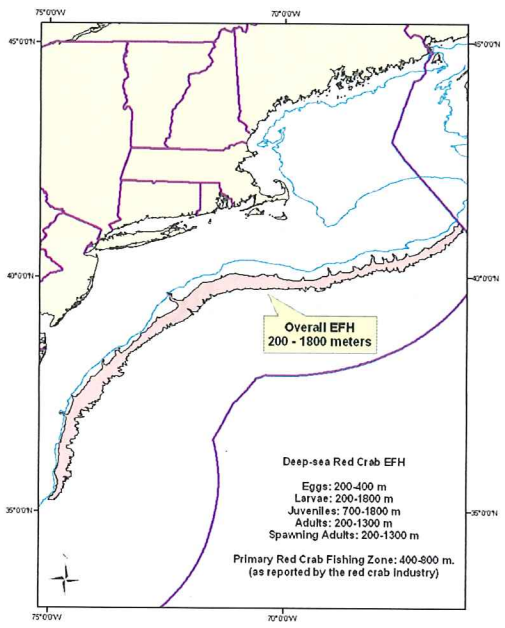
Red Crab PDT
MSY Proxy Reevaluation

March 16, 2010

Summary

- The PDT agrees with the recommendation of the DPSWG for "a catch limit that mimics both recent and long term mean annual landings…"
- The PDT agrees with the Review Panel preference for the DCAC model, but believes that the sustainable yield estimates should be adjusted to reflect the expected difference between DCAC results and MSY.
- The PDT developed additional information related to concerns expressed by DPSWG



Fishing began in 1973

FMP implemented 2002

Year-round

Male-only (EFP for 1 million lbs females 09-10)

Limited access – 5 permits
Max 4 boats active since 2002

Trip limit of 75,000 lbs

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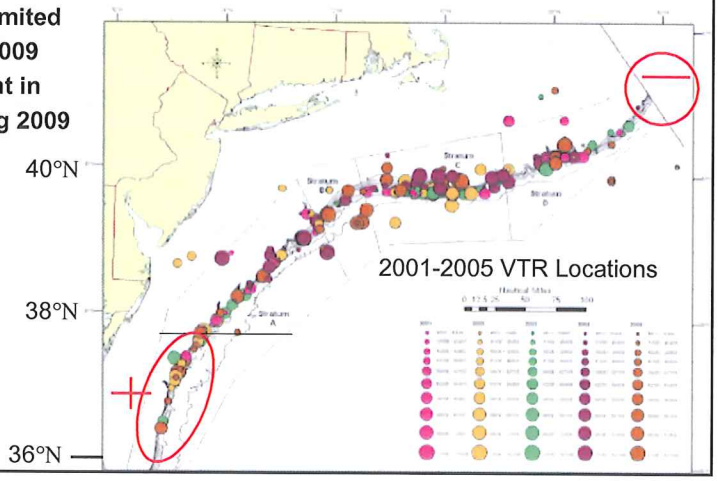
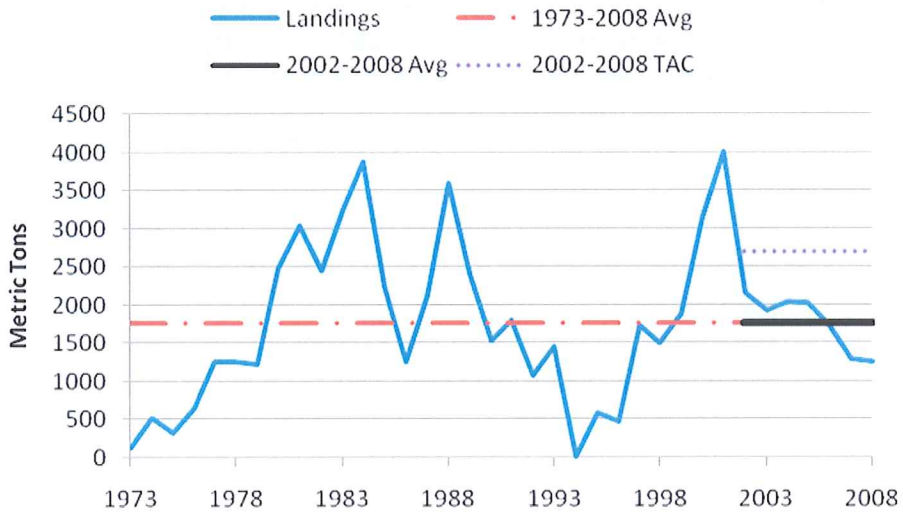
Year-round
Historically market limited
MSC Certified Sept 2009
New Processing Plant in New Bedford Aug 2009



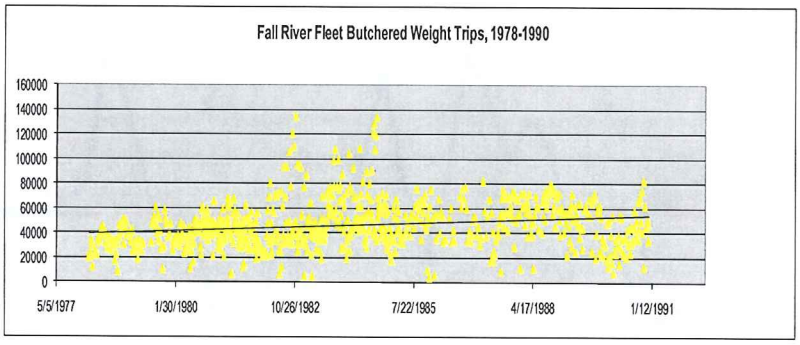
Landings 1973-2008



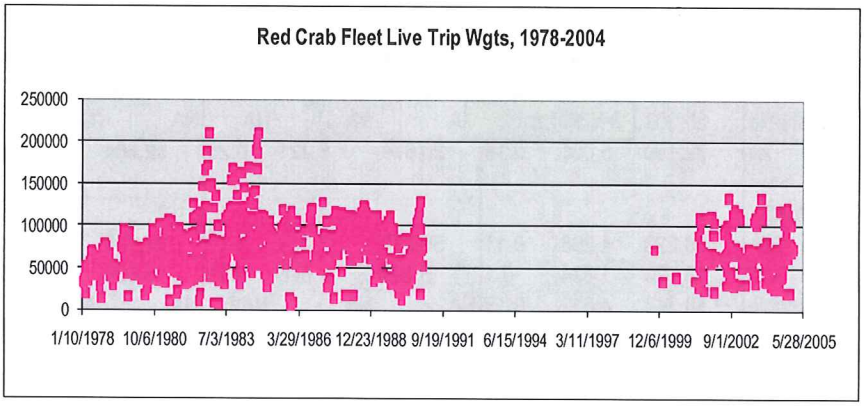
Survey Area Biomass Estimates (DPSWG)

