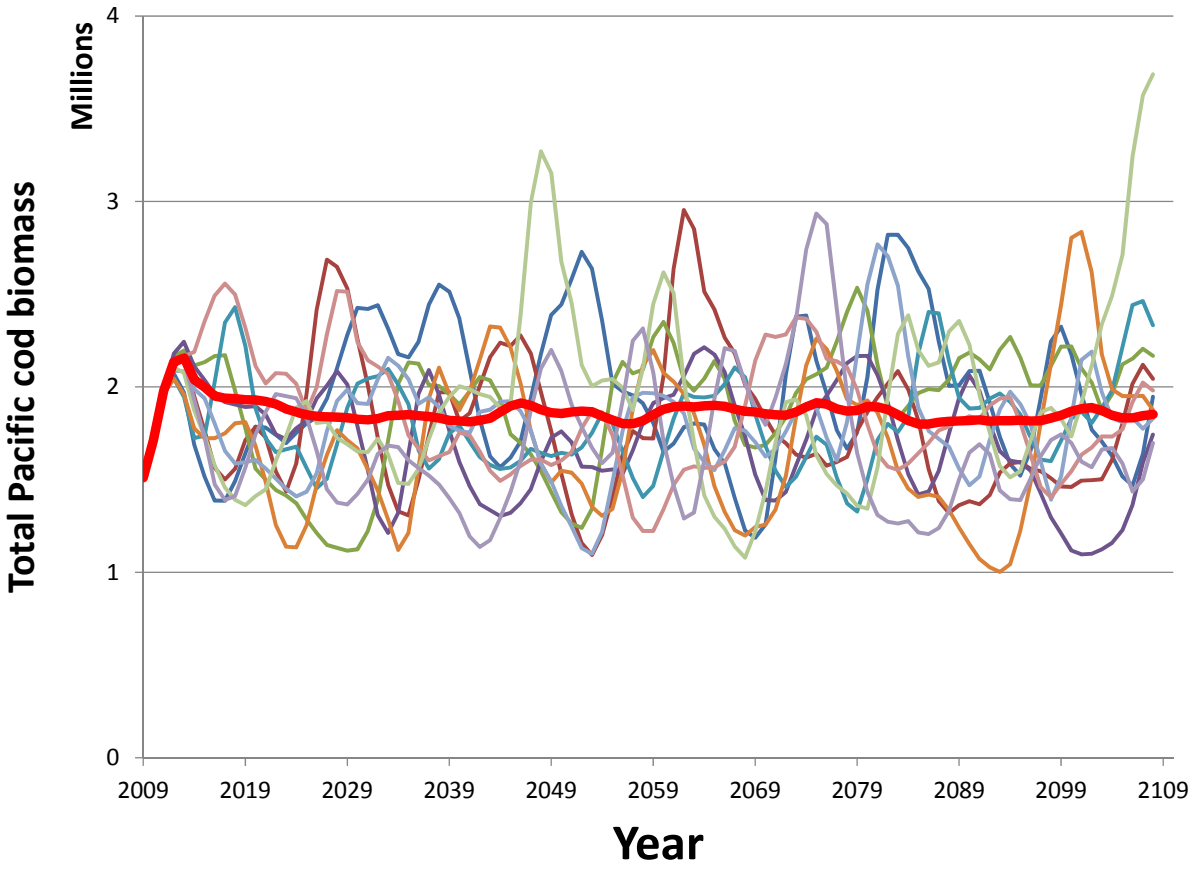

Figure 2. Mean total biomass over simulations (solid thick line) compared to some of the Monte Carlo realizations.

Table 1. Results of 100 simulations out 100 years in the future over 21 different F_{ABC} multipliers for a range of target total (Aleutian-wide) Atka mackerel biomass. Blank cells indicate the fact that biomass fell below the target in all of the 100 future years.

