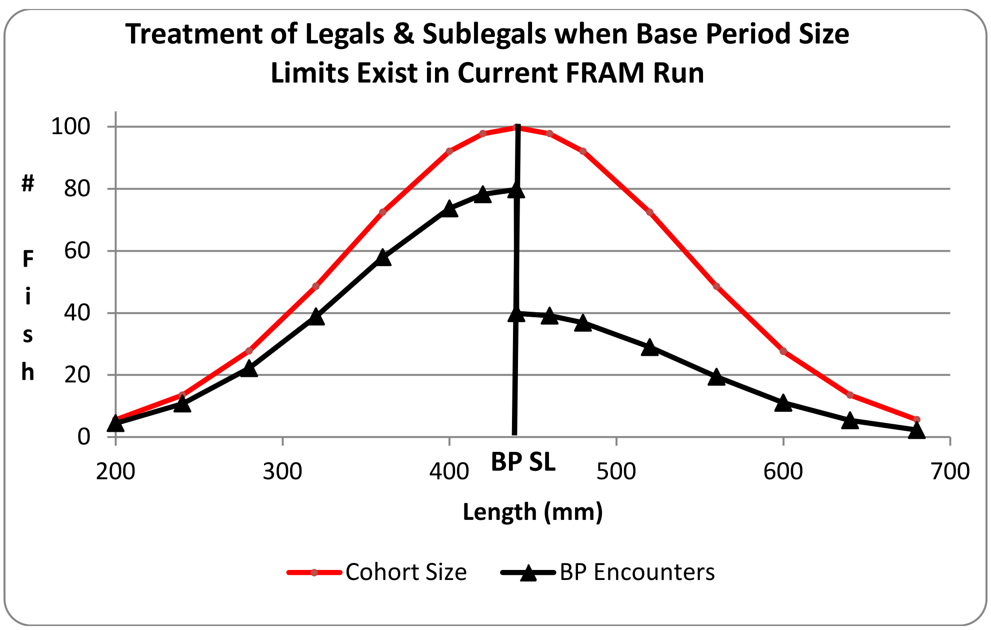
Agenda Item C.3.a
Attachment 5
November 2012

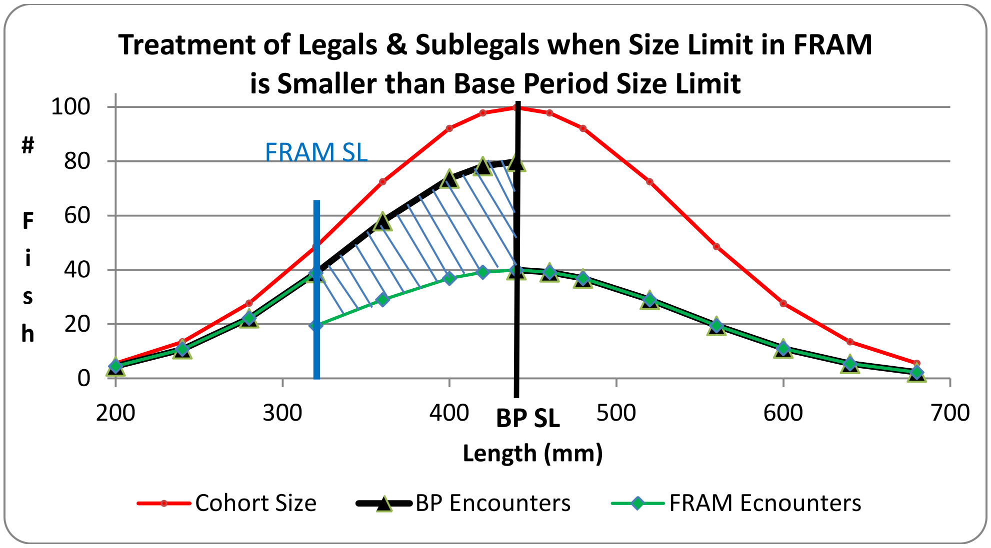
FRAM Size Limit Modeling

In recent years, Chinook FRAM hasn't been used to evaluate the effects of size limit changes, because modeling outcomes were deemed unreliable. Direct comparisons of landed catches and shaker mortalities between two FRAM runs that only differed in the minimum size limit could produce unexpected results, i.e. total mortality rising with a size limit increase.

