Estimation of an F_{MSY} Proxy Reference Point for Spiny Dogfish

Paul Rago
Northeast Fisheries Science Center
National Marine Fisheries Service
Woods Hole, MA 02543

Report to
Mid-Atlantic Fishery Management Council
Science and Statistical Committee
August 10, 2011

INTRODUCTION

The purpose of this report is to refine the estimate of the F_{MSY} proxy for spiny dogfish. In 2010 the MAFMC Science and Statistical Committee (SSC) approved a new estimator of the Spawning Stock Biomass (SSB) and a new swept area SSB target of 159,288 mt. The target is defined as the SSB corresponding to the estimated maximum recruitment in a Ricker stock recruitment model (Rago and Sosebee 2010). The swept area target corresponds to 30.343 kg/tow in the NEFSC spring bottom trawl survey and a trawl survey footprint of 0.0119 nm^2.

Previous attempts to develop a fully integrated stock assessment model for spiny dogfish have not been successful (e.g. NEFSC 1994, 1998, 2003, 2006, and TRAC 2010a, b) and it has not been possible to develop an absolute measure of population abundance. However several lines of evidence (see Rago and Sosebee 2009) suggest that the NEFSC trawl captures about 50% of the spiny dogfish encountered between the trawl doors. The ratio of the distance between the doors and wings of the net is about 2 which, owing to known herding behavior in dogfish, implies an wing-to-wing efficiency near 100%. The current management of spiny dogfish is based on an assumption that the spawning stock biomass can be adequately indexed by the NEFSC spring bottom trawl survey. Juvenile spiny dogfish, particularly those less than 40 cm are thought to be more pelagic and hence less vulnerable to trawl gear. Ontogenetic changes in behavior result in increasing availability to demersal habitats with size and age. The unknown selectivity pattern for juvenile spiny dogfish complicates the determination of fishing mortality reference points. Since spiny dogfish recruits may be underestimated compared to adult spawners, conventional analyses of a stock recruitment function cannot be conducted. For example many of the observed recruitments fall below the replacement line when F=0. This further emphasizes the problem of establishing the scale of the dogfish recruits (i.e., individuals less than 36 cm TL).

Target and threshold fishing mortality rates have been based on a life history model presented in Rago et al. (1998). The length-based life history model derives an estimate of the first year survival rate So calibrated to a stanza (1987-1994) of population growth corresponding to a finite rate of increase of 1.044(See Rago et al. 1998, Fig.7). It was noted that the model estimates are highly sensitive to the average size at entry to the fishery (see Rago et al. Fig. 8). Using a knife edge

Draft Working Paper for Predissemination Peer Review Only

selection pattern, the replacement F ranged from 0.08 at 65 cm to 0.25 at 84 cm.   The life history model has subsequently been improved to incorporate a logistic selectivity pattern (Rago and Sosebee 2009). Analyses of that model for the selectivity pattern estimated in 2006-2008 (Rago and Sosebee 2010) resulted in an F threshold of 0.325 when the median size at entry in the fishery was 90 cm. The target fishing mortality rate, defined as an F which would allow 1.5 female pups per recruit, was 0.207. Both of these values are dependent on a derived first year survival rate of 0.68. This corresponds to the first year survival rate in Rago et al. 1998 p. 174 of 0.34 (this value includes both male and female pups at a 50:50 sex ratio)

Following adoption of the revised biomass reference points, the MAFMC SSC examined the population trajectories corresponding to the life history model estimates and noted that the population trajectory associated with F=0.325 (and L_{50} =90 cm) and noted that the decline in population size was not consistent with a stable equilibrium. The SSC rejected the estimate of the Fmsy proxy of 0.325 and instead chose an F=0.207 (with expected lifetime pup production of 1.5 female pups per recruit) as an interim value for setting an Acceptable Biological Catch. They further requested an update of the estimate of Fmsy proxy to achieve a value consistent with the projection model. This report summarizes a re-evaluation of the fishing mortality reference points for spiny dogfish with a focus on using a length-based projection model rather than the equilibrium life-history model.

METHODS

Life History Model

The life history model estimates pups per recruit as a function of length specific growth, maturation and fecundity. Details on the methodology may be found in Rago et al. (1998, p 167-168) . Only the summary equation is presented below. A modification made in Rago and Sosebee (2009) was the incorporation of length specific selectivity for fishing mortality.

$$PPR = S_o\left(R_1 + \sum_{j=2}^{J}\prod_{i=1}^{j-1}\frac{S_i R_j}{\lambda^{T_j}}\right)$$

where

$$T_j = \sum_{i=1}^{j} t_i$$

(1)

Instead of a knife-edge function, we used a smooth function for selectivity as follows:

$$S_j = e^{-\left(Sel_{L_j}F+M\right)\Delta t_j}$$

(2)

where the selectivity at length L_j is described in Eq. 1. A von Bertalanffy growth model is used to estimate length at age and the duration of each age class at length L_j. A maximum size of 110 cm was used for females. The parameterization of the model is very sensitive to the size of the time steps associated with the duration of each 1 cm increment in length.