Target Total biomass, kt	**Atka mackerel ABC Multiplier**																				
	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0.00
500	2017	2016	2016	2016	2015	2015	2015	2014	2014	2014	2013	2013	2013	2012	2012	2012	2012	2011	2011	2011	2011
520				2017	2017	2016	2016	2015	2015	2015	2014	2014	2014	2013	2013	2013	2012	2012	2012	2012	2012
540						2019	2017	2016	2016	2016	2015	2015	2014	2014	2014	2013	2013	2013	2013	2012	2012
560									2018	2017	2016	2016	2015	2015	2014	2014	2014	2013	2013	2013	2013
580											2018	2017	2016	2016	2015	2015	2014	2014	2014	2013	2013
600												2019	2017	2017	2016	2015	2015	2015	2014	2014	2014
620														2018	2017	2016	2016	2015	2015	2014	2014
640															2019	2017	2016	2016	2015	2015	2015
660																2020	2018	2017	2016	2015	2015
680																		2018	2017	2016	2016
700																		2020	2018	2017	2016
720																			2020	2018	2017
740																				2019	2018
760																					2019
780																					2044
800																					

Table 2. Results of 100 simulations out 100 years in the future over 21 different F_{ABC} multipliers for a range of target total (EBS) Pacific cod biomass. Blank cells indicate the fact that biomass fell below the target in all of the 100 future years.

Target Total biomass, kt	**Pacific cod ABC Multiplier**																				
	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0.00
1.50	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
1.55	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
1.60	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
1.65	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
1.70	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
1.75	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
1.80	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
1.85	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
1.90	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
1.95	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
2.00	2012	2012	2012	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
2.05	2012	2012	2012	2012	2012	2012	2012	2012	2012	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
2.10	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2011	2011	2011	2011	2011	2011	2011
2.15	2013	2013	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2011
2.20			2013	2013	2013	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012
2.25					2013	2013	2013	2013	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012

Table 3. The percentage of simulations that exceed the target total Atka mackerel biomass (500, 550, 600, 650, 700 and 750 kt) for the range of F_{ABC} multipliers, by year (2010-2030).

500 kt target

	Atka mackerel ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
2011	13	14	14	14	14	14	16	17	19	25	27	29	30	32	35	38	40	41	45	50	
2012	17	17	18	19	20	23	27	31	32	35	39	41	43	47	49	53	56	58	63	65	
2013	24	26	27	28	30	33	34	37	40	43	48	50	53	54	56	59	61	67	71	78	
2014	31	31	31	33	35	37	39	45	46	49	56	57	58	61	64	69	70	76	84	86	
2015	37	38	40	43	43	44	47	52	54	56	59	63	68	72	77	80	83	84	85	90	
2016	43	47	49	50	53	54	55	61	64	66	67	70	73	76	80	83	85	89	91	92	
2017	43	46	48	51	54	56	59	62	63	67	71	75	80	80	80	86	90	93	93	96	
2018	49	53	53	55	56	58	62	63	67	69	72	77	80	82	85	90	92	96	97	99	
2019	42	45	48	54	60	63	65	66	68	70	71	72	75	80	85	95	96	97	97	100	
2020	43	47	47	50	51	54	59	59	65	68	70	75	78	83	86	91	94	96	98	99	
2021	37	43	44	50	54	55	56	58	62	65	73	77	82	84	86	87	92	95	96	97	
2022	42	44	45	48	50	51	54	62	65	68	72	78	79	82	85	90	91	92	96	97	
2023	39	43	45	45	47	54	61	62	63	66	69	73	76	87	88	89	90	91	97	98	
2024	39	42	44	46	50	54	55	58	63	65	70	72	75	80	84	87	90	94	95	97	
2025	39	42	44	45	46	53	57	57	58	61	63	70	75	80	82	88	91	92	94	97	
2026	38	38	40	43	44	48	52	55	61	62	68	71	73	77	80	86	89	93	95	97	
2027	36	36	38	40	44	46	47	52	53	58	64	70	75	77	82	85	88	95	96	99	
2028	39	39	40	40	41	44	45	49	49	51	57	65	69	75	83	85	89	95	98	99	
2029	36	38	43	45	48	51	51	52	55	57	62	63	65	70	76	81	91	94	99	99	
2030	37	41	42	43	44	49	54	58	60	63	63	66	66	68	71	80	88	91	97	99	

