A Summary of Current Stock Assessment Information Used in Managing Alaska Groundfish Stocks

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Fishery Stock Assessment Models for the 21st Century: Combining Multiple Information Sources

by
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Table of Contents

List of Tables

Abstract

The North Pacific Fishery Management Council (NPFMC) is responsible for effectively managing the groundfish fisheries in the Bering Sea (BS), Aleutian Islands (AI), and Gulf of Alaska (GOA). These fisheries target walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), Atka mackerel (*Pleurogrammus monopterygius*) and numerous flatfish (*Pleuronectes* sp. and *Hippoglossoides sp.*) and rockfish (*Sebastes* sp. and *Sebastolobus* sp.) species. These stocks are routinely evaluated by National Marine Fisheries Service (NMFS) scientists, who are relied on by the Council to recommend harvest levels that will maintain healthy stocks. Alaska Department of Fish and Game scientists evaluate the stocks of three species of demersal shelf rockfish, for which the NPFMC has delegated management authority to the State of Alaska.

Introduction

Stock assessments have evolved since 1978 in response to changes in target species, data collection, and assessment methodology. Currently, biomass for most groundfish stocks is estimated using a stock synthesis model described by Methot (1990). The lack of age data, however, has prevented the traditional application of the synthesis model to some stocks of flatfish, rockfish, GOA Atka mackerel, and squid. Instead, stock biomass is estimated using an area-swept index from trawl survey data.

There also have been changes in methodology for estimating optimal harvest rates and overfishing rates. These harvest rates, when applied to estimated biomass for individual stocks, result in a preliminary recommendation for acceptable biological catch (ABC) and an overfishing level. For most stocks, ABC estimates are determined by calculating the fishing mortality which reduces the equilibrium level of spawning biomass per recruit to 40% of its unfished level ($F_{40\%}$) (Clark 1993). The overfishing level for most stocks is currently based on an $F_{30\%}$ rate. In the absence of maturity and growth information, ABC is based on an F=0.75M harvest strategy, and overfishing is based on F=M.

Historical Assessment Methodologies

The groundfish assessments are compiled into a stock assessment and fishery evaluation (SAFE) report, which is prepared and reviewed annually for each fishery management plan. These assessments undergo a thorough peer review process, first by the Council's groundfish plan teams which review the stock assessments and then by the Council's Scientific and Statistical Committee (SSC), both of which are composed of biologists and economists from state and federal agencies, and academia.

Conservation-based scientific assessment advice, along with strict adherence to scientific advice by managers, has resulted in relatively healthy stocks of groundfish in the North Pacific. Of 37 North Pacific groundfish stocks examined, three-year trends in relative abundance, based on stock assessment and survey CPUE trends, indicate 8 stocks are increasing, 8 stocks are stable, 13 stocks are decreasing, and 8 stocks are of unknown status (Table 1). Total groundfish harvests in 1996 relative to their respective ABCs are shown in (Table 2). Harvests for all species except GOA Pacific cod and BS/AI and GOA Pacific ocean perch were held at or below the respective ABC. Overruns occurred due to difficulty of in-season management of Pacific cod and Pacific ocean perch (*Sebastes alutus*).

The Council's reliance on the plan teams and SSC is well-documented. During 1987-1997 (Table 3), the Council exceeded the SSC ABC recommendation only twice in 344 ABC determinations (Pautzke, Unpubl.). In 1980, the Council set the AI sablefish ABC at 4,500 mt, higher than the SSC recommendation of 3,700 mt, but lower than the plan team recommendation of 9,600 mt. In 1992, the Council set the GOA pollock ABC midway between the SSC and plan team recommendations. The Council set ABC lower than

the SSC recommendation in five instances. At no time has the Council set total allowable catch (TAC), or quota, higher than ABC. In fact, the Council set TAC lower than ABC for 54% of the determinations and set TAC equal to ABC in 44% of determinations. ABCs were not specified by the Council in 2% of cases; these occurred in the GOA between 1987 and 1990.

Based on current criteria in the Magnuson-Stevens Act, the Congressional Act under which the Council is authorized to manage North Pacific fish stocks, NMFS has determined that of 106 groundfish stocks under the Council's jurisdiction, 0 are overfished or approaching overfished condition, 64 are not overfished, and 42 are of unknown status (NMFS 1997). Nationally 86 stocks are overfished, 10 are approaching overfished, 183 are not overfished, and 448 are unknown. Stock status may change under revised guidelines that should be published in late 1998.