Estimation of Population Size

The variability of initial population size is a primary determinant of the short term dynamics and precision of catch estimates for a given harvest strategy. The magnitude of the population is not important for defining the target fishing mortality rates since this depends only on the population's rate of change in a linear model.

As the details of the population uncertainty are less important for this exercise, the details of this approach are summarized in Appendix 1.

Projection Model

Since inception of the FMP a length-based stochastic projection model has been used to evaluate effects of alternative fishing mortality scenarios and guide management advice. Short term

Draft Working Paper for Predissemination Peer Review Only

management advice on catches relies predominantly on the current non-equilibrium age structure. Transient oscillatory effects of the current age structure are expected to dominate the pattern of landings for the next decade. The magnitude of fishing mortality can offset those effects by damping the oscillations. The model has implications for long-term effects of harvest policies because it can provide insights into the expected population growth rates.

The model incorporates sex specific rates of growth and fishing mortality. Discard mortality is assumed to act equally all size ranges of both sexes. Reproduction in the model is assumed to be proportional to stock abundance. The basic model can be written in terms of two matrix equations as

$$N_{f,t+1} = S_{f,Z,t} P_f N_{f,t} + N_{f,t}^T Pup \, S_o \varphi R_f^o$$

$$N_{m,t+1} = S_{m,Z,t} P_m N_{m,t} + N_{f,t}^T Pup \, S_o (1-\varphi) R_m^o$$

(3)

where

$N_{f,t}$= Vector of female population abundance at length. Dimension = (l_{max}- l_{min}+1)

$N_{m,t}$= Vector of male population abundance at length. Dimension = (l_{max}- l_{min}+1)

$S_{f,Z,t}$=Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for females at time t. Dimensions = (l_{max}- l_{min}+1, l_{max}- l_{min}+1)

$S_{m,Z,t}$=Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for males at time t. Dimensions = (l_{max}- l_{min}+1, l_{max}- l_{min}+1)

R^o=Vector of proportions at length of new recruits. Dimension = (l_{max}- l_{min}+1)

P_f= Growth projection matrix for females. Dimensions = (l_{max}- l_{min}+1, l_{max}- l_{min}+1)

P_m= Growth projection matrix for males. Dimensions = (l_{max}- l_{min}+1, l_{max}- l_{min}+1)

Pup= Vector of length specific pup production rates for mature females. Dimension = (l_{max}- l_{min}+1)

S_o = Scalar first year survival rate of newborn pups. Derived from analysis of life history model

T = Transpose operator

φ = proportion of female pups at birth; 0.5 implies an equal sex ratio.

The projection equation for males is a function of the numbers of recruits produced by females. The component processes of the matrix model and quantities derived from the population states are described below.

Growth in length at age is modeled by the von Bertalanffy equation applied separately to each sex. The model parameters are taken from Nammack et al. (1985). The projection matrices, $\mathbf{P_f}$ and $\mathbf{P_m}$ for females and males, respectively are defined as square matrices consisting of 0, 1 elements. The non-zero elements in cell i, j indicate the projection of individuals from cell i to cell j. The growth of individual dogfish from length i to length j is modeled by first inverting the von Bertalanffy equation to obtain the age of individuals of length i to obtain age$_i$. The projected length at age$_{i+1}$ by sex then obtained substituting age$_i$+1 back into the von Bertalanffy equation to obtain length j as follows:

Step 1. *Find age for* L_i

$$a_{f,i} = \frac{\log\left(1-\frac{L_i}{L_\infty}\right)}{K} + t_o$$

(4)

Step 2. *Compute L in next time step*

$$L_j = L_\infty(1 - e^{-K(a_{,i}+1-t_o)})$$

Step 3. *Compute element of projection matrix*

$$P(\text{int}(L_j), \text{int}(L_i)) = 1$$

Natural mortality was assumed equal to 0.092 for all length classes. Fishing mortality in year t, defined as F_t, is multiplied by sex-specific selectivity functions to estimate the sex- and length-

Draft Working Paper for Predissemination Peer Review Only

specific fishing mortality rates. The diagonal matrices that decrement the populations for fishing and natural mortality are defined as $\mathbf{S_{f,Z,t}}$ and $\mathbf{S_{m,Z,t}}$ with elements defined by

$$S_{f,Z,t}(\ell,\ell) = e^{-(sel_f(\ell)F_t + M)}$$
$$S_{m,Z,t}(\ell,\ell) = e^{-(sel_m(\ell)F_t + M)} \qquad (5)$$

The total number of pups produced is written at the product of the length-specific pup production rates and the number of females alive in year t.