550 kt target

	Atka mackerel ABC Multiplier																			
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	3	4	4	5	6	6	6	8	8	8	8	8	8	11	13	14	14	14	14	15
2012	10	11	11	11	12	12	12	13	15	16	17	18	19	22	25	30	32	35	41	43
2013	14	15	16	16	16	18	18	18	21	24	27	28	33	35	39	44	49	51	54	56
2014	22	22	23	23	25	26	26	26	28	28	34	37	40	43	48	53	57	60	63	69
2015	27	27	28	29	32	33	34	35	37	39	41	43	48	54	56	61	66	70	76	80
2016	30	33	34	36	37	38	39	43	46	47	52	54	60	64	66	70	73	77	81	84
2017	33	34	34	36	38	40	43	45	47	49	56	59	62	64	67	76	79	80	84	91
2018	28	31	33	35	39	42	45	49	51	54	57	59	64	69	72	76	82	83	88	92
2019	29	30	31	31	34	37	42	43	53	55	59	63	65	70	71	74	78	86	94	97
2020	25	26	29	32	36	37	42	46	49	50	55	58	62	68	73	77	80	87	91	96
2021	26	27	29	31	32	36	37	42	45	51	55	57	62	67	72	78	85	87	88	93
2022	27	29	30	30	32	38	40	42	44	48	52	58	65	69	72	78	82	88	91	92
2023	20	23	24	28	30	35	40	43	44	50	57	60	64	66	71	77	85	88	90	91
2024	23	24	26	28	29	31	35	43	44	51	54	59	61	67	72	76	79	85	89	94
2025	22	26	28	32	35	35	35	39	43	46	56	58	59	63	67	74	79	85	91	92
2026	25	27	28	30	31	33	35	37	40	43	48	54	60	64	68	73	77	83	87	93
2027	22	23	28	30	31	31	33	34	37	41	44	51	52	60	70	73	78	82	87	95
2028	22	26	27	29	34	34	36	37	39	39	42	46	48	53	61	67	80	82	89	93
2029	22	22	23	26	28	30	32	37	40	42	46	49	52	59	62	65	70	80	88	94
2030	23	24	24	26	29	31	33	35	39	43	50	53	58	61	65	66	68	75	87	91

600 kt target

	Atka mackerel ABC Multiplier																			
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	1	1	1	2	2	2	2	3	3	4	4	5	6	6
2012	8	8	8	8	9	9	9	9	10	10	11	11	11	12	12	13	16	16	18	19
2013	9	9	10	10	10	13	13	13	14	14	16	16	18	18	20	23	27	31	34	38
2014	10	12	13	16	18	19	21	21	22	22	23	26	26	26	28	32	38	43	46	53
2015	16	17	17	17	17	20	23	25	29	30	30	32	33	38	40	42	47	53	57	64
2016	17	19	21	23	24	26	27	30	31	35	38	42	42	44	51	54	61	64	68	73
2017	24	25	27	27	29	31	32	34	35	36	38	41	47	48	55	61	64	67	77	78
2018	18	20	22	22	23	25	27	30	35	40	42	45	49	54	56	60	66	73	76	82
2019	20	21	22	23	24	25	29	30	32	32	39	46	50	56	59	63	67	72	75	84
2020	22	22	23	23	24	25	25	28	32	35	40	42	47	52	57	61	66	72	79	83
2021	17	19	20	21	22	23	24	27	29	35	36	43	47	51	56	61	66	72	79	87
2022	13	14	17	17	18	20	26	29	30	35	37	41	46	49	56	63	69	76	80	85
2023	13	14	14	15	16	18	21	25	26	30	36	39	47	52	59	62	68	75	83	88
2024	12	12	13	13	15	19	22	23	28	30	34	39	46	52	58	62	69	73	79	85
2025	14	15	15	17	18	20	21	25	28	33	35	38	44	51	58	60	65	70	78	83
2026	14	15	18	19	20	22	24	25	28	30	34	36	40	44	53	63	67	69	77	83
2027	14	15	16	17	17	19	21	23	29	30	31	33	38	42	46	55	64	71	78	82
2028	16	16	17	18	19	20	21	24	27	33	34	35	39	43	44	46	58	66	78	82
2029	12	14	15	16	18	19	21	24	27	28	30	35	40	42	46	49	59	63	69	80
2030	13	13	14	16	16	19	23	23	25	28	30	32	38	46	53	56	60	65	67	77