		Males			Females			Total	
Year Size Groups (mm CW)	Biomass (mt)	SE (mt)	CV (mt)	Biomass (mt)	SE (mt)	CV (mt)	Biomass	SE	CV
1974									
90+	29,991	6,298	0.21	15,654	3,719	0.24	45,645	7,314	0.16
114+	23,794	4,303	0.18	2,106	433	0.21	25,900	4,325	0.17
Fishable	30,302	34,300 mt		A	NA	NA	NA	NA	NA
All	32,190	5,001	0.16	20,674	5,221	0.25	52,864	7,230	0.14
2003 to 2005									
90+	38,220	4,298	0.11	55,279	7,033	0.13	93,499	8,242	0.09
114	13,770	1,334	0.1	5,224	576	0.11	18,994	1,453	0.08
Fishable	36,247	4,612	0.13	NA	NA	NA	NA	NA	NA
All	56,443	4,646	0.08	74,689	10,102	0.14	131,132	11,119	0.08

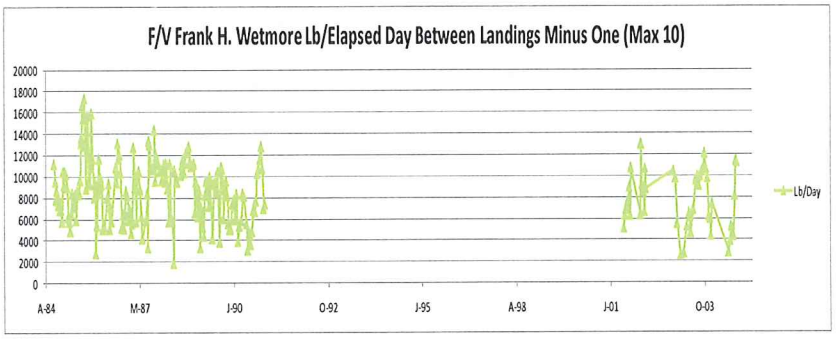
- **Figure 5- Trip weights for butchered crabs landed by the Fall River, MA fleet from 1978 through 1990. (Industry data published with permission of the vessel owners.)**



- **Figure 6- Live equivalent crab trip weights landed by the Fall River, MA fleet from 1978 through 1990 and 2000 through 2004. (Industry data published with permission of the vessel owners.)**



- Figure 7- Pounds per day between landings (minus one with a maximum of ten) for the F/V Frank H. Wetmore for 1984 through 1991 and 2001 through 2004. (Industry data published with permission of the vessel owner.)



Risk Policy

- "The scope of work may not request reviewers to provide advice on scientific policy (e.g., amount of uncertainty that is acceptable or amount of precaution used in an analysis). Such policy considerations are in the purview of the Secretary and the Councils." *NS 2 Guidelines*

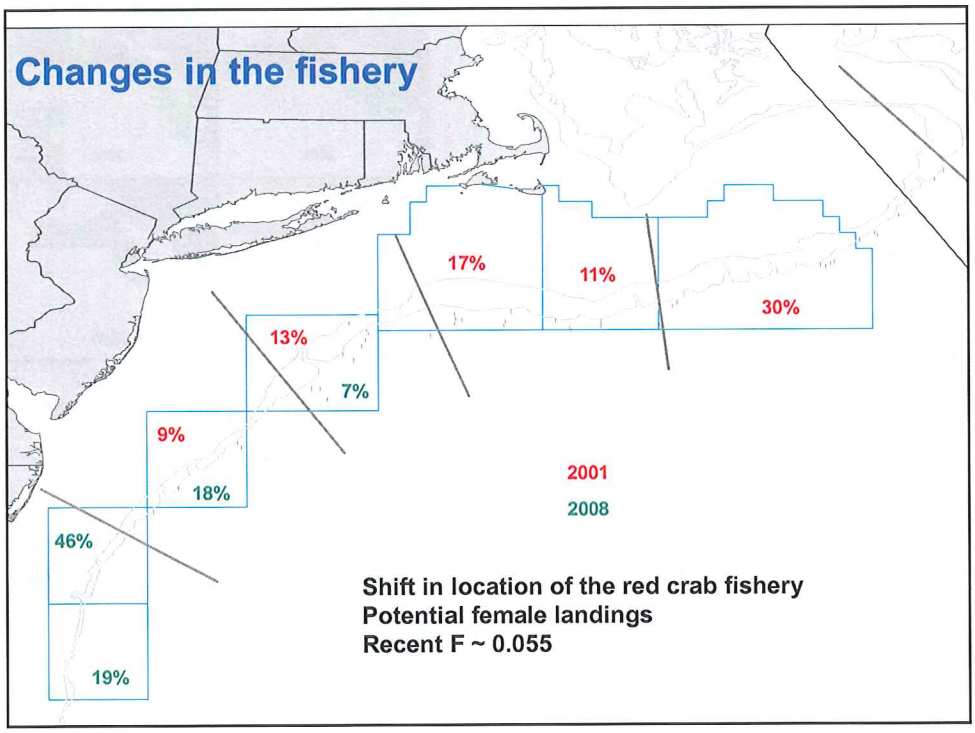
- "Determining the acceptable level of risk of overfishing that results from scientific uncertainty is the policy issue. The SSC must recommend an ABC to the Council after the Council advises the SSC what would be the acceptable probability that a catch equal to the ABC would result in overfishing." *NS 1 Guidelines*

DPSWG Problematic Conclusions

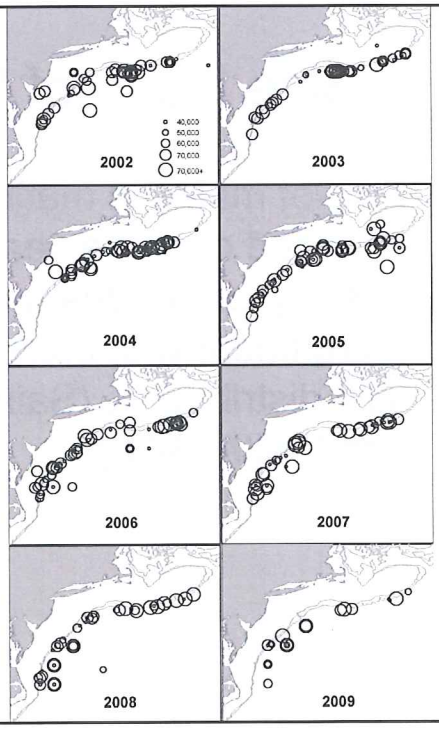
- "assumptions that reductions in the size structure of landings that have been observed indicate that previous higher landings were not at a sustainable MSY levels as had been previously assumed."