$$Pup_{TOT,t} = S_o N_{f,t}^T Pup \qquad (6)$$

The numbers of recruits produced by length and size category is estimated by splitting the total pup number by sex and multiplying by the observed proportion of dogfish at length for lengths <35 cm (assumed to be less than one year old at the time of the survey). The resulting numbers of pups by sex produced is written as:

$$female\ pups = R_{f,t} = \varphi Pup_{TOT,t} R_f^o$$
$$male\ pups = R_{m,t} = (1-\varphi) Pup_{TOT,t} R_m^o \qquad (7)$$

The $\mathbf{R^o_f}$ and $\mathbf{R^o_m}$ vectors of length (l_{max}- l_{min}+1) represent the proportions by length class and was estimated from the proportions in the 2006-2008 spring surveys. The male and female vectors have equivalent proportions but differ with respect to vector length, owing to the larger maximum size attained by females. Spawning stock biomass is expressed in terms of female biomass only and is defined as the sum of mature females. Females are assumed to be mature at 80 cm so that the spawning stock biomass can be written as

$$SSB_t = \sum_{j=80}^{\ell_{max}} N_{f,t}(j)W_f(j) \qquad (8)$$

Draft Working Paper for Predissemination Peer Review Only

The initial condition of the population was defined as the 3-yr average (2008-2010) of dogfish abundance in the NEFSC spring R/V trawl survey. The projection model incorporates the variation in abundance defined by survey abundance. Variation in mean abundance is used to scale the index numbers at length by generating values of mean abundance over 500 equally-spaced probability intervals.

When length specific fecundity is held constant and none of the other model parameters vary as a function of population size, Equation 3 is a linear system of equations and has properties similar to a stage-based Leslie matrix model. Briefly, the linear system of the form $AX_t=X_{t+1}$ with a positive definite matrix A will be expected to achieve a constant rate of increase λ such that $AX_t= \lambda X_t$ as t approaches infinity. Generally we don't have to wait that long and the model equilibrates after a modest number of iterations. Alternatively one can estimate the dominant eigenvalue and eigenvector of A to derive the steady state growth rate and population size structure.

Model complexity can be increased by introducing a stock recruitment model

$$Pup_{TOT,t} = G(SSB_t \mid \Theta) \tag{9}$$

Where SSB is defined by Eq. 8 and Θ represents a vector of parameters. For example the stock recruitment model defined in Rago and Sosebee (2010) could be used. Details on this exploratory exercise are described in Appendix 2.

RESULTS

The predicted female pups per female recruit from the equilibrium life history model are depicted in Fig. 1. The model incorporates the selectivity pattern for 2006-2008 fishery (Appendix 1). Fthreshold (0.325) corresponds to a lifetime production of 1 female pup per female recruit. Ftarget (0.207) corresponds to a lifetime production of 1.5 female pups per female recruit.

The inconsistency between the predicted population trajectories associated with F=0.325 (and L_{50} =90 cm) is demonstrated in Fig. 2. When F=0.207 the population increases at about 1% per year

Draft Working Paper for Predissemination Peer Review Only

(λ=1.00892) but when F=0.325 the population declines at about 1.9% per year (λ=1.00892).   The differences between the life-history model predictions and the projection model are small in absolute terms but result in large differences over the time span of 50 years or more.

The Newton-Raphson algorithm was used to estimate a fishing mortality rate that would achieve a (λ=1.00) given the initial conditions of the population (Table 1). When F=0.2439 the population stabilizes at a target biomass of about 125,000 mt. However, since the model is linear, the population can be stabilized at any population size by applying an alternative F until the desired population SSB is achieved. A two stage harvest policy is applied in Fig. 4 wherein a   fishing mortality rate of 0.235 is applied from 2010 to 2129 and followed by the threshold F= 0.2439 from 2130 to 2259. The harvest policy allows the population to grow between 2010 and 2129. The population fluctuates slightly when the fishing mortality increases and then returns to equilibrium at the target female SSB of 159,288 mt. A detailed summary of the statistical properties of the stable population is provided in Table 2.

Using a harvest control rule of 75% of the Fmsy proxy gives an F of 0.18293. Expected annual population growth is 1.52% per year or a finite rate of increase of 1.01527 (Fig. 5). The maximum population growth rate, attainable occurs when F=0.0, is estimated to be about 7% per year (λ=1.07)(Fig. 6). The rate of population growth decreases linearly with F (Fig. 7).

As shown by numerous authors in the ecological and fisheries literature, Leslie matrix type models are very sensitive to the first year survival rate (S_o) The effect of variation in So on the equilibrium F is shown in the text tables below. If So increases from 0.68 to 0.892 the equilibrium Fmsy proxy would increase to 0.3269. Similarly, a decline in So to 0.468 would reduce the Fmsy proxy to 0.15289.