650 kt target

	Atka mackerel ABC Multiplier																			
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2012	1	1	1	1	1	2	3	3	6	7	8	8	8	9	9	9	10	10	11	11
2013	6	6	6	6	8	8	9	9	9	10	10	10	13	13	13	14	16	17	18	20
2014	6	6	6	8	9	10	10	10	13	14	16	19	20	22	22	24	26	26	28	32
2015	10	10	10	12	13	15	15	16	17	17	19	20	26	28	31	32	33	37	40	45
2016	11	13	13	13	14	14	16	17	19	22	24	25	30	33	39	42	43	46	54	61
2017	12	13	13	16	18	20	22	25	26	27	30	33	34	37	38	42	50	55	61	65
2018	13	13	14	14	15	16	18	22	23	25	26	29	35	40	42	45	54	56	63	69
2019	11	11	11	13	13	16	18	21	23	24	28	30	31	37	43	48	56	61	64	69
2020	13	14	14	16	18	20	22	22	22	23	24	30	32	37	43	48	51	58	63	71
2021	12	12	12	13	14	16	16	20	21	22	24	25	31	35	42	47	53	56	65	70
2022	9	9	9	9	11	12	14	16	17	19	25	29	30	35	39	46	54	57	66	75
2023	7	8	11	12	13	14	14	14	15	18	21	26	28	32	40	45	54	60	67	76
2024	11	11	11	11	12	12	12	12	15	17	20	22	29	33	39	47	55	61	67	73
2025	7	8	11	11	11	11	13	14	16	17	21	24	28	34	40	46	53	60	65	70
2026	9	9	12	12	13	14	14	14	17	20	24	25	29	33	37	42	49	59	65	71
2027	11	12	12	12	13	14	15	15	17	18	20	21	28	30	32	38	45	52	63	71
2028	7	7	9	11	13	13	15	15	18	19	20	23	26	32	35	40	44	46	55	67
2029	9	9	10	10	10	11	13	14	15	16	19	25	27	30	36	39	43	46	56	64
2030	9	9	10	11	13	13	13	13	13	17	19	24	25	29	33	36	50	54	59	64

700 kt target

	Atka mackerel ABC Multiplier																			
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	1	1	1	1	1	1	1	1	1	3	3	6	8	8	8
2013	4	4	5	5	5	5	6	6	6	6	6	7	9	9	9	10	10	12	13	13
2014	5	5	5	5	5	6	6	6	6	7	7	9	9	12	14	15	20	20	23	24
2015	5	5	5	7	7	8	8	8	12	13	13	15	15	16	19	20	24	29	30	32
2016	7	7	7	8	8	8	9	10	11	13	16	17	19	20	22	28	30	37	41	43
2017	5	7	7	8	9	11	12	13	17	19	21	21	24	26	29	35	36	39	42	52
2018	9	10	11	11	12	12	12	13	15	16	19	21	25	25	29	33	39	42	50	54
2019	8	9	9	9	10	10	11	11	11	13	17	21	24	27	29	32	40	45	53	59
2020	9	9	9	9	9	10	12	15	18	18	22	22	22	22	29	34	38	46	51	58
2021	8	9	10	10	10	10	12	12	14	15	16	21	21	24	26	30	39	45	51	56
2022	6	6	7	8	8	8	8	8	9	13	14	16	17	24	28	33	37	43	51	59
2023	3	4	4	5	5	6	9	10	13	14	14	14	16	20	25	29	37	40	54	58
2024	5	6	6	6	7	9	10	10	10	12	12	14	15	21	24	30	35	40	55	58
2025	6	6	6	7	7	7	9	11	11	11	12	13	15	20	23	28	38	44	52	62
2026	7	7	8	8	9	9	10	12	13	13	13	14	18	21	24	31	34	40	48	59
2027	6	7	7	8	9	10	10	13	13	14	15	16	17	20	21	27	31	37	44	53
2028	3	3	3	5	5	7	8	11	12	14	15	16	17	18	22	28	32	39	44	49
2029	5	6	6	6	8	9	10	10	10	11	12	14	16	18	22	26	32	38	43	48
2030	4	5	5	5	7	9	9	10	11	13	13	13	16	18	20	24	32	36	46	55