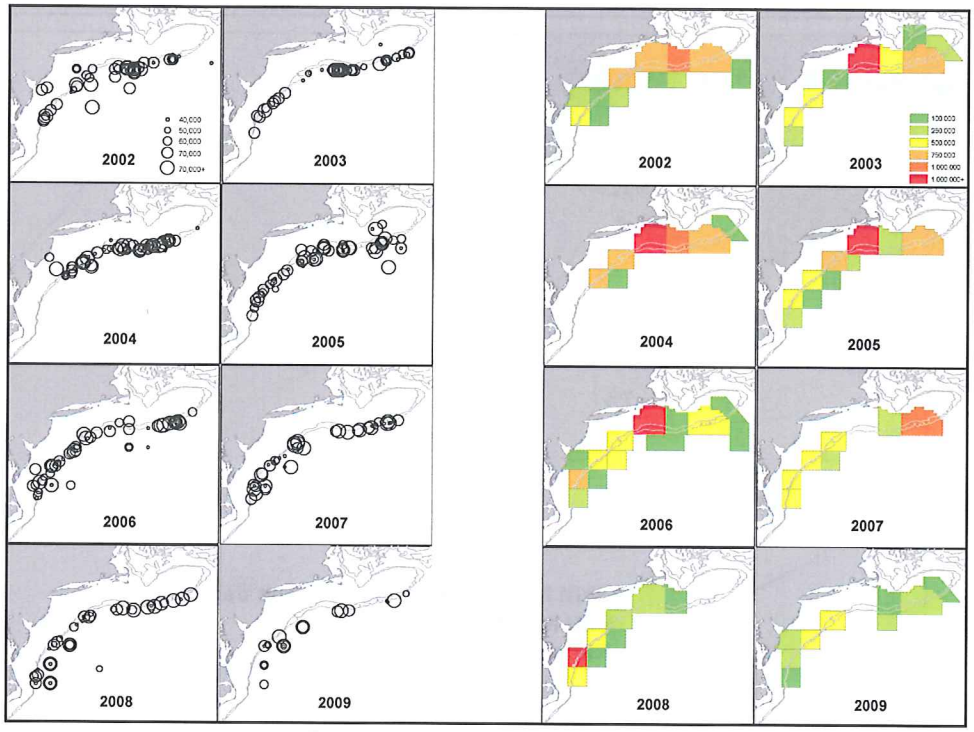
DPSWG Problematic Conclusions

- The [Review] Panel concluded that estimates of MSY in the male only fishery of 1700-1900 mt represent the best available scientific information, based on the congruence of average landings and results from the DCAC model.
- Zero depletion DELTA assumption
- DCAC model results 50-72% of MSY



Concern Over Geographic Shift Unfounded





Size Ratio of Mating Pairs

- Size of males in mating snow crab pairs changed over the years in relation to the passing of troughs and waves of recruitment with corresponding changes in size distribution. (Sainte-Marie, Sevigny and Smith 1996)

Size of Males in Mating Pairs

- Elner (1987) observed three mating pairs of *C. quinquedens* in captivity in which males were 10.2, 15.1, and 20.6 % larger than the females. These females were later found to contain sperm masses.
- Zheng and Kruse (2003) point out that "large oldshell mature males outcompete small newshell males in mating with females" in snow and Tanner crab populations.

Unexpected Population Increase with Fishing

- Pre-fishery populations of *C. opilio* were maintained in a stagnant phase by larger males which monopolized niche space and restricted resources available to pre-recruits. By removing large males, the fishery presumably relaxed competition and allowed greater survival and/or faster growth of pre-recruits, thereby contributing to increased stock productivity. (Waewood and Elner (1982) in Sainte-Marie et al. (1996))

Population Increase with Fishing

- "removal of adult males allowed prerecruitment survival rates of crayfish to the fishery to increase. As a result, expansion of the population took place despite increased trapping pressure." (Momot 1998)

Population Increase with Fishing

- **"Culling experiments demonstrate size-class specific biomass increases with mortality." (Schroder, Persson, and de Roos 2008)**

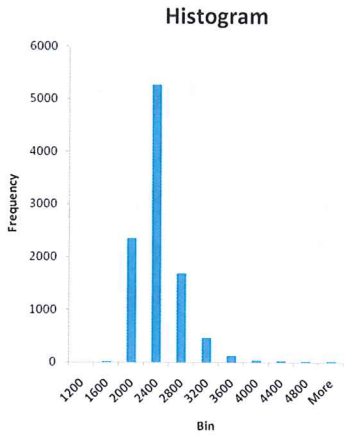
Population Increase with Fishing

- "An intensive seven-year removal of adult, juvenile, and young-of-the-year smallmouth bass (*Micropterus dolomieu*) from a north temperate lake (Little Moose Lake, New York, USA) resulted in an increase in overall population abundance, primarily due to increased abundance of immature individuals." (Zipkin et al. 2008)

Additional Information and Analysis

- Alternative Long-term Average Landings Calculations.
- Depletion-Corrected Average Catch (DCAC) Model
  - Zero depletion DELTA
  - -0.2 depletion DELTA
- Confidence intervals for DCAC results
- MSY to DCAC sustainable yield relationship
- Analysis of size distribution
- Yield per recruit analysis

DCAC Results with CI



Depletion Corrected Average Catch Model Version 1.1.1 (Calculation Engine

Warning - 1 Iterations Have Negative Values

Case Description: Minus pt2 dep delta sd 1 m=1sd 25 fmsy =08 sd05

Number of Years	35	
Random Number Seed	29815167	
Number of Iterations	10000	
	Value	STD Deviation
Sum of Catch	62132	
Natural Mortality	0.1	0.25
FMSY to M	0.8	0.05
Depletion Delta	-0.2	0.1
Uncorrected Avg. Catch	1775	
Average DCAC	2194	
Median DCAC	2168	
Confidence Intervals	Lower Bound	Upper Bound
1% - 99% CI	1712	3567
5% - 95% CI	1833	2908
10% - 90% CI	1897	2669
20% - 80% CI	1976	2454