So	F	r	lambda
0.892	0.2439	0.018433	1.018603936
0.892	0.3649	-0.00842455	0.991610837
0.892	0.326945287	0	1

So	F	r	lambda
0.468	0.2439	-0.024720102	0.975582937
0.468	0.12195	0.008405458	1.008440884
0.468	0.152894251	0	1

DISCUSSION

The revised estimate of the Fmsy proxy for spiny dogfish is 0.2439. Using a 75% of Fmsy proxy as a candidate target F results in population growth rate of 1.5% per year. The effects of these alternative fishing mortality reference points on predicted USA landings, total catch and SSB in 2011 are summarized in Table 3 and 4 for Fmsy proxy and 75% Fmsy proxy, respectively. These summaries are done for illustrative purposes only and are meant to show the properties of the new estimators on predicted catch using the same initial conditions as employed during the 2010 specifications setting process. Choice of a target F reference point is typically based on a desired population growth rate or buffer associated with uncertainty in the Overfishing Limit (OFL).

There are multiple factors influencing the uncertainty in the fishing mortality rate estimator for spiny dogfish in the projection model. While it is possible to develop a parametric Monte Carlo sampling approach to estimate the uncertainty in Fmsy, it would be desirable to discuss the potential range of input parameters. Variations in growth rate, selectivity, maturity and first year survival would likely be key parameters to vary. The derived sampling distribution of Fmsy proxies could then be convolved with the uncertainty in population abundance to obtain a better approximation of the OFL uncertainty.

Ultimately it would be desirable to develop an integrated stock assessment model for spiny dogfish. The TRAC made considerable progress toward that objective. The projection model described herein could be used as a basis for developing a length based assessment model. Alternatively, something like Sullivan's CASA model could be applied. One of the key obstacles for such a model is the estimation of selectivity for the more pelagic pups. It is hypothesized that juvenile dogfish gradually become more demersal with age, but the age or size at full recruitment to the bottom habitat has not been estimate. The difficulties of rescaling the recruitment estimates to be

Draft Working Paper for Predissemination Peer Review Only

consistent with the predictions of the Ricker stock recruitment model (Rago and Sosebee 2010) are examined in Appendix 2.

REFERENCES

NEFSC [Northeast Fisheries Science Center]. 1994. Report of the 18th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee Consensus Summary of Assessments. National Marine Fisheries Service,Northeast Fisheries Science Center Reference Document, CRD 94-22. Woods Hole, MA, USA.

NEFSC [Northeast Fisheries Science Center]. 1998. Report of the 26th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee Consensus Summary of Assessments. National Marine Fisheries Service, Northeast Fisheries Science Center Reference Document, CRD 98-04. Woods Hole, MA, USA.

NEFSC [Northeast Fisheries Science Center]. 2003. Report of the 37th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee Consensus Summary of Assessments. National Marine Fisheries Service, Northeast Fisheries Science Center Reference Document, CRD 03-16. Woods Hole, MA, USA.

NEFSC [Northeast Fisheries Science Center]. 2006. Report of the 43rd Northeast Regional Stock Assessment Workshop (43rd SAW): 43rd SAW Assessment Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Science Center Reference Document, CRD 06-25. 400 pp. Woods Hole, MA, USA

Rago, P. J., K. A. Sosebee, J. K. T. Brodziak, S. A. Murawski, and E. D. Anderson. 1998. Implications of recent increases in catches on the dynamics of Northwest Atlantic spiny dogfish (*Squalus acanthias*). Fisheries Research 39:165–181.

Rago, P. J. and K. A. Sosebee. 2009 The Agony of Recovery: Scientific Challenges ofSpiny Dogfish Recovery Programs. pp 343-372. *In* V. F. Gallucci, G. A. McFarlane and G. G. Bargman eds. Biology and Management of Dogfish Sharks.American Fisheries Society, Bethesda Maryland.

Rago PJ and KA Sosebee. 2010. Biological Reference Points for Spiny Dogfish . Northeast Fish Sci Cent Ref Doc. 10-06; 52 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at:
http://www.nefsc.noaa.gov/nefsc/publications/

TRAC. 2010a. Northwest Atlantic Spiny Dogfish. TRAC Status Report 2010/02.