750 kt target

	Atka mackerel ABC Multiplier																			
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
2013	0	1	2	2	2	2	3	3	4	4	4	5	6	6	6	6	7	7	9	10
2014	2	2	2	3	3	3	4	4	5	5	6	6	6	7	7	7	9	12	14	16
2015	3	3	3	3	3	4	5	5	5	7	7	7	10	13	13	15	15	17	20	24
2016	2	3	3	3	3	6	6	6	7	7	8	8	11	13	15	18	20	22	28	32
2017	0	0	0	1	1	2	3	5	6	7	9	13	15	20	21	23	26	31	34	37
2018	2	3	4	4	4	5	7	9	11	12	12	12	15	17	21	25	27	31	36	40
2019	4	5	6	6	6	7	8	9	9	10	10	11	12	15	19	24	27	31	39	44
2020	5	5	5	6	6	7	8	9	9	9	11	14	17	20	22	22	25	31	38	46
2021	5	5	6	6	6	7	9	10	10	10	10	12	14	15	20	21	25	30	37	46
2022	3	3	3	3	4	6	7	7	7	8	8	9	12	12	16	19	27	32	35	44
2023	2	2	2	2	2	2	2	5	5	7	9	10	11	14	15	19	24	28	37	43
2024	3	3	3	3	4	5	6	6	6	8	9	10	10	13	14	17	24	27	35	46
2025	3	5	5	5	5	6	6	6	7	8	9	11	11	12	14	17	21	26	38	46
2026	5	5	5	5	6	6	6	7	8	8	11	12	12	13	15	18	22	28	35	45
2027	1	2	2	2	4	5	7	8	8	10	11	12	14	14	16	18	20	25	30	40
2028	1	2	2	2	2	3	3	3	6	7	9	13	13	15	16	18	19	22	32	40
2029	2	2	2	3	3	3	5	5	6	10	10	10	11	12	15	18	21	25	30	39
2030	3	3	3	3	3	4	5	5	7	7	9	11	12	13	15	18	18	22	31	38

Table 4. The percentage of simulations that exceed the target total Pacific cod biomass (1,500, 1,650, 1,800, 1,950, 2,100, 2,250 kt) for the range of F_{ABC} multipliers, by year (2010-2030).

1,500 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2011	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2012	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2013	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2014	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2015	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2016	92	96	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2017	91	92	94	96	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2018	88	91	93	94	98	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2019	92	93	93	94	96	96	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100
2020	93	94	96	97	98	99	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100
2021	90	93	94	96	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2022	89	89	91	94	95	96	96	98	99	100	100	100	100	100	100	100	100	100	100	100	100
2023	84	85	87	91	93	95	96	97	97	97	99	100	100	100	100	100	100	100	100	100	100
2024	86	88	89	90	91	93	95	96	96	98	99	100	100	100	100	100	100	100	100	100	100
2025	85	86	90	90	93	95	96	96	97	98	99	99	100	100	100	100	100	100	100	100	100
2026	84	85	88	91	92	94	94	96	97	98	98	99	100	100	100	100	100	100	100	100	100
2027	79	80	87	91	92	93	94	96	96	97	98	98	98	100	100	100	100	100	100	100	100
2028	82	82	84	87	91	95	96	97	97	98	98	99	99	100	100	100	100	100	100	100	100
2029	85	86	87	91	93	94	96	99	99	99	99	99	99	99	99	100	100	100	100	100	100
2030	82	85	88	91	93	95	97	98	99	99	99	99	99	99	99	100	100	100	100	100	100

1,650 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2011	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2012	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2013	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2014	98	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2015	88	91	94	95	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2016	83	83	85	89	91	96	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2017	79	82	84	86	91	92	94	96	99	100	100	100	100	100	100	100	100	100	100	100	100
2018	76	79	83	86	89	91	92	95	98	98	100	100	100	100	100	100	100	100	100	100	100
2019	78	81	84	85	90	93	94	94	96	98	99	100	100	100	100	100	100	100	100	100	100
2020	74	79	82	86	90	91	93	96	98	99	99	100	100	100	100	100	100	100	100	100	100
2021	74	78	80	82	91	92	96	96	96	99	100	100	100	100	100	100	100	100	100	100	100
2022	74	76	80	85	86	87	93	94	96	96	98	99	100	100	100	100	100	100	100	100	100
2023	77	79	79	82	84	84	86	90	94	95	97	97	98	100	100	100	100	100	100	100	100
2024	73	75	78	81	82	85	90	91	91	95	96	96	99	99	100	100	100	100	100	100	100
2025	67	70	75	81	85	87	88	90	91	94	96	97	98	99	100	100	100	100	100	100	100
2026	68	71	73	75	79	82	86	90	93	93	96	97	98	99	99	100	100	100	100	100	100
2027	66	69	74	76	78	81	86	90	92	93	95	96	97	98	98	100	100	100	100	100	100
2028	68	71	73	75	77	79	84	88	92	95	97	97	97	99	99	99	100	100	100	100	100
2029	63	65	73	77	79	82	85	88	92	95	98	99	99	99	99	99	99	100	100	100	100
2030	63	70	71	73	77	81	88	90	93	95	99	99	99	99	99	99	99	100	100	100	100