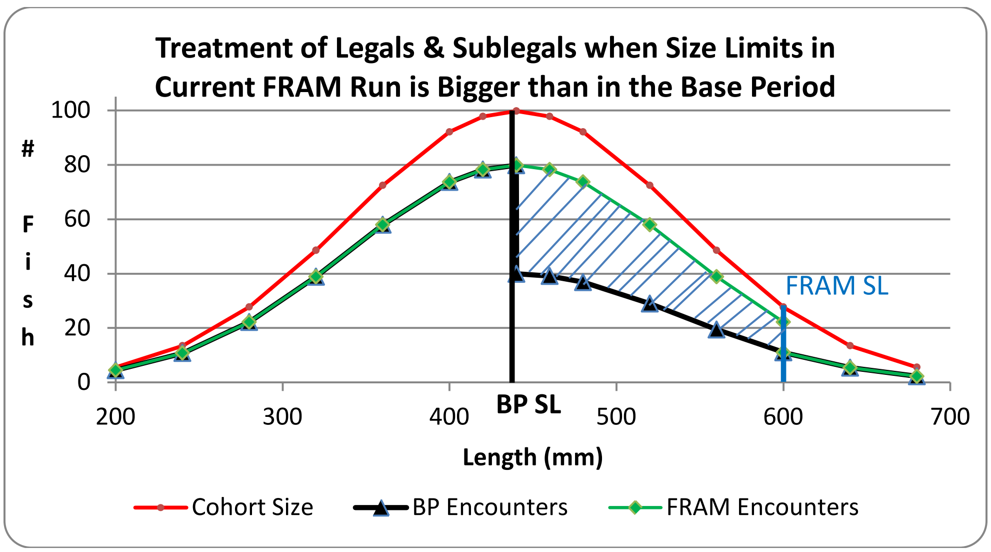
FRAM uses different rates to model encounters of legal and sub-legal fish. These rates are computed during the calibration process and are based on landed catch and encounter information during the base period years (1976-1984). As such, they reflect the size limit conditions as they existed at the time.
When size limits are modeled in FRAM, each fish smaller than the size limit is treated as a sub-legal fish. Sub-legal encounter rates are used to compute release mortalities. Conversely, each fish larger than the size limit is deemed legal and legal encounter rates are used to estimate catch. As the size limit is changed, a portion of the population (with sizes between the old and the new size limit) that previously received a sub-legal encounter rate will receive a legal encounter rate or vice versa. This leads to the total number of computed encounters varying with size limits, an incorrect outcome, if effort remains constant.

The graphs below illustrate the effects of size limit changes when the sublegal encounter rate is higher than the legal encounter rate.





The blue stripped area designates the catch that FRAM is underestimating when the size limit is lowered.



The blue stripped area designates the number of encounters that FRAM is overestimating when the size limit is increased.

FRAM Sub-Legal Shaker Mortality Algorithms

FRAM models sub-legal sized Chinook shaker mortalities through the use of the von Bertalanffy growth equation for stocks that contribute to each fishery. The mean size of each stock at the midpoint of the time step is evaluated against the stock-specific growth equation to estimate the proportion vulnerable by stock. The algorithms from the PFMC (2007) (pgs. 21-22) FRAM documentation are as follows:

$$(27)\ \ KTime_{s,a,t} = (Age_s - 1)\ \times\ 12 + \overbrace{MidTimeStep(Months)}$$

$$(28)\ \ MeanSize_{s,a,t} = \overbrace{L_s}\ \times\ (1-(\exp(-\overbrace{K_s})\ \times\ (\overbrace{KTime_{s,a}} - \overbrace{T0_s})))$$

$$(29)\ \ StdDev_{s,a,t} = \overbrace{CV_{s,a}}\ \times\ \overbrace{MeanSize_{s,a,t}}$$

$$(30)\ \ PV_{s,a,t} = 1 - NormalDistr(\underbrace{Minsize_{f,t}}, \overbrace{Meansize_{s,a,t}}, StdDev_{s,a})$$

where:

$KTime_{s,a}$	=	Time for estimate of growth equation for stock ***s***, age ***a***,
$PV_{s,a,t}$	=	Percent Vulnerable for stock *s*, age *a*, at time step *t*,
L_s	=	Von Bertalanffy growth parameter for stock *s (Max Size)*,
K_s	=	Von Bertalanffy growth parameter for stock *s (Slope)* ,
$T0_s$	=	Von Bertalanffy growth parameter for stock *s (Time Zero)*,
$CV_{s,a}$	=	Coefficient of Variation of size distribution at $KTime_{s,a}$ for stock *s*, age *a*,
$MinSize_{f,t}$	=	Minimum Size Limit for fishery *f*, time step *t*, and
$MeanSize_{s,a,t}$	=	Mean total length of a fish of stock *s* at age *a* at time step *t*.

The distribution of Chinook sizes by age at a particular time is assumed to be normal with a variance that was calculated using lengths from CWT recovery data. Evaluation of the normal distribution is done using a calculation method developed for the original WDF/NBS Chinook model.

$$(31)\ \ Z = (\underbrace{MinSize_{f,t}} - \overbrace{Meansize_{s,a,t}}) \Big/ StdDev_{s,a}$$

$$(32)\ A1 = Z\ \times\ (0.000005383\ \times\ Z + 0.0000488906) + 0.0000380036$$

$$(33)\ A2 = Z\ \times\ (A1 + 0.0032776263) + 0.0211410061$$

$$(34)\ \ A3 = 1/(1 + Z\ \times\ (Z\ \times\ A2 + 0.049867347))$$

$$(35)\ \ A4 = 1 - (0.5\ \times\ A3^{16}) = PV_{s,a,t}$$

For Chinook, the sub-legal and legal size encounters are stock- and age- specific and are calculated using the von Bertalanffy growth curves described above. The calculations for sub-legal sized Chinook (shakers) are shown below:

$$(36)\ \ SubLegProp_{s,a,t} = 1 - PV_{s,a,t}$$

$$(37)\ \ SubLegPop_{s,a,t} = Cohort_{s,a,t}\ \times\ SubLegProp_{s,a,t}$$

$$(38)\ \ Shakers_{s,a,f,t} = \overbrace{SubER_{s,a,f,t}} \times SubLegPop_{s,a,t} \times \underbrace{FishScalar_{f,t}} \times \overbrace{RelRate_{f,t}}$$

where all components are defined previously and (1-$PV_{s,a,t}$) is the proportion of the cohort for stock s, age a, not vulnerable to the gear at time step t (for Chinook PV is function of von Bertalanffy growth curve.

Base Period Sub-Legal Encounter Rate Calculations

The Chinook FRAM base-period Sub-Legal Encounter Rate is calculated from the individual CWT-based stock catch estimates, externally estimated Target Sub-Legal Encounter Rates by fishery, and stock/age Sub-Legal population estimates. This methodology was used to match model estimates of sub-legal encounters with observed base-period sub-legal encounters and to estimate sub-legal encounters for stock/age cohorts that did not have CWT recoveries in a fishery because of the minimum size limit restriction. The Target Sub-Legal Encounter Rates are shown in Table 1.

The Sub-Legal Encounter Rates used in FRAM are computed in four major steps during the calibration (calibration program ChCal).