TRAC 2010b. Proceedings of the Transboundary Resources Assessment Committee (TRAC) Spiny Dogfish Review Benchmark Data Meeting 30 March – 2 April 2009 and Benchmark Model and Assessment Meeting 25-29 January 2010. Woods Hole, Massachusetts. Meeting Chairpersons: L. O'Brien and T. Worcester. Transboundary Resources Assessment Committee Proceedings 2010/01.
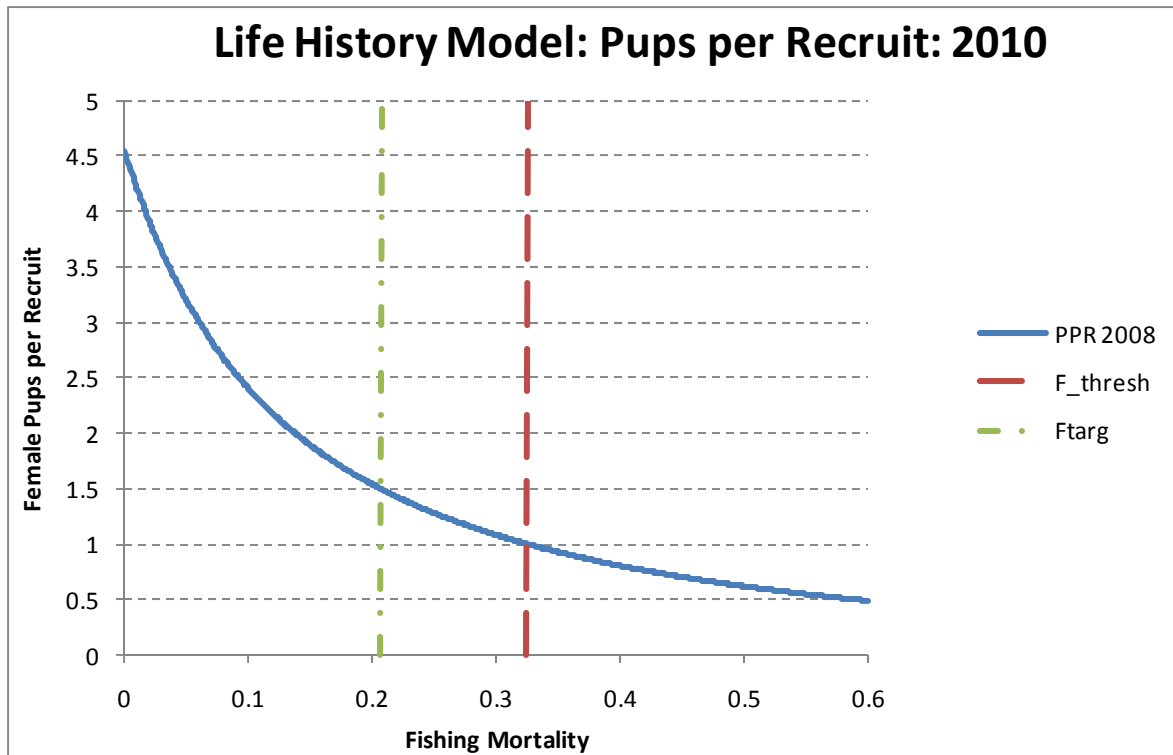
Fig. 1. Current estimates of fishing mortality reference points for spiny dogfish based on equilibrium life history model. Model incorporates selectivity pattern for 2006-2008 fishery. Fthreshold (0.325) corresponds to a lifetime production of 1 female pup per female recruit. Ftarget (0.207) corresponds to a lifetime production of 1.5 female pups per female recruit.

Stochastic Projections at F=0.207 and F=0.325

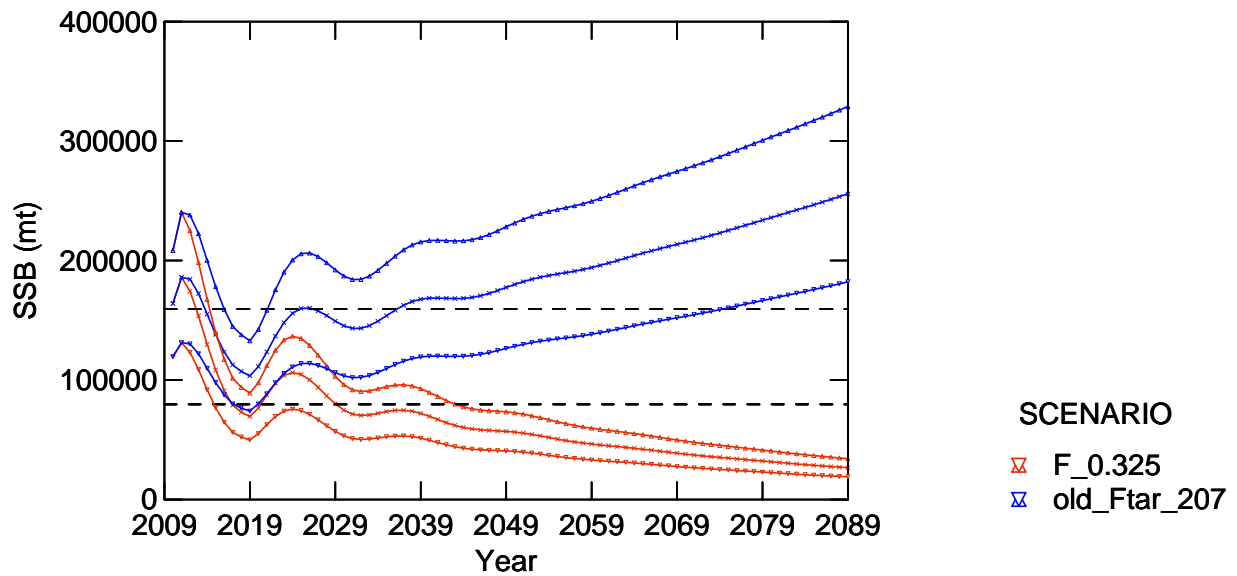
Fig 2. Stochastic projections of SSB at current fishing mortality threshold (F=0.325) and target (F=0.207) fishing mortality rates defined in Rago and Sosebee (2010). Threshold and target Fs are based on life history model. Horizontal dashed lines represent biomass target and threshold values of 159,288 mt and 79644 mt, respectively. Projections depict 2.5%, 50% and 97.5% iles for each scenario. The expected finite rate of population increase at F=0.325 is 0.98128 or about 1.9% decline per year. The finite rate of population increase at F=0.207 is 1.00892 or about a 0.9% increase per year.