The Council is routinely apprised of changing data needs and assessment methodologies as they affect groundfish management. When a directed fishery for black rockfish began developing in the GOA, the GOA plan team informed the Council that the NMFS bottom trawl survey did not adequately assess black (*S. melanops*) and blue rockfishes (*S. mystinus*) and recommended that the Council separate those rockfishes from the pelagic shelf rockfish (PSR) management grouping to prevent overexploitation under the large PSR TAC. In 1997, the Council submitted a plan amendment to do so, and deferred their management to the State of Alaska (NPFMC 1997). The Council has responded to plan team and SSC recommendations for enhanced groundfish management by separating or grouping appropriate species within the management unit of the FMPs. The history of assessment models for the BSAI and GOA for species/complexes with sufficient biological information since 1986 is presented in (Table 4). Trawl, longline (sablefish), and hydroacoustic (pollock) research surveys collect required biological information to implement the models (Table 5). Life history information is summarized in Table 6.

The Council also employs a precautionary approach in applying stock assessment results to commercial fisheries. New assessment models and modifications to existing models are reviewed and phased-in only after considerable peer review by the plan teams and SSC. New models are generally introduced in one year, but do not replace the existing model until tested and reviewed. In its December 1996 meeting minutes, the SSC requested that beginning in 1997, stock assessment authors incorporate: (1) biomass and yield projections for an $F_{40\%}$ harvest strategy under varying assumptions regarding recruitment and for other relevant exploitation rates; (2) standard errors or confidence intervals for important model parameters; (3) sensitivity analyses for key parameters and input assumptions; (4) weightings given to individual data components with justifications; and (5) risk analyses.

In the SAFE report for 1998, Hollowed et al. (1997) included an appendix to the walleye pollock chapter that incorporated predation mortality by arrowtooth flounder, Pacific halibut, and Steller sea lion as a fishery type into the stock synthesis model. A second appendix demonstrated the use of the AD Model Builder software in the GOA pollock stock assessment, which facilitates the rapid development of nonlinear statistical models. This modeling software may also be used in the near future for GOA sablefish and rockfish species.

Conclusions

In the future, assessments will continue to be further developed to more explicitly account for uncertainty and provide more precautionary advice, and management will likely become more precautionary and risk averse. Risk averse management is most feasible where effective management practices are in place, for example, the North Pacific. Recent advances in management, such as the NPFMC's quota tier system (Table 7), suggest that under a risk adverse policy, greater uncertainty in important model parameters will generally result in lower quotas. Increasing complexity in stock assessment models directly results from

improved data collection and modeling software, along with incorporation of ecosystem interactions and uncertainty. Faced with increased complexity in the stock assessment modeling, management agencies will rely increasingly on its scientific advisors.

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Table 1. Relative Abundance (exploitable biomass in mt) of Bering Sea (BS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish, 1996.

Species	Area	1996 Biomass	Mean Biomass	Reference Years	Biomass relative to mean	3-Year Trend
Pollock	BS	6,200,000	8,540,000	1964-1996	below	down
	AI	230,000	688,000	1978-1996	below	down
	Bogoslof	680,000	1,210,000	1988-1996	below	stable
	GOA	574,000	1,495,600	1969-96	below	down
Pacific cod	BSAI	1,106,000	1,364,000	1978-1996	below	up
	GOA	314,000	453,300	1978-96	above	up
Deepwater flatfish	GOA	101,400	116,000	1978-96	below	down
Yellowfin sole	BSAI	2,862,000	1,979,000	1960-1996	above	stable
Greenland turbot	BSAI	127,000	448,000	1960-1996	below	down
Arrowtooth flounder	BSAI	556,400	279,700	1975-1996	above	stable
	GOA	1,640,000	924,000	1961-96	above	up
Rock sole	BSAI	2,183,000	1,187,000	1975-1996	above	stable
Rex sole	GOA	72,300	85,900	1990-96	below	down
Flathead sole	BSAI	616,400	403,000	1975-1996	above	stable
	GOA	206,000	217,400	1990-96	stable	unknown
Other flatfish	BSAI	589,500	595,000	1975-1996	near	stable
Shallow water flatfish	GOA	316,000	306,700	1990-96	stable	down
Sablefish	BS	24,100	41,200	1979-1996	below	stable
	AI	24,100	54,200	1979-1996	below	down
	GOA	271,000	390,000	1979-96	below	down
Pacific ocean perch	BS	72,500	97,300	1960-1996	below	down
	AI	324,000	234,000	1962-1996	above	up
	GOA	774,000	360,000	1984-96	above	up
Sharpchin/Northern	AI	96,800	96,646	1980-1996	near	unknown
Northern rockfish	GOA	85,000	73,100	1984-96	above	up
Shortraker/Rougheye	AI	45,600	45,616	1980-1996	near	unknown
	GOA	65,000	68,800	1984-96	near	down
Pelagic shelf rockfish	GOA	78,000	56,300	1984-96	above	up
Other slope rockfish	GOA	131,000	138,100	1984-96	near	up
Other red rockfish	BS	29,700	unknown	unknown	unknown	unknown
Other rockfish	BS	7,100	5,200	1979-1996	unknown	unknown
	AI	13,600	13,600	1980-1996	unknown	unknown
Thornyheads	GOA	47,000	65,100	1967-96	below	down
Atka mackerel	AI	576,000	699,000	1977-1996	below	down
	GOA	unknown	unknown	unknown	unknown	unknown
Squid	BSAI	unknown	unknown	unknown	unknown	unknown
Other species	BSAI	621,000	574,000	1975-1996	above	stable