Minimum = -507732.466462 - Maximum = 9221.308928

DCAC Confidence Intervals

	-0.2 Depletion Delta		0 Depletion Delta	
M=0.05				
Average DCAC	3441		1870	
Median DCAC	2761		1781	
	LCI	UCI	LCI	UCI
1% - 99% CI =	-4028	17833	1181	3553
5% - 95% CI =	1862	7177	1340	2639
10% - 90% CI =	2007	5154	1434	2356
20% - 80% CI =	2210	3898	1545	2114
M=0.10				
Average DCAC	2193		1797	
Median DCAC	2168		1777	
	LCI	UCI	LCI	UCI
1% - 99% CI =	1711	3567	1419	2367
5% - 95% CI =	1833	2907	1528	2123
10% - 90% CI =	1896	2668	1586	2025
20% - 80% CI =	1975	2454	1652	1930
M=0.15				
Average DCAC	2050		1786	
Median DCAC	2019		1777	
	LCI	UCI		
1% - 99% CI =	1732	2669	1520	2131
5% - 95% CI =	1813	2398	1602	1993
10% - 90% CI =	1854	2285	1645	1934
20% - 80% CI =	1904	2176	1691	1875

Alec MacCall DCAC/MSY

K	1
r	0.2

Biomass	Production
0	0
0.01	0.00198
0.02	0.00392
0.03	0.00582
0.04	0.00768
0.05	0.0095
0.06	0.01128
0.07	0.01302
0.08	0.01472
0.09	0.01638
0.1	0.018
0.11	0.01958
0.12	0.02112
0.13	0.02262
0.14	0.02408
0.15	0.0255
0.16	0.02688
0.17	0.02822
0.18	0.02952
0.19	0.03078
0.2	0.032
0.21	0.03318
0.22	0.03432
0.23	0.03542
0.24	0.03648
0.25	0.0375
0.26	0.03848
0.27	0.03942