1,800 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2012	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2013	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2014	81	87	91	94	96	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100
2015	68	70	79	86	88	91	95	95	99	100	100	100	100	100	100	100	100	100	100	100	100
2016	65	66	72	78	80	83	87	90	95	99	100	100	100	100	100	100	100	100	100	100	100
2017	61	66	70	75	79	83	84	88	92	93	96	99	100	100	100	100	100	100	100	100	100
2018	66	69	70	72	74	78	83	88	91	92	95	98	100	100	100	100	100	100	100	100	100
2019	61	64	71	73	76	79	82	85	92	94	94	96	98	99	100	100	100	100	100	100	100
2020	60	64	66	67	76	79	82	87	90	93	96	98	99	99	100	100	100	100	100	100	100
2021	57	63	65	68	72	73	78	84	92	95	96	96	99	100	100	100	100	100	100	100	100
2022	54	58	61	64	69	74	78	83	85	94	95	96	98	98	100	100	100	100	100	100	100
2023	54	56	58	65	73	77	80	84	85	87	91	94	96	97	98	100	100	100	100	100	100
2024	51	55	60	62	69	76	79	82	84	90	91	91	95	96	97	99	100	100	100	100	100
2025	55	56	62	64	66	69	72	82	87	89	90	91	94	96	98	99	100	100	100	100	100
2026	53	55	61	62	67	69	72	76	80	83	91	93	94	97	98	99	99	100	100	100	100
2027	51	55	58	61	64	66	71	74	78	85	90	92	94	95	97	98	98	100	100	100	100
2028	48	49	53	62	67	70	75	76	78	83	87	93	95	97	97	98	99	99	100	100	100
2029	47	50	52	57	60	64	73	78	80	83	87	92	96	97	99	99	99	99	99	100	100
2030	43	49	51	55	56	60	69	76	79	86	89	93	94	99	99	99	99	99	99	100	100

1,950 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2012	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2013	94	96	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2014	58	63	66	70	75	85	90	92	96	98	99	100	100	100	100	100	100	100	100	100	100
2015	51	58	60	61	68	73	80	87	90	94	95	99	100	100	100	100	100	100	100	100	100
2016	43	49	54	60	65	69	75	80	83	87	90	95	99	100	100	100	100	100	100	100	100
2017	44	49	51	56	62	67	74	79	81	85	89	93	94	98	100	100	100	100	100	100	100
2018	45	49	54	59	67	70	72	74	79	82	88	91	92	97	99	100	100	100	100	100	100
2019	40	44	52	58	60	66	71	74	79	81	87	92	94	95	98	99	100	100	100	100	100
2020	46	47	54	57	60	63	65	72	80	84	87	91	93	97	99	99	100	100	100	100	100
2021	38	43	50	54	59	62	64	69	73	77	84	92	96	96	98	100	100	100	100	100	100
2022	39	43	46	49	55	59	62	65	73	79	81	88	94	96	98	98	100	100	100	100	100
2023	34	37	43	49	52	55	61	66	76	80	85	86	87	93	95	97	98	100	100	100	100
2024	37	41	42	45	51	57	61	66	74	78	82	87	91	91	94	96	98	99	100	100	100
2025	33	38	41	46	52	60	63	66	70	74	83	87	89	91	93	96	98	99	100	100	100
2026	34	37	40	45	51	56	60	65	69	74	78	80	85	93	94	96	98	99	99	100	100
2027	36	38	40	44	51	54	59	62	67	70	75	79	87	92	94	95	97	98	98	100	100
2028	34	35	40	42	46	49	56	64	68	72	76	79	86	88	95	97	97	98	99	99	100
2029	33	34	36	40	45	48	52	61	64	72	77	81	86	89	96	97	98	99	99	99	100
2030	35	36	38	40	44	46	52	54	59	67	75	83	88	91	94	98	99	99	99	99	99