Table 2. Exploitable biomass and harvest specifications (mt) of Bering Sea (BS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish, 1997.

Species	Area	Biomass	OFL	ABC	TAC
Pollock	BS	6,120,000	1,980,000	1,130,000	1,130,000
	AI	100,000	38,000	28,000	28,000
	Bogoslof	558,000	43,800	32,100	1,000
	GOA	1,097,830	111,270	79,980	79,980
Pacific Cod	BSAI	1,590,000	418,000	306,000	270,000
	GOA	562,000	180,000	81,500	69,115
Deepwater flatfish	GOA	101,430	9,440	7,710	7,710
Yellowfin sole	BSAI	2,530,000	339,000	233,000	230,000
Greenland turbot	BSAI	118,000	22,600	12,350	9,000
Arrowtooth flounder	BSAI	587,000	167,000	108,000	20,760
	GOA	1,639,671	280,800	197,840	35,000
Rock sole	BSAI	2,390,000	427,000	296,000	97,185
Rex sole	GOA	72,330	11,920	9,150	9,150
Flathead sole	BSAI	632,000	145,000	101,000	43,500
	GOA	206,340	34,010	26,110	9,040
Shallow water flatfish	GOA	315,590	59,540	43,150	18,630
Other flatfish	BSAI	616,000	150,000	97,500	50,750
Sablefish	BS	17,900	2,750	1,308	1,100
	AI	18,600	2,860	1,367	1,200
	GOA	206,060	35,950	14,520	14,520
Other slope rockfish	GOA	103,710	7,560	5,260	2,170
Northern rockfish	GOA	83,370	9,420	5,000	5,000
Pelagic shelf rockfish	GOA	55,640	8,400	5,140	5,140
Demersal shelf rockfish	GOA	60,510	1,450	950	950
Pacific Ocean Perch	BS	72,500	5,400	2,800	2,800
	AI	324,000	25,300	12,800	12,800
	GOA	242,300	19,760	12,990	9,190
Sharpchin/Northern	AI	96,800	5,810	4,360	4,360
Shortraker/Rougheye	AI	45,600	1,250	938	938
	GOA	65,380	2,740	1,590	1,590
Other red rockfish	BS	29,700	1,400	1,050	1,050
Other rockfish	BS	7,100	497	373	373
	AI	13,600	952	714	714
Thornyheads	GOA	46,110	2,400	1,700	1,700
Atka mackerel	AI	450,000	81,600	66,700	66,700
	GOA	n/a	6,200	1,000	1,000
Squid	BSAI	n/a	2,620	1,970	1,970
Other species	BSAI	688,000	138,000	25,800	25,800
	GOA	n/a	n/a	n/a	13,470
TOTAL (all species)	BSAI	17,004,800	3,998,839	2,464,130	2,000,000
TOTAL (all species)	GOA	4,797,760	784,860	493,050	282,815
TOTAL (all species)	BOTH	21,802,560	4,783,699	2,957,180	2,282,815

OFL = overfishing level; TAC = total allowable catch; ABC = allowable biological catch

Table 3. Comparison of Allowable Biological Catch (ABC) and Total Allowable Catch (ABC) recommendations for groundfish targets in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) area, from the North Pacific Fishery Management Council and its Scientific and Statistical Committee (SSC), 1987 - 1997, based on one allowable biological catch (ABC) per species or complex.*