1. Compute Landed Catch by Fishery and Time Step

$$TimeCatch_{f,t} = \sum_{s,a}(BaseCWTRec_{s,a,f,t} * PEF_s)$$

2. Compute Sub-Legal Encounters by Fishery and Time Step

$$TotSubEnc_{f,t} = TimeCatch_{f,t} * TargetEncRate_{f,t}$$

3. Split Sub-legal Encounters into Stocks and Ages

$$SubLegEnc_{s,a,f,t} = TotSubEnc_{f,t} * PropSubPop_{s,a} * StockCatchProp_{s,f}$$

$$PropSubPop_{s,a} = \frac{SubLegalPop_{s,a}}{SubLegalPop_s}$$

$$StockCatchProp_{s,f} = \frac{LandedCatch_{s,f}}{LandedCatch_f}$$

4. Compute Sub-Legal Encounter Rates

$$SubER_{s,a,f,t} = SubLegEnc_{s,a,f,t}/(Cohort_{s,a,t} * SubLegalProp_{s,a,t})$$

Where:

$TimeCatch_{f,t} = Base\ Period\ \ Catch\ by\ Fishery\ and\ Time\ Step$
$BaseCWTRec_{s,a,f,t} = Base\ Period\ CWT\ Recoveries\ by\ Stock, Age, Fishery, Time\ Step$
$PEF_s = Base\ Period\ Production\ Expansion\ Factor$
$TotSubEnc_{s,f} = Base\ Period\ Total\ SubLegal\ Encounters\ by\ Fishery\ and\ Time\ Step$

$TargetEncRate_{f,t}$ = Base Period Target Encounter Rate Adjustment by Fishery, Time Step
$PropSubPop_{s,a}$= Proportion of the Sub-Legal Population of a Stock that is of a Given Age
$SubLegalPop_{s,a}$= Number of Sub-Legal fish of a Given Stock and Age
StockCatchProp= Proportion of the Landed Catch of a Fishery that is of a Given Stock
$BaseShaker_{s,a,f,t}$ = Base Period SubLegal Mortalities by Stock, Age, Fishery, Time Step
$SubLegEnc_{s,a,f,t}$ = Base Period SubLegal Encounters by Stock, Age, Fishery, Time Step
$SubER_{s,a,f,t}$ = Base Period SubLegal Encounter Rate by Stock, Age, Fishery, Time Step
$SubLegalProp_{s,a,t}$=Proportion of the Cohort that is Sub-Legal by Stock, Age, Time Step

Proposed Evaluation of Minimum Size Limit Change

The method for calculating the Chinook FRAM base-period Sub-Legal Encounter Rates does not allow for a simple algorithm to evaluate a change from the base-period minimum size limit. This is primarily due to the Target Sub-Legal Encounter Rate Adjustment Factor (TargetEncRate) and the Stock Fishery Catch Proportion (StockCatchProp) variables used to calculate the base-period shakers. The combination of these two variables results in an uneven distribution of legal and sub-legal sized fish by stock and age for most fisheries and time steps. The simplest approach for evaluating a size limit change from the base period is to calculate the legal and sub-legal encounters for both the base period and new minimum size limits and then adjusting the differences. Encounter differences occur in the region between the base period size limit and the new minimum size limit.

When the new size limit is less than the base-period size limit, the difference in sub-legal encounters between the base size-limit and the new size-limit becomes landed catch that is added to the calculated landed catch evaluated at the base-period size limit. Encounters are calculated by dividing the shaker estimates by the sub-legal release mortality rate. The difference in encounters is used in this case because it incorporates the base-period sub-legal encounter rates, which are always different than the base-period exploitation rates. It also allows for landed catch estimates for stock and age combinations that do not have base-period exploitation rates because of the base-period minimum size limit restriction.

When the new size limit is greater than the base-period size limit, the difference in landed catch between the new size limit and the base-period size limit becomes sub-legal encounters and is converted to sub-legal shakers by multiplying times the sub-legal mortality rate. This shaker difference is added to the calculated shakers from the base-period size limit to get total sub-legal shaker mortality. The difference in landed catch is used in this case because base-period CWT recoveries can be used to estimate an actual observed difference.