2,100 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	1	12	21	45	80	100	100	100	100	100
2012	64	73	82	89	96	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2013	59	63	67	78	83	86	95	97	99	100	100	100	100	100	100	100	100	100	100	100	100
2014	36	42	44	51	55	59	64	70	75	85	90	94	98	99	99	100	100	100	100	100	100
2015	30	39	44	50	52	59	61	64	69	79	86	89	94	95	99	100	100	100	100	100	100
2016	29	32	34	40	45	52	59	62	69	72	80	83	87	93	96	100	100	100	100	100	100
2017	32	38	39	42	44	51	54	61	66	73	79	83	87	91	94	97	100	100	100	100	100
2018	30	34	39	42	45	51	58	65	70	73	74	81	88	91	92	97	99	100	100	100	100
2019	32	35	36	38	42	49	56	62	66	71	77	79	82	90	94	95	98	99	100	100	100
2020	28	31	36	43	45	49	54	60	63	66	75	82	85	90	93	97	99	99	100	100	100
2021	27	31	33	35	38	48	54	58	61	64	71	75	82	90	94	96	97	100	100	100	100
2022	24	27	30	34	40	44	47	55	60	64	68	77	79	86	92	96	98	98	100	100	100
2023	24	25	26	32	36	41	47	51	54	61	70	76	82	87	87	93	95	97	99	100	100
2024	20	22	28	32	37	40	44	51	55	60	71	75	79	86	90	91	94	96	99	100	100
2025	18	22	27	27	31	36	43	50	57	64	68	72	80	87	89	91	93	96	98	99	100
2026	16	19	23	30	32	38	45	49	58	61	66	70	75	79	84	91	95	95	98	99	100
2027	19	22	26	29	35	37	43	51	54	60	64	67	73	79	86	92	94	96	98	98	99
2028	21	24	24	28	32	37	39	42	49	57	66	70	73	79	86	87	95	97	97	98	99
2029	20	22	25	28	32	34	39	45	48	53	62	70	74	79	84	90	95	97	98	99	99
2030	20	24	25	29	34	36	37	44	46	52	56	61	71	82	87	91	95	98	99	99	99

2,250 kt target

	Pacific cod ABC Multiplier																				
Year	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	8	13	14	15	19	24	31	38	50	61	73	85	92	98	100	100	100	100	100	100	100
2013	25	29	35	39	45	53	61	65	74	81	86	95	97	99	100	100	100	100	100	100	100
2014	17	19	22	28	34	39	44	51	55	59	65	71	80	90	92	96	98	99	100	100	100
2015	18	19	22	25	30	40	47	50	57	60	63	70	79	88	90	95	98	100	100	100	100
2016	21	23	24	27	29	33	39	44	51	59	63	69	76	80	87	92	95	100	100	100	100
2017	18	20	27	30	34	38	41	45	49	55	64	69	78	81	86	90	94	97	100	100	100
2018	20	22	27	28	32	38	43	45	51	59	67	70	74	80	84	91	92	97	100	100	100
2019	23	28	28	31	34	36	38	43	51	58	63	69	75	79	81	90	94	95	98	99	100
2020	16	19	22	26	31	35	43	45	50	56	61	64	71	80	85	91	93	97	99	99	100
2021	16	21	24	26	29	33	35	43	49	57	59	63	68	74	83	90	93	96	98	100	100
2022	18	21	22	23	26	28	34	41	45	49	57	61	67	73	79	86	91	97	98	100	100
2023	14	17	19	22	24	25	29	37	44	48	54	59	65	73	82	87	88	93	96	98	99
2024	11	12	16	19	21	27	31	33	40	47	54	56	67	74	79	86	90	91	95	98	100
2025	12	14	15	17	19	27	28	31	38	43	53	60	67	71	80	87	89	91	93	98	99
2026	12	12	14	16	19	22	27	31	39	46	54	58	64	70	75	80	85	92	95	97	99
2027	12	14	15	15	21	23	26	33	38	48	52	58	63	67	75	80	86	91	94	97	98
2028	13	13	16	17	21	24	27	32	37	42	44	52	66	69	74	78	85	91	95	97	98
2029	15	15	16	17	20	20	25	30	34	38	46	51	61	70	73	80	86	93	95	98	99
2030	14	16	18	18	21	22	26	34	35	37	45	49	55	60	70	81	88	92	95	98	99