Gulf of Alaska

Year	# of species or complexes	ABC's > SSC	# of times Council set: ABC's < SSC	TAC's > ABC	TAC's = ABC	TAC's < ABC
1997	16	0	0	0	10	6
1996	16	0	1	0	8	8
1995	16	0	1	0	9	7
1994	16	0	1	0	8	8
1993	13	0	0	0	5	8
1992	13	1	0	0	7	6
1991	13	0	0	0	7	6
1990	10	0	1	0	5	4
1989	8	0	1	0	3	4
1988	8	0	0	0	4	3
1987	9	0	0	0	1	5
Total GOA	138	1	5	0	67	65

Bering Sea/Aleutian Islands

Year	# of species or complexes	ABC's > SSC	# of times Council set: ABC's < SSC	TAC's > ABC	TAC's = ABC	TAC's < ABC
1997	21	0	0	0	11	10
1996	21	0	0	0	4	17
1995	21	0	0	0	4	17
1994	20	0	0	0	14	6
1993	20	0	0	0	6	14
1992	20	0	0	0	13	7
1991	19	0	0	0	12	7
1990	17	1	0	0	6	11
1989	17	0	0	0	2	15
1988	15	0	0	0	5	10
1987	15	0	0	0	8	7
Total BSAI	206	1	0	0	85	121
TOTAL	344	2	5	0	152	186

*some rows do not sum as reported as a result of unspecified ABCs in some years for Atka mackerel, DSR, and other rockfish.

POP = Pacific ocean perch, OFD= overfishing definition; DSR = demersal shelf rockfish

Table 4. Stock assessment models employed by NMFS for North Pacific groundfish, 1986-97.

BSAI		Pacific		Atka		Pacific	Greenland		other	yellowfin
	pollock	cod	sablefish	mackerel	arrowtooth	ocean perch	turbot	rock sole	flatfish	sole
97	Ch, Ca, SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
96	Ch, Ca, SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
95	Ch, Ca, SS	SS	SRA	SS	SS	SS	SS	SS	none	SS
94	Ca, Ch	SS	SRA	SS	YPR	SS	SS	SS	none	SS
93	Ca, Ch	SRA	SRA	SS	YPR	SS	SRA	SS	YPR	SS
92	Ca, Ch	SRA	SRA	SS	YPR	SRA	SRA	S. Index	YPR	SS
91	Ca, Ch	SRA	SRA	Ch	YPR	SRA	SRA	S. Index	YPR	S. Index
90	Ca, Ch	SRA	SRA	Ch	YPR	SRA	SRA	S. Index	YPR	S. Index
89	Ca, Ch	SRA	SRA	Ch	YPR	SRA	SRA	S. Index	YPR	S. Index
88	Ca, Ch	ASA	SRA	none	YPR	SRA	SRA	S. Index	YPR	S. Index
87	Ca, Ch	ASA	none	none	none	SRA	SRA	S. Index	none	S. Index
86	Ch	ASA	GPM	none	none	SRA	none	S. Index	none	S. Index

GOA				Atka		POP/slope	thorny-	other
	pollock	P. cod	sablefish	mackerel	arrowtooth	rockfish	heads	flatfish
97	SS	SS	SRA	none	SS	SS	SS	Index
96	SS	SS	SRA	none	SS	SS	SS	DD
95	SS	SS	SRA	none	SS	SS	SS	DD
94	SS	SRA	SRA	none	in flatfish	SS	YPR	DD
93	SS	SRA	SRA	none		SS	YPR	DD
92	SS	SRA	SRA	in other		SS	YPR	DD
91	SS	SRA	SRA	species		SRA	YPR	YPR
90	SS	SRA	SRA			SRA	YPR	YPR
89	SRA	SRA	SRA			SRA	YPR	YPR
88	SRA	YPR	SRA			SRA	none	YPR
87	none	PYM	SPM			SRA	none	none
86	ASA	PYM	SPM			SRA	none	none

ASA = Age-structured analysis (Thompson et al)
Ca = CAGEAN
Cohort = ASA (Pope)
DD = Delay-Difference (Deriso; Schnute)
GPM = Growth production model
S. Index = survey index
PYM = Production yield model
SPM = Stock production model ( ).
SRA = Stock reduction analysis (Kimura)
SS = Stock Synthesis (Methot)
YPR = Yield-per-recruit analyses (Ricker, Beverton-Holt)

Table 5. Current research surveys conducted for Bering Sea (BS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish, by species and area.