When New Size Limit is Less Than Base-Period Size Limit:

$$BaseSizeLimitShaker_{s,a,f,t} = SubER_{s,a,f,t} * BaseSubLegalPop_{s,a,t} * RelRate_{f,t} * FishScaler_{f,t}$$

$$NewSizeLimitShaker_{s,a,f,t} = SubER_{s,a,f,t} * NewSubLegalPop_{s,a,t} * RelRate_{f,t} * FishScaler_{f,t}$$

$$BaseSizeLimitEncounters_{s,a,f,t} = BaseSizeLimitShaker_{s,a,f,t} / RelRate_{f,t}$$

$$NewSizeLimitEncounters_{s,a,f,t} = NewSizeLimitShaker_{s,a,f,t} / RelRate_{f,t}$$

$$ShakerEncounterDiff_{s,a,f,t} = BaseSizeLimitEncounters_{s,a,f,t} - NewSizeLimitEncounter_{s,a,f,t}$$
$$BaseSizeLimitCatch_{s,a,f,t} = Cohort_{s,a,t} * BPER_{s,a,f,t} * FishScalar_{f,t} * BasePV_{s,a,t} * SHRS_{s,f,t}$$

$$LandedCatch_{s,a,f,t} = BaseSizeLimitCatch_{s,a,f,t} + ShakerEncounterDiff_{s,a,f,t}$$

Then if MSF apply MSF Calculations (PFMC-2007) by stock type (Marked and Un-Marked)

Where:

$BaseSizeLimitShaker_{s,af,t} = Shakers\ evaluated\ at\ Base\ Period\ Size\ Limit$
$NewSizeLimitShaker_{s,af,t} = Shakers\ evaluated\ at\ New\ Size\ Limit$
$BaseSubLegalPop_{s,a,t} = SubLegal\ Population\ evalauted\ at\ Base\ Period\ Size\ Limit$
$BaseSizeLimitEncounters_{s,af,t} = BaseSizeLimitShakers\ divided\ by\ Release\ Mortality\ Rate$
$NewSizeLimitEncounters_{s,af,t} = FRAM\ Shakers\ divided\ by\ Release\ Mortality\ Rate$
$ShakerEncounterDiff_{s,a,f,t} = Difference\ between\ Base\ and\ New\ Size\ Limit\ Encounters$
$BaseSizeLimitCatch_{s,a,f,t} = FRAM\ Landed\ Catch\ at\ Base\ Period\ Size\ Limit$
$BasePV_{s,a,t} = Proportion\ Vulnerable\ evaluated\ at\ Base\ Period\ Size\ Limit\ by\ Stock, Age, Time$
$RelRate_{f,,t}$ = *Release Mortality Rate*

Remaining variables are described in PFMC, 2007.

When New Size Limit is Greater Than Base-Period Size Limit:

$$BaseSizeLimitCatch_{s,a,f,t} = Cohort_{s,a,t} * BPER_{s,a,f,t} * FishScalar_{f,t} * BasePV_{s,a,t} * SHRS_{s,f,t}$$
$$NewSizeLimitCatch_{s,a,f,t} = Cohort_{s,a,t} * BPER_{s,a,f,t} * FishScalar_{f,t} * PV_{s,a,t} * SHRS_{s,f,t}$$
$$BaseSizeLimitShaker_{s,a,f,t} = SubER_{s,a,f,t} * BaseSubLegalPop_{s,a,t} * RelRate_{f,t} * FishScaler_{f,t}$$

$$Shaker_{s,a,f,t} = BaseSizeLimitShaker_{s,a,f,t} + (BaseSizeLimitCatch_{s,a,f,t} - NewSizeLimitCatch_{s,a,f,t}) * RelRate_{f,t}$$

Comparison of Model Runs with Size Limit Changes

Model runs were done for two Puget Sound sport fisheries using the old and new size limit algorithms to show the differences between the two methods. The fisheries were chosen from the 2009 PFMC final FRAM run with one using a fishery (effort) scaler (Area 5 – Sekiu, Time 1) and the other with mark-selective parameters (Area 8-1 –Port Susan, Time 1). Tables 2 and 3 show the results for the Area 5 fishery and Tables 4 and 5 for the Area 8-1 fishery. The differences between the runs are highlighted in Tables 3 and 5. When the size limit is greater than the base-period size limit the sub-legal shaker mortality is greater for the new method. When the size is less than the base-period size limit the landed catch is smaller for the new method. The magnitude of the differences between comparative runs will be relative to the Target Encounter Rate used for the fishery. The Area 5 sport fishery has a rate of 0.28 and the Area 8-1 sport fishery is 2.18. The differences by mark-type for the Area 8-1 sport fishery are shown in Tables 6 and 7 and are consistent with the previous results.