DCAC-like average
0.0358

MSY
0.05

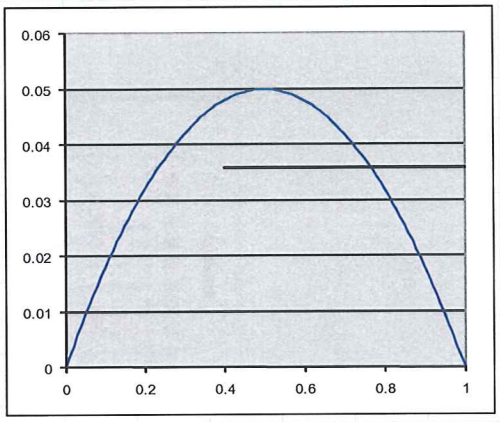
DCAC/MSY
0.716

$Y = 0.4 * B_{UNFISHED} * c * M$

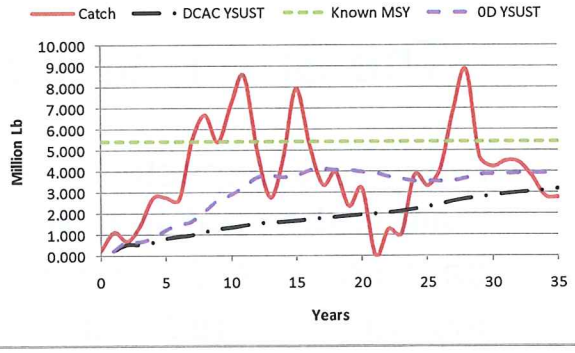
$W/Y = \Delta/(0.4 * c * M)$

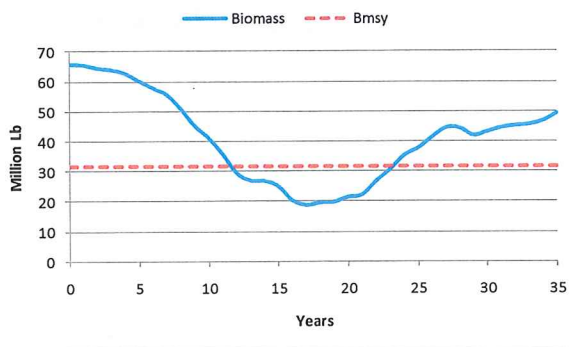
$Y_{SUST} = \Sigma(C)/(n + W/Y)$

M	0.1
c	0.8

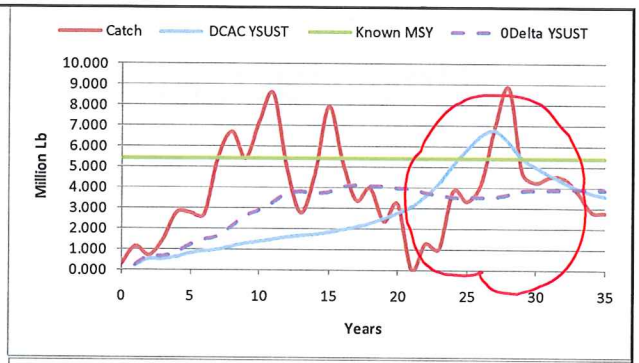


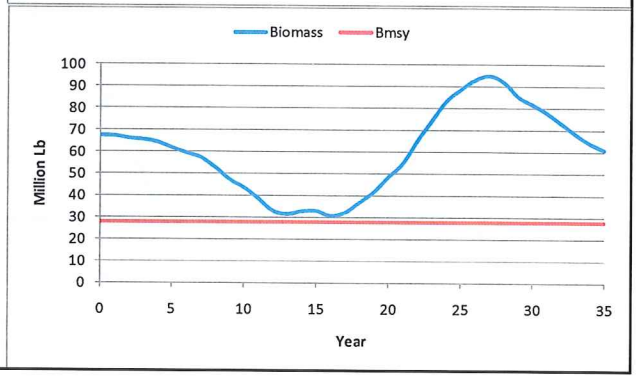
DCAC for $B_{fished} < B_0$





DCAC for $B_{fished} > B_0$

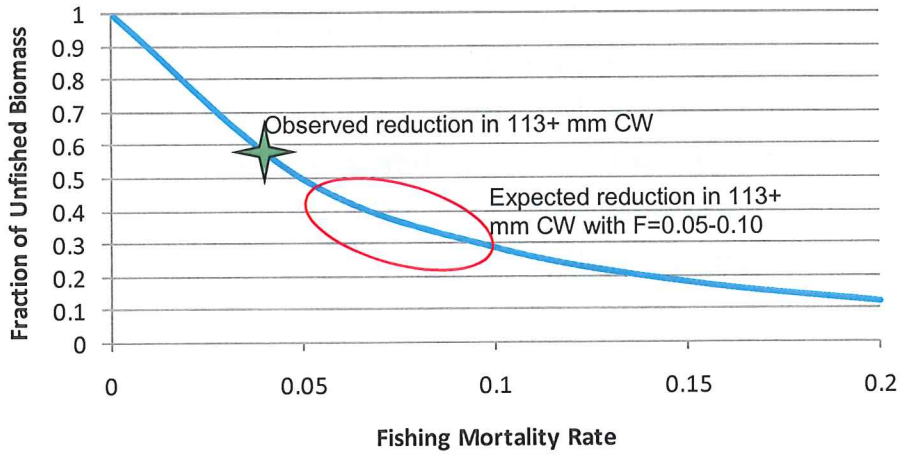




The Size Distribution Issue

- Analysis of expected size distribution of male crabs relative to exploitation rates based on age/CW model for *G. maritae*, the Namibian red crab; CW/weight model for *C. quinquedens*, with M=0.10.

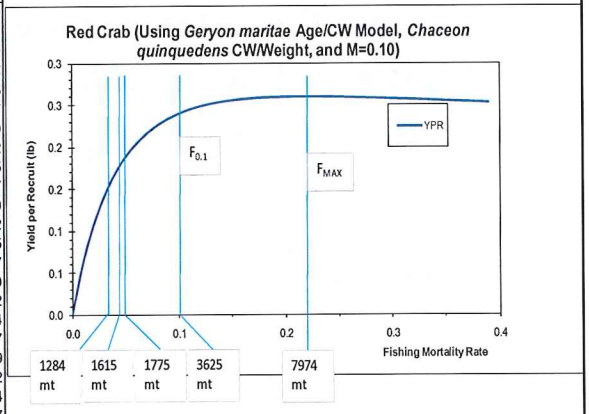
Model Results - 113+mm CW Biomass vs F (*G. maritae* growth, M = 0.10)



Yield-per-recruit analysis based on analogy with *Geryon maritae*.

F	YPR	Yield Lost	TAC with Biomass of †79910136.2	
			Lbs	MT
0.010	0.06061	77%	1,598,203	725
0.020	0.10601	59%	2,397,304	1087
0.030	0.14047	46%	3,196,405	1450
0.040	0.16691	36%	3,995,507	1812
0.050	0.18738	28%	4,794,608	2175
0.060	0.20335	22%	5,593,710	2537
0.070	0.21588	17%	6,392,811	2900
0.080	0.22575	13%	7,191,912	3262
0.090	0.23355	10%	7,991,014	3625
*0.100	0.23973	8%	8,790,115	3987
0.110	0.24462	6%	9,589,216	4350
0.120	0.24848	4%	10,388,318	4712
0.130	0.25152	3%	11,187,419	5075
0.140	0.25391	2%	11,986,520	5437
0.150	0.25575	2%	12,785,622	5800
0.160	0.25716	1%	13,584,723	6162
0.170	0.25821	1%	14,383,825	6524
0.180	0.25897	0%	15,182,926	6887
0.190	0.25950	0%	15,982,027	7249
0.200	0.25982	0%	16,781,129	7612
**0.220	0.26002	0%	17,580,230	7974
0.230	0.25994	0%	18,379,331	8337

*$F_{0.1}$
**F_{max}
† Fishable biomass estimated from 2003-2005 survey



Additional Information

- SRR
  - implications for expected biomass at maximum sustainable yield relative to unexploited biomass.
  - Is there a consistent difference between Ricker and Beverton-Holt?
  - $0.5B_0$ vs $0.4B_0$

F_{MSY}/M Ratio

- DPSWG - Walters and Martell (2004) suggest that *FMSY* is lower and approximately 0.8*M* for many species.
- Consideration of length at capture and length at sexual maturity as indicators of the appropriate F_{MSY}/M. (Hilborn 2010, MRAG 1996)

Garcia, Sparre and Csirke (1989)

- *Option 3e: MSY estimator based on Schaeffer Model.*

$$MSY = \frac{(F_{MSY}B_c)^2}{2F_{MSY}B_c - Y_c}$$

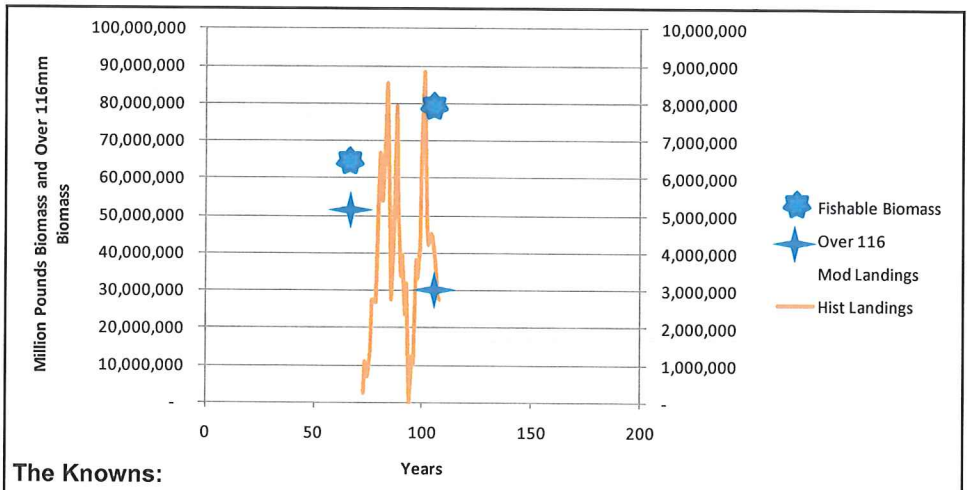
  - MSY=(0.8*M*Bc)^2/2*M*0.8*Bc-Yc
  - MSY=(0.8*0.1*36247)^2/2*0.1*0.8*36247-2040
  - MSY=2237 mt
  - Adjustment for Management Unit = 2386
- *Option 3f: MSY estimator based on Fox Model*

$$MSY = F_{MSY}B_c \exp\left(\frac{Y_c}{F_{MSY}B_c} - 1\right)$$

  - MSY=.8*.1*36247exp(2040/(.8*.1*36247)-1)
  - MSY=2156 mt
  - Adjustment for Management Unit = 2251