Species	Area	EBS Trawl Survey	EBS Acoustic Survey	Bogoslof Acoustic Survey	EBS+AI Longline Survey	AI Trawl Survey	GOA Acoustic Survey
Pollock	BS	annual	triennial	-	-	-	-
	AI	-	-	-	-	triennial	-
	Bog	-	-	annual	-	-	-
	GOA	-	-	-	-	triennial	annual
Pacific cod	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Yellowfin sole	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Gr Turbot	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Arrowtooth	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Rock sole	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Flathead sole	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Other flatfish	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-
Sablefish	BS	annual	-	-	biennial	-	-
	AI	-	-	-	biennial	triennial	-
	GOA	-	-	-	-	triennial	-
P. ocean perch	BS	annual	-	-	-	-	-
	AI	-	-	-	-	triennial	-
	GOA	-	-	-	-	triennial	-
Sharp/northern	AI	-	-	-	-	triennial	-
	GOA	-	-	-	-	triennial	-
Short/rougheye	AI	-	-	-	-	triennial	-
	GOA	-	-	-	-	triennial	-
O red rockfish	BS	annual	-	-	-	-	-
Other rockfish	BS	annual	-	-	-	-	-
	AI	-	-	-	-	triennial	-
	GOA	-	-	-	-	triennial	-
Atka mackerel	AI	-	-	-	-	triennial	-
	GOA	-	-	-	-	triennial	-
Squid	BSAI	annual	-	-	-	-	-
Other species	BSAI	annual	-	-	-	-	-
	GOA	-	-	-	-	triennial	-

Table 6. Life history characteristics for BSAI/GOA groundfish used in 1997 stock assessments, including natural mortality rate (M), length and age at 50% maturity (females), growth parameters (Linf and k or von Bertalanffy equation where $L=L_{inf}\{[_1\text{-}exp(-k(t-t_0)]\}$, and weight parameters ($W=alpha*L^{beta}$) for both sexes combined. Length is measured in centemeters (cm) and weight in grams (g).

		Growth Parameters			Maturity Indicators		Weight Parameters	
Species	Area	M	L_{inf}	k	$L_{50\%}$	$A_{50\%}$	alpha	beta
Pollock	BS	0.30	59.0	0.228	n/a	n/a	1.14E-05	2.877
	AI	0.30	52.8	0.368	n/a	n/a	2.73E-05	2.651
	Bogoslof	0.20	55.7	0.171	n/a	n/a	1.29E-06	3.436
	GOA	0.30	56.2	0.328	n/a	n/a	1.27E-05	2.885
Pacific cod	BSAI	0.30	98.2	0.227	67	5.7	5.29E-06	3.206
	GOA	0.37	120.0	0.119	67	6.6	5.29E-06	3.206
Rex sole	GOA	0.20	59.5	0.20	n/a	n/a	4.46E-03	3.471
Dover sole	GOA	0.10	n/a	n/a	n/a	n/a	n/a	n/a
Yellowfin sole	BSAI	0.12	35.8	0.147	30	10.5	9.72E-04	3.056
	GOA	0.20	34.0	0.18	n/a	n/a	6.68E-03	3.18
Greenland Turbot	BSAI	0.18	n/a	n/a	60	9.0	2.69E-06	3.309
Arrowtooth	BSAI	0.20	59.0	0.170	n/a	n/a	5.68E-06	3.103
	GOA	0.20	59.6	0.17	47	n/a	3.92E-03	3.223
Rock sole	BSAI	0.20	45.1	0.180	n/a	n/a	7.61E-03	3.120
	GOA	0.20	38.8	0.21	n/a	n/a	9.98E-03	3.047
Flathead sole	BSAI	0.20	42.6	0.165	n/a	n/a	3.96E-03	3.259
	GOA	0.20	29.9	0.49	n/a	n/a	4.06E-03	3.237
Other flatfish	BSAI	0.20	72.2	0.053	n/a	n/a	8.84E-03	3.111
Sablefish	BS	0.10	70.7	0.275	n/a	4	3.23E-03	3.294
	AI	0.10	77.6	0.206	n/a	4	3.23E-03	3.294
	GOA	0.10	89.3	0.142	65	4	2.99E-03	3.30
Pacific ocean perch	BS	0.05	39.9	0.135	n/a	n/a	1.19E-05	3.037
	AI	0.05	39.6	0.167	n/a	n/a	1.22E-05	3.030
	GOA	.02-.08	44.8	0.088	10.5	n/a	1.54E-05	2.96
Sharpchin/Northern	AI	0.06	n/a	n/a	n/a	n/a	n/a	n/a
rockfish	GOA	.05/.06	34.9/35.6	.095/.190	n/a	n/a	1.63E-05	2.98
Shortraker/Rougheye	AI	0.03	n/a	n/a	n/a	n/a	n/a	n/a
rockfish	GOA	.027-.042	54.7	0.050	n/a	n/a	n/a	n/a
Other red rockfish	BS	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Demersal shelf rockfish	GOA	0.02	68.9	0.053	52	21	4.35E-06	3.396
Thornyheads	GOA	0.07	n/a	n/a	22	n/a	1.36E-06	3.390
Other rockfish	BS	0.07	n/a	n/a	n/a	n/a	n/a	n/a
	AI	0.07	n/a	n/a	n/a	n/a	n/a	n/a
	GOA	.01-.07	n/a	n/a	n/a	n/a	n/a	n/a
Atka mackerel	AI	0.30	43.5	0.449	31.1	3.6	5.05E-06	3.240
	GOA	0.30	47.3	0.610	38.3	3.6	1.55E-05	2.979
Squid	BSAI	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 7. Tiers used to determine Allowable Biological Catch (ABC) and Overfishing Level (OFL) for North Pacific groundfish stocks.