The biggest improvement for the new method is the consistency in total encounters for each of the size limits modeled. In Tables 2, 4, and 6 (New FRAM) the encounters are essentially the same with some variance for rounding error using integer numbers in the tables. The old method varied substantially between the size limits used and illustrates the problem with this method.

Pacific Fishery Management Council. 2007. *Fisheries Regulation Assessment Model (FRAM) Technical Documentation for Coho and Chinook.* (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Table 1: Chinook FRAM Base Period Target Shaker Adjustment Factors

Fishery Title	Time1	Time2	Time3	Time4
SE Alaska Troll	1.09	1.09	1.09	1.09
SE Alaska Net	-1	-1	-1	-1
SE Alaska Sport	2.62	2.62	2.62	2.62
BC No/Cent Net	-1	-1	-1	-1
BC WCVI Net	-1	-1	-1	-1
BC Georgia Strait Net	-1	-1	-1	-1
BC JDF Net	-1	-1	-1	-1
BC Outside Sport	0.78	0.78	0.78	0.78
BC No/Cent Troll	1.1	0.55	0.68	1.1
BC WCVI Troll	0.59	0.63	0.62	0.59
BC WCVI Sport	0.59	0.63	0.62	0.59
BC Georgia Strait Troll	0.34	0.34	0.34	0.34
BC N Georgia Strait Sport	0.01	0.01	0.01	0.01
BC S Georgia Strait Sport	0.01	0.01	0.01	0.01
BC JDF Sport	0.01	0.01	0.01	0.01
NT Area 3:4:4B Troll	-1	0.48	1.65	-1
Tr Area 3:4:4B Troll	0.64	0.48	1.65	0.64
NT Area 3:4 Sport	0.5	0.5	0.5	0.5
No Wash. Coastal Net	-1	-1	-1	-1
NT Area 2 Troll	0.51	0.39	1.59	0.51
Tr Area 2 Troll	-1	0.39	1.59	-1
NT Area 2 Sport	-1	0.5	0.5	-1
NrT G. Harbor Net	-1	-1	-1	-1
T G. Harbor Net	-1	-1	-1	-1
Willapa Bay Net	-1	-1	-1	-1
Area 1 Troll	0.55	1.16	4.52	0.55
Area 1 Sport	-1	0.5	0.5	-1
Columbia River Net	-1	-1	-1	-1
Buoy 10 Sport	-1	-1	-1	-1
Central OR Troll	1.05	1.05	1.05	1.05
Central OR Sport	-1	0.5	0.5	-1
KMZ Troll	-1	1.05	1.05	-1
KMZ Sport	-1	0.5	0.5	-1
So Calif. Troll	-1	1.05	1.05	-1
So Calif. Sport	0.5	0.5	0.5	0.5
NT Area 7 Sport	2.18	0.98	0.94	2.18
NT Area 6A:7:7A Net	-1	-1	-1	-1
Tr Area 6A:7:7A Net	-1	-1	-1	-1