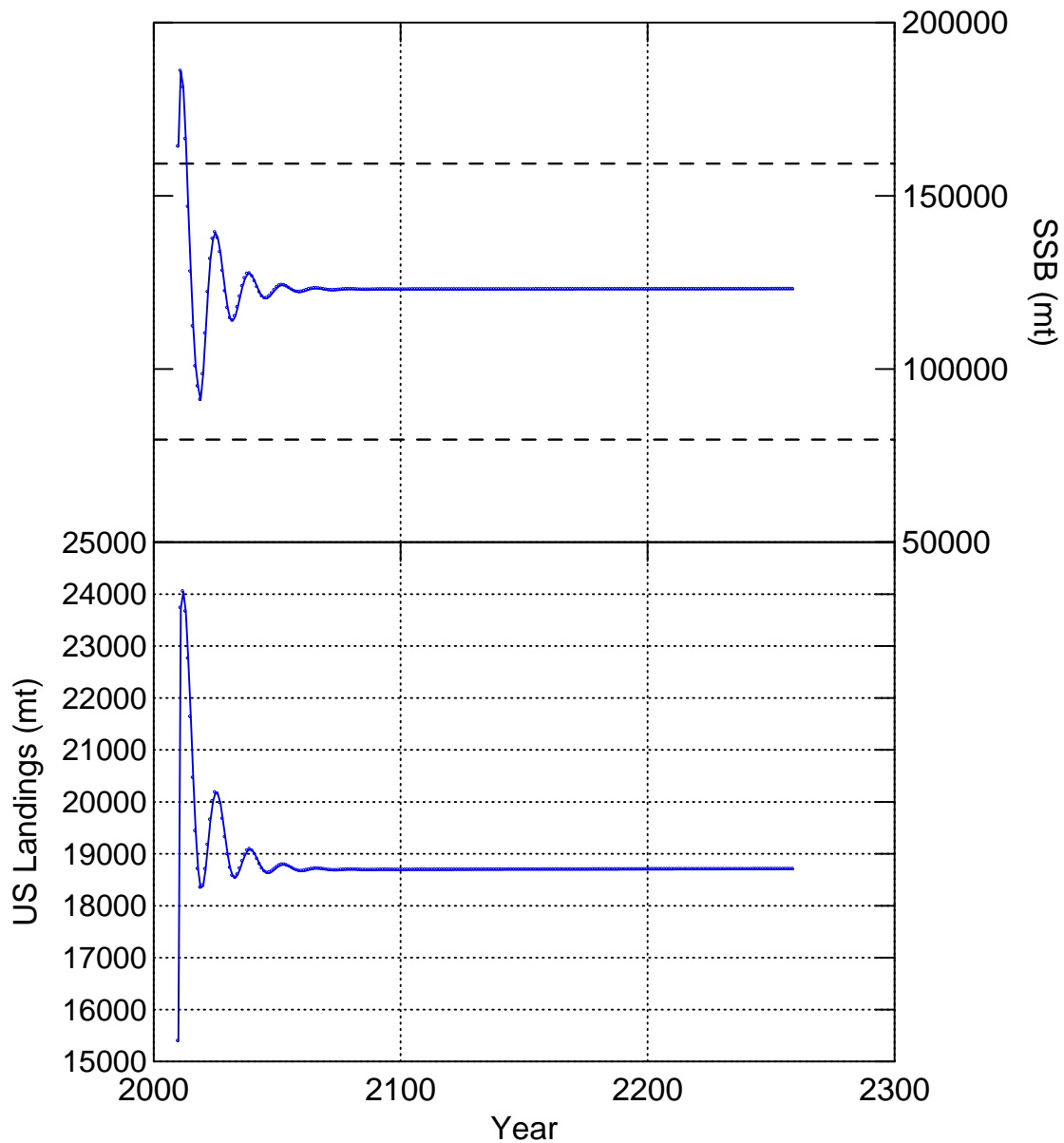# Longterm Projection at Fmsyproxy given 2010 Initial Condition

Fig. 3. Median projection of female spawning stock biomass (mt) and projected US landings (mt) using estimated fishing mortality rate of 0.2439 that achieves a finite rate of increase equal to 1.0. Horizontal dashed lines represent biomass target and threshold values of 159,288 mt and 79644 mt, respectively. Transient population dynamics prior to 2050 are induced by the non-equilibrium initial condition of population size structure.