(1) Information available: Reliable point estimates of B and B_{MSY} and reliable pdf of F_{MSY}.
- 1a) Stock status: $B/B_{MSY} > 1$
  $F_{OFL} = m_A$, the arithmetic mean of the pdf
  $F_{ABC} \leq m_H$, the harmonic mean of the pdf
- 1b) Stock status: $a < B/B_{MSY} \leq 1$
  $F_{OFL} = m_A \times (B/B_{MSY} - a)/(1 - a)$
  $F_{ABC} \leq m_H \times (B/B_{MSY} - a)/(1 - a)$
- 1c) Stock status: $B/B_{MSY} \leq a$
  $F_{OFL} = 0$
  $F_{ABC} = 0$

(2) Information available: Reliable point estimates of B, B_{MSY}, F_{MSY}, $F_{30\%}$, and $F_{40\%}$.
- 2a) Stock status: $B/B_{MSY} > 1$
  $F_{OFL} = F_{MSY} \times (F_{30\%}/F_{40\%})$
  $F_{ABC} \leq F_{MSY}$
- 2b) Stock status: $a < B/B_{MSY} \leq 1$
  $F_{OFL} = F_{MSY} \times (F_{30\%}/F_{40\%}) \times (B/B_{MSY} - a)/(1 - a)$
  $F_{ABC} \leq F_{MSY} \times (B/B_{MSY} - a)/(1 - a)$
- 2c) Stock status: $B/B_{MSY} \leq a$
  $F_{OFL} = 0$
  $F_{ABC} = 0$

(3) Information available: Reliable point estimates of B, $B_{40\%}$, $F_{30\%}$, and $F_{40\%}$.
- 3a) Stock status: $B/B_{40\%} > 1$
  $F_{OFL} = F_{30\%}$
  $F_{ABC} \leq F_{40\%}$
- 3b) Stock status: $a < B/B_{40\%} \leq 1$
  $F_{OFL} = F_{30\%} \times (B/B_{40\%} - a)/(1 - a)$
  $F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - a)/(1 - a)$
- 3c) Stock status: $B/B_{40\%} \leq a$
  $F_{OFL} = 0$
  $F_{ABC} = 0$

(4) Information available: Reliable point estimates of B, $F_{30\%}$, and $F_{40\%}$.
  $F_{OFL} = F_{30\%}$
  $F_{ABC} \leq F_{40\%}$

(5) Information available: Reliable point estimates of B and natural mortality rate M.
  $F_{OFL} = M$
  $F_{ABC} \leq 0.75 \times M$

(6) Information available: Reliable catch history from 1978 through 1995.
  OFL = the average catch from 1978 through 1995, unless an alternative value is established by the SSC on the basis of the best available scientific information
  $ABC \leq 0.75 \times OFL$

F= fishing mortality; B = biomass; MSY = maximum sustainable yield; OFL = overfishing level; ABC = allowable biological catch; SSC = scientific and statistical committee; pdf = probability density function.