Fishery Title	Time1	Time2	Time3	Time4
NT Area 7B-7D Net	-1	-1	-1	-1
Tr Area 7B-7D Net	-1	-1	-1	-1
Tr JDF Troll	0.28	0.24	0.44	0.28
NT Area 5 Sport	0.28	0.24	0.44	0.28
NT JDF Net	-1	-1	-1	-1
Tr JDF Net	-1	-1	-1	-1
NT Area 8-1 Sport	2.18	0.98	0.94	2.18
NT Skagit Net	-1	-1	-1	-1
Tr Skagit Net	-1	-1	-1	-1
NT Area 8D Sport	-1	-1	-1	-1
NT St/Snohomish Net	-1	-1	-1	-1
Tr St/Snohomish Net	-1	-1	-1	-1
NT Tulalip Bay Net	-1	-1	-1	-1
Tr Tulalip Bay Net	-1	-1	-1	-1
NT Area 9 Sport	2.18	0.98	0.94	2.18
NT Area 6 Sport	-1	-1	-1	-1
Tr Area 6B:9 Net	-1	-1	-1	-1
NT Area 10 Sport	2.18	0.98	0.94	2.18
NT Area 11 Sport	2.18	0.98	0.94	2.18
NT Area 10:11 Net	-1	-1	-1	-1
Tr Area 10:11 Net	-1	-1	-1	-1
NT Area 10A Sport	-1	-1	-1	-1
Tr Area 10A Net	-1	-1	-1	-1
NT Area 10E Sport	-1	-1	-1	-1
Tr Area 10E Net	-1	-1	-1	-1
NT Area 12 Sport	2.18	0.98	0.94	2.18
NT Hood Canal Net	-1	-1	-1	-1
Tr Hood Canal Net	-1	-1	-1	-1
NT Area 13 Sport	2.18	0.98	0.94	2.18
NT SPS Net	-1	-1	-1	-1
Tr SPS Net	-1	-1	-1	-1
NT Area 13A Net	-1	-1	-1	-1
Tr Area 13A Net	-1	-1	-1	-1
Freshwater Sport	-1	-1	-1	-1
Freshwater Net	-1	-1	-1	-1

Note: -1 value = no shaker adjustment used

Comparison of FRAM using Adjusted Size Limit Algorithms

PS Sport Fishery using Fishery Scaler (Area 5 Sport, Time Step 1, 2009 PFMC Run)

Table 2: New FRAM

Size Limit	Landed Catch	Sub-Legal Mortality	Total Encounters
480 mm (BP)	384	40	584
520 mm	300	57	585
425 mm	408	35	583

Table 3: Old FRAM

Size Limit	Landed Catch	Sub-Legal Mortality	Total Encounters
480 mm (BP)	384	40	584
520 mm	300	44	520
425 mm	499	35	674

PS Sport Fishery with MSF Regulations (Area 8-1 Sport, Time Step 1, 2009 PFMC Run)

Table 4: New FRAM

Size Limit	Landed Catch	Sub-Legal Mortality	Total Encounters
480 mm (BP)	1996	2012	13982
520 mm	942	2373	13984
425 mm	2651	1765	13983

Table 5: Old FRAM

Size Limit	Landed Catch	Sub-Legal Mortality	Total Encounters
480 mm (BP)	1996	2012	13982
520 mm	942	2172	12974
425 mm	3663	1765	15601

PS Sport Fishery with MSF Regulations (Area 8-1 Sport, Time Step 1, 2009 PFMC Run)

Table 6: New FRAM by Mark Type

Size Limit	**Un-Mark Enc (Legal)**	**Un-Mark Enc (SL)**	**Un-Mark Enc Tot**	**UnMark DO Mort**	**Un-Mark Retained**	**Un-Mark Total Mort**
480 mm (BP)	1747	3715	5462	87	105	738
520 mm	1108	4355	5463	55	67	668
425 mm	2264	3195	5459	113	136	795

Table 7: Old FRAM by Mark Type

Size Limit	**Un-Mark Enc (Legal)**	**Un-Mark Enc (SL)**	**Un-Mark Enc Tot**	**Un-Mark DO Mort**	**Un-Mark Retained**	**Un-Mark Total Mort**
480 mm (BP)	1747	3715	5462	87	105	738
520 mm	1108	4050	5158	55	67	638
425 mm	2756	3195	5951	138	165	898

Unmarked drop-off is computed as 5% of legal unmarked encounters.
Unmarked retained is computed as 6% of legal unmarked encounters.