Population Projection Models

- "Analysis of related stocks or species is a powerful tool for inferring the likely traits of stocks for which stock-specific data are unavailable or are not sufficient to produce reliable estimates." *NS 2 Guidelines*
- By analogy with age/CW for *Geryon maritae*
- CW/weight for *Chaceon quinquedens*
- Candidate SRRs to match known history
- Deterministic through 2010
- Stochastic projections
  - Variable M
  - Variable Recruitment



The Knowns:

- Age-CW relationship by analogy with *Geryon maritae*; CW-weight relationship for *Chaceon quinquedens*;
- A natural mortality rate calculated to produce the size distribution that was observed in 1974, given the age-weight relationship.
- The historical landings, which may be under-reported to some extent in some years;
- The abundance by size estimated from the 2003-2005 survey.
- There is more uncertainty surrounding the population estimate from the 1974 survey. The size distribution should be reliable.

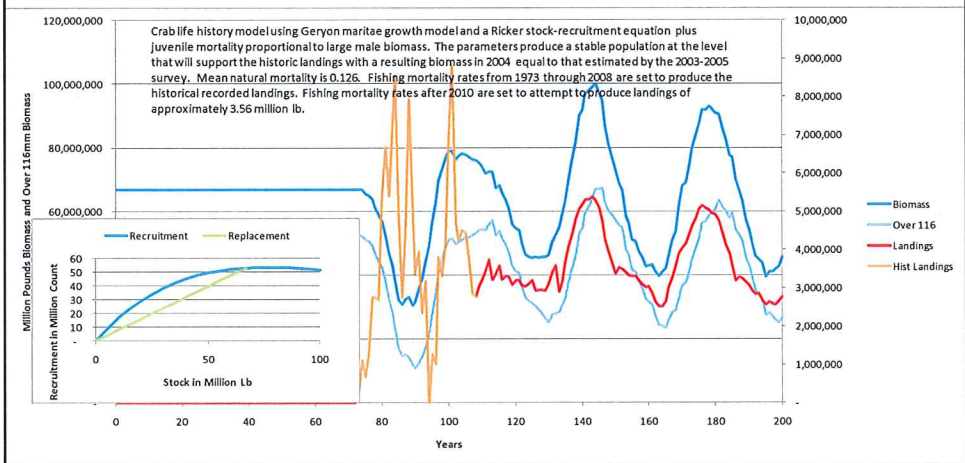
Deterministic Model

- Find Recruitment and M to produce equil initial biomass and size structure with SRR and/or juvenile mortality to produce 2003-2005 fishable biomass after removing landings
- Deterministic through 2010 to fit history
  - Solver to find Conditional MSY, F_{MSY}, B_{MSY}
  - 116+ mm CW males > 25% B_{init}

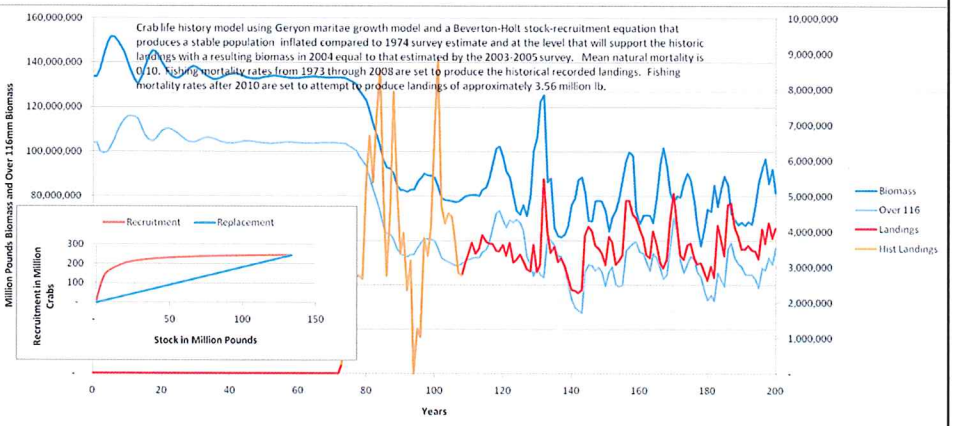
Monte Carlo Simulation

- Stochastic from 2011
  - M = NORMINV(RAND(),Deterministic M,0.05)
  - R = NORMINV(RAND(),Deterministic R, SD)
  - (SD *ad hoc* somewhat less than Deterministic R)
- Risk Measure One
  - % years $B<0.5B_{MSY}$ after 300 runs of 89 yrs with TAC ≈1615 mt
- Risk Measure Two
  - Mean and CI for 100 runs of 89 yrs
  - Conditioned on 116+ mm CW $B>.25B_{init}$

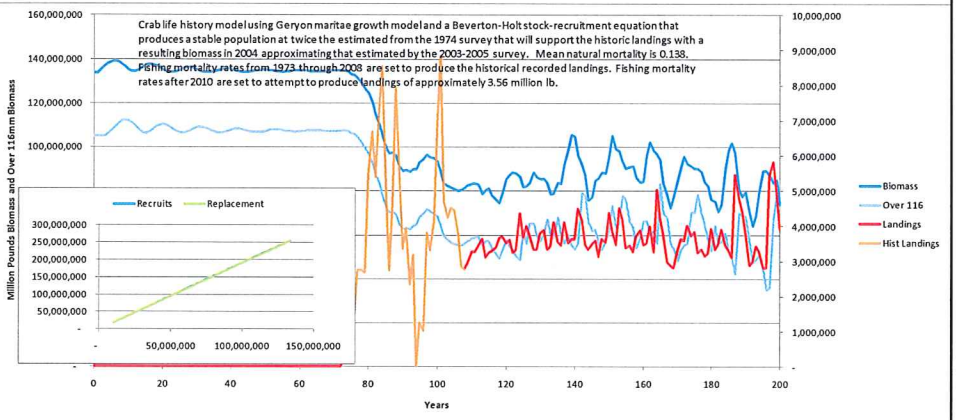
Moderate Ricker Plus Predation on Juveniles by 116+ mm CW Males