Draft Working Paper for Predissemination Peer Review Only

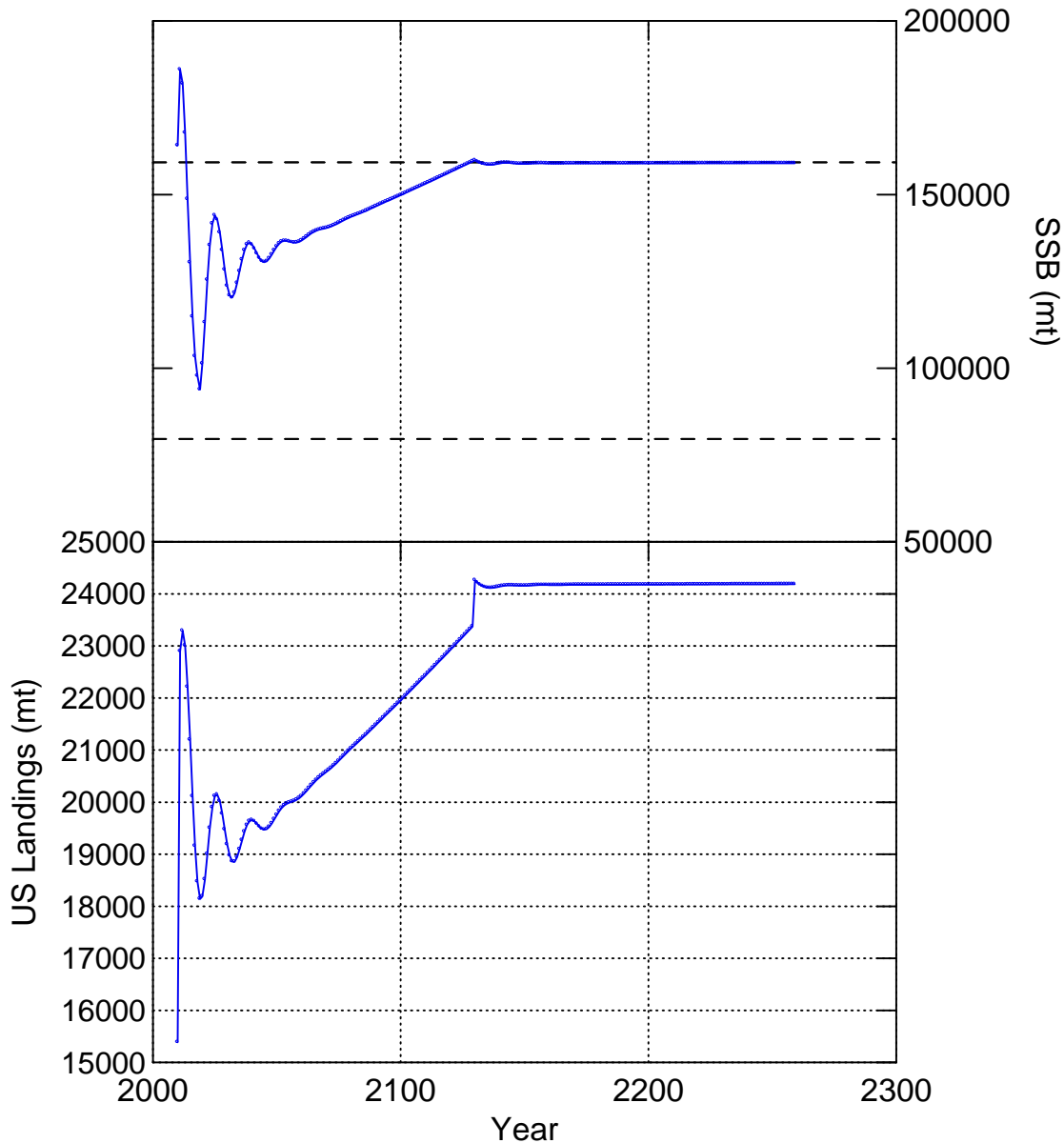Transitional F= 0.235 to F=0.244 Attain SSBmsy proxy

Fig. 4. Median projection of female spawning stock biomass (mt) and projected US landings (mt) using a two stage fishing mortality harvest policy designed to achieve a target biomass of 159,288 mt. The harvest policy allows the population to grow between 2010 and 2129. A fishing mortality rate of 0.235 from 2010 to 2129 and followed by the threshold F= 0.2439 from 2130 to 2259. The population fluctuates slightly when the fishing mortality increases and then returns to equilibrium at the target female SSB . Horizontal dashed lines represent biomass target and threshold values of 159,288 mt and 79644 mt, respectively.