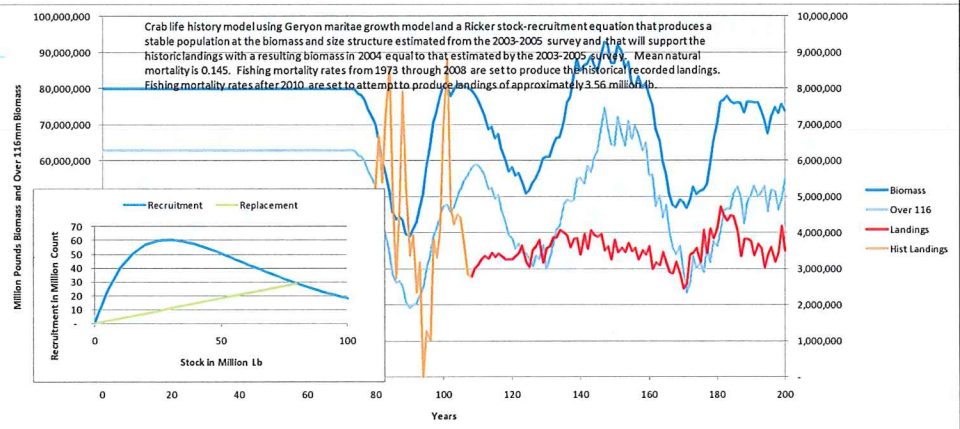
Beverton-Holt with Inflated 1974 Biomass and Juvenile Mortality Scaled Exponentially to Biomass of Older Juveniles



Linear B-H with Inflated 1974 B and Juvenile Mortality Scaled Exponentially to B of Older Juveniles

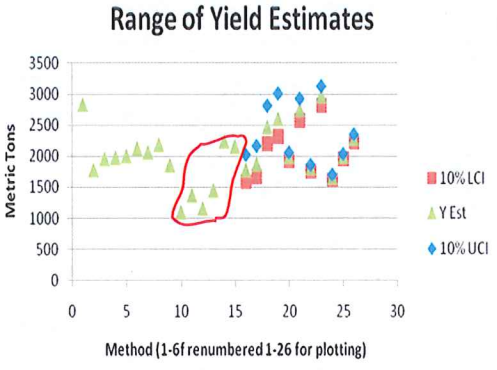


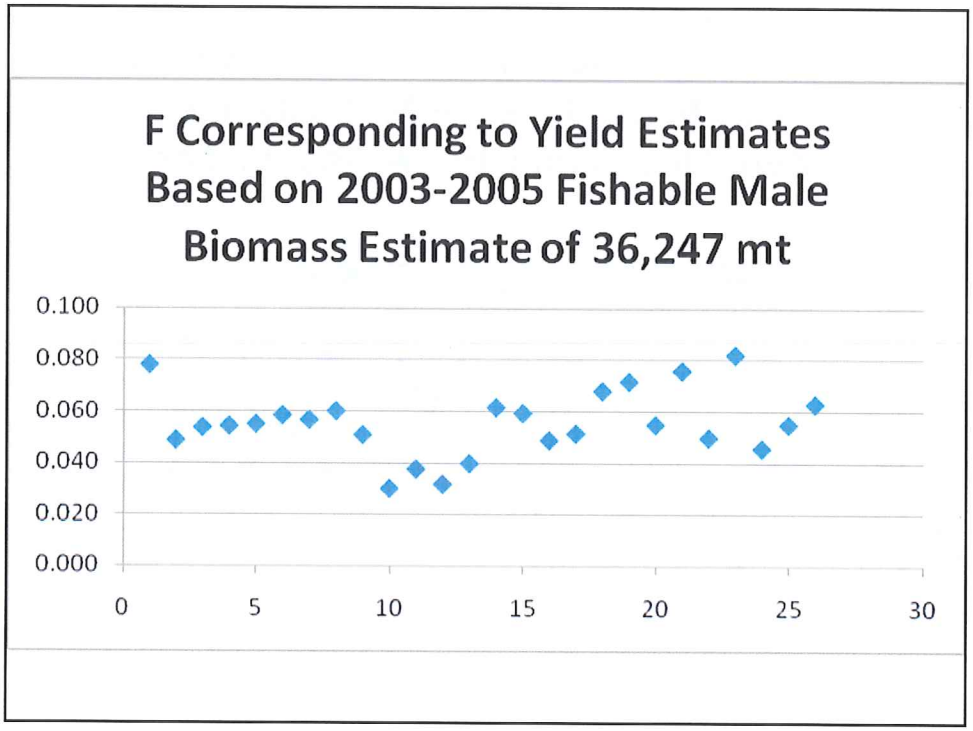
Overcompensatory Ricker SRR with No Additional Juvenile Mortality and Zero Depletion DELTA Assumption



Plot #	Method	Y Est	20% LCI	10% LCI
1	1	2830		
2	2a	1775		
3	2b	1954		
4	2c	1975		
5	2d	2002		
6	2e	2126		
7	2f	2062		
8	2g	2185		
9	2h	1853		
10	3a	1098		
11	3b	1372		
12	3c	1160		
13	3d	1450		
14	3e	2237		
15	3f	2156		
16	4a	1777	1652	1586
17	4b	1872	1734	1668
18	4c	2468	2294	2203
19	4d	2600	2408	2317
20	5	1996		1932
21	6a	2751	2615	2576
22	6b	1812	1774	1763
23	6c	2974	2856	2822
24	6d	1662	1630	1621
25	6e	1996	1966	1958
26	6f	2286	2237	2224

Alternative Yield Estimates



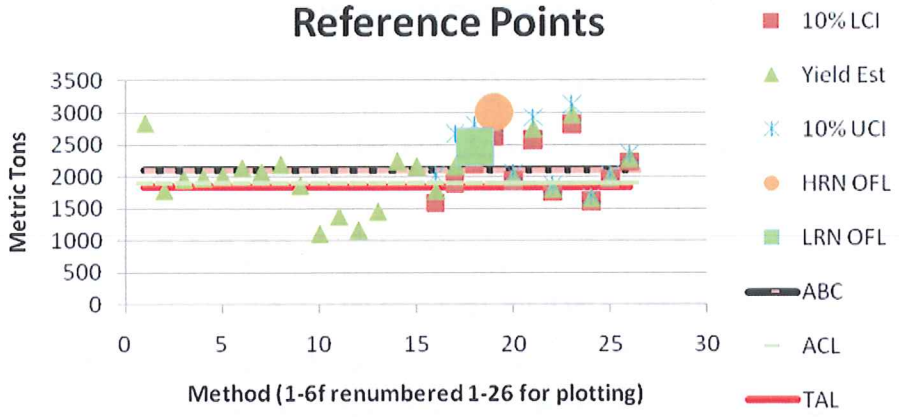


PDT Recommendations

Total Allowable Landings = 2002-2007 Avg. Landings MSY/OFL based on adjusted DCAC model results	mt	% of Lower Risk Neutral MSY/OFL	% of Higher Risk Neutral MSY/OFL	% of Average of LRN and HRN MSY/OFL
Total Allowable Landings of Male Red Crabs (TAL)	1850	75%	61%	68%
Dead Discards (5% of 30% of Total Catch)	40			
ACL (10% buffer for Management Uncertainty)	1890			
ABC	2100	85%	70%	77%
*Lower Risk Neutral MSY/OFL	2469			
Avg of Lower Risk Neutral and Higher Risk Neutral MSY/OFL	2740			
*Higher Risk Neutral MSY/OFL	3011			
20% CI on Lower Risk Neutral MSY/OFL	2294			
20% CI on Higher Risk Neutal MSY/OFL	2744			

* Risk neutral refers to the median DCAC model result divided by 0.72 to provide an estimate of MSY given the model and the assumptions incorporated into the model and the expected relationship between DCAC sustainable yield estimates and MSY. The use of a zero depletion DELTA to produce the "lower risk neutral" MSY/OFL estimate and the use of the 0.72 divisor to adjust from the DCAC results to MSY could be considered precautionary considering the expected range of 0.50 to 0.72. The use of an F_{MSY} to M ratio of 0.8 in the DCAC model may also be precautionary.

Comparison of Yield Estimates and Reference Points



HRN = High Risk-Neutral

LRN = Low Risk-Neutral

LCI = Lower Confidence Interval

UCI = Upper Confidence Interval

Buffer Size cf Risk Reduction

Zero Depletion DCAC/.72*			PDT Recommended ABC	
	Median	2469	2100	85%
	CI	LCI		
	1%	1969	2100	
	5%	2122	2100	
	10%	2203	2100	
	20%	2294	2100	
-0.20 Depl DELTA DCAC/.72*				
	Median	3011	2100	70%
	CI	LCI		
	1%	2378	2100	
	5%	2547	2100	
	10%	2634	2100	
	20%	2744	2100	
* This table presents results based on M=0.10				

Potentially Precautionary Characteristics

- F_{MSY} to M ratio = 0.8
- Zero Depletion DELTA in DCAC
- M = 0.10
- Use of 0.72 for conversion of DCAC to MSY when range is 0.50-0.72.
- Use of sum of recorded landings in DCAC creates unknown downward bias
- Biomass estimates for SAW 43 don't include crabs deeper than 500F

Potentially Precautionary Characteristics

- B estimated for survey area not management unit (FMP incr by 13.6%)
- Strata A and D show less impact from fishing – Area south of Strata A likely similar
- Gulf of Maine population not included and no directed fishery
- No directed fishery on Canadian extension of population

Summary

- The PDT agrees with the recommendation of the DPSWG for "a catch limit that mimics both recent and long term mean annual landings…"
- The PDT agrees with the Review Panel preference for the DCAC model, but with an adjustment to reflect the expected difference between DCAC results and MSY.
- Recommendations combine both

Growth Model

Molt Schedule		79-year Total				
Age	Instar	Molt?	mmCW	Selectivity	Wgt (lbs)	Wgt grams
1			17.8072604	3.81469E-10	0.003330275	1.511
2	7	yes	28.5422007	8.62595E-09	0.014374036	6.520
3	8	yes	38.6139314	1.60873E-07	0.036680454	16.638
4	9	yes	48.0634259	2.50411E-06	0.072297846	32.794
5	10	yes	56.9291264	3.28972E-05	0.122184093	55.422
6	10	no	65.2470998	0.000368494	0.186465997	84.580
7	11	yes	73.0511849	0.003545124	0.264660843	120.048
8	11	no	80.3731301	0.028983811	0.355857776	161.414
9	12	yes	87.2427222	0.180052888	0.45886252	208.137
10	12	no	93.6879077	0.58815348	0.572310519	259.596
11	12	no	99.7349066	0.892159378	0.694753719	315.135
12	13	yes	105.408319	0.977270875	0.824725743	374.089
13	13	no	110.731226	0.99506974	0.96078964	435.807
14	13	no	115.725281	0.998840023	1.101571736	499.665
15	13	no	120.410801	0.999702363	1.245784539	565.078
16	13	no	124.806847	0.999916984	1.392241145	631.510
17	14	yes	128.931304	0.999974948	1.539863095	698.470
18	14	no	132.800949	0.99999186	1.687683313	765.520
19	14	no	136.431527	0.999997165	1.834845392	832.272
20	14	no	139.837805	0.999998946	1.980600247	898.385
21	14	no	143.033642	0.999999583	2.124300941	963.567
22	14	no	146.032039	0.999999826	2.265396308	1027.566
23	14	no	148.845194	0.999999923	2.403423848	1090.175
24	15	yes	151.48455	0.999999964	2.538002275	1151.218
25	15	no	153.960846	0.999999983	2.668823978	1210.558
26	15	no	156.284155	0.999999991	2.795647604	1268.084
27	15	no	158.463929	0.999999995	2.918290908	1323.714
28	15	no	160.509036	0.999999997	3.036623962	1377.389
29	15	no	162.427795	0.999999999	3.150562788	1429.071
30	15	no	164.228012	0.999999999	3.260063462	1478.740
31	15	no	165.917011	0.999999999	3.365116679	1526.391
32	15	no	167.501663	1	3.465742814	1572.034
33	16	yes	168.988414	1	3.561987437	1615.690
34	16	no	170.383313	1	3.653917284	1657.389
35	16	no	171.692034	1	3.741616648	1697.169
36	16	no	172.919903	1	3.75	1735.074
37	16	no	174.071913	1	3.75	1771.156

Outstanding Issues

- Most appropriate years for average catch
- Most appropriate F_{MSY} to M ratio
- Confidence level in 1974 survey
- SRR and juvenile mortality - projection
- CPUE and LPUE
- ABC Control Rule
- Implications of possible stock cycling