Draft Working Paper for Predissemination Peer Review Only

Longterm Projection at 75% Fmsyproxy given 2010 Initial Condition

Fig. 5. Median longterm projection of female spawning stock biomass (mt) and projected US landings (mt) using a harvet policy of 75% of the Fmsy proxy (= 0.2439). Trajectories represent SSB and landings under a fishing mortality rate of 0.18293. Expected annual population growth is 1.52% per year or a finite rate of increase of 1.01527 Horizontal dashed lines represent biomass target and threshold values of 159,288 mt and 79644 mt, respectively.

Draft Working Paper for Predissemination Peer Review Only

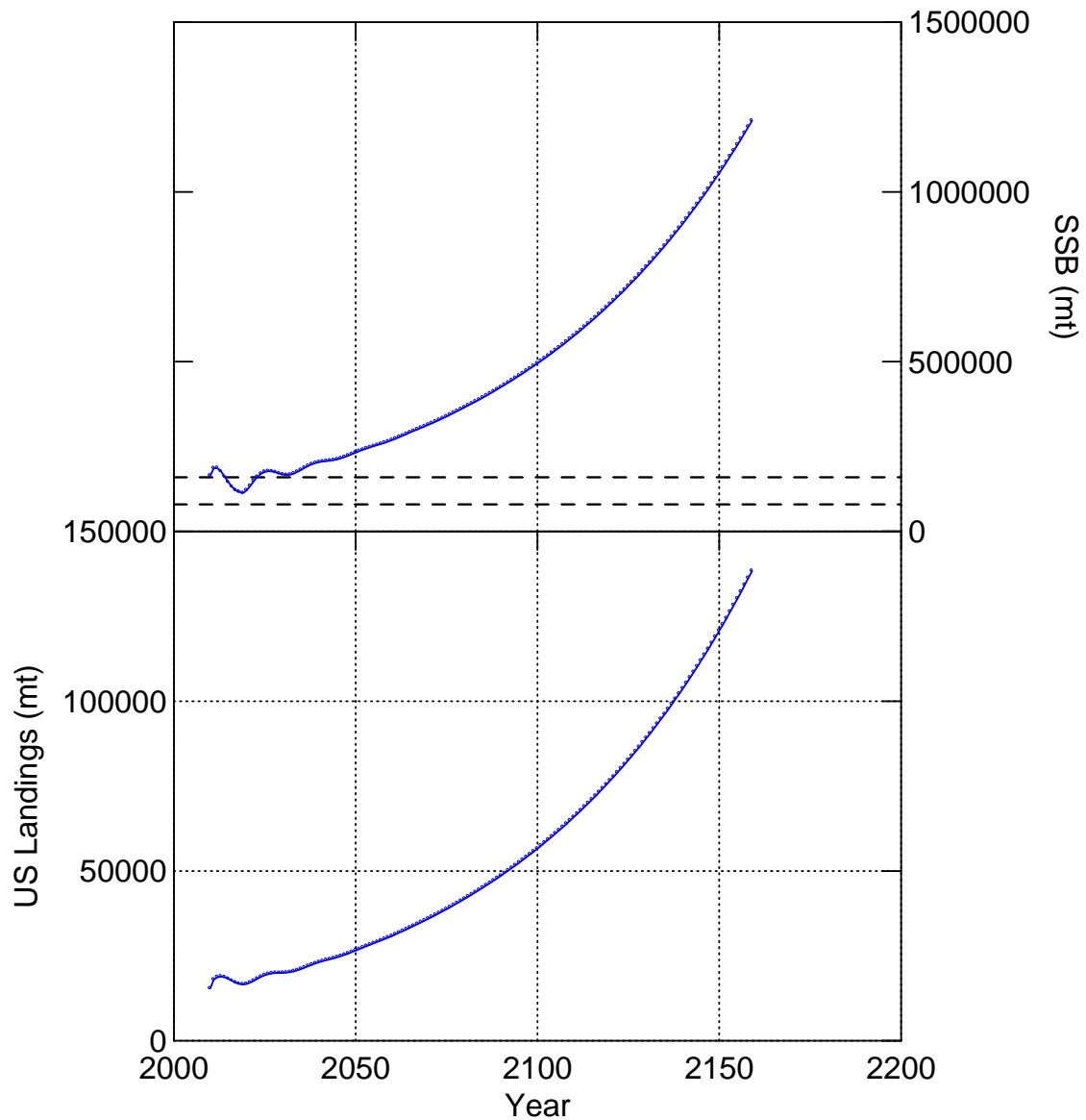## Longterm Projection at F=0.0 given 2010 Initial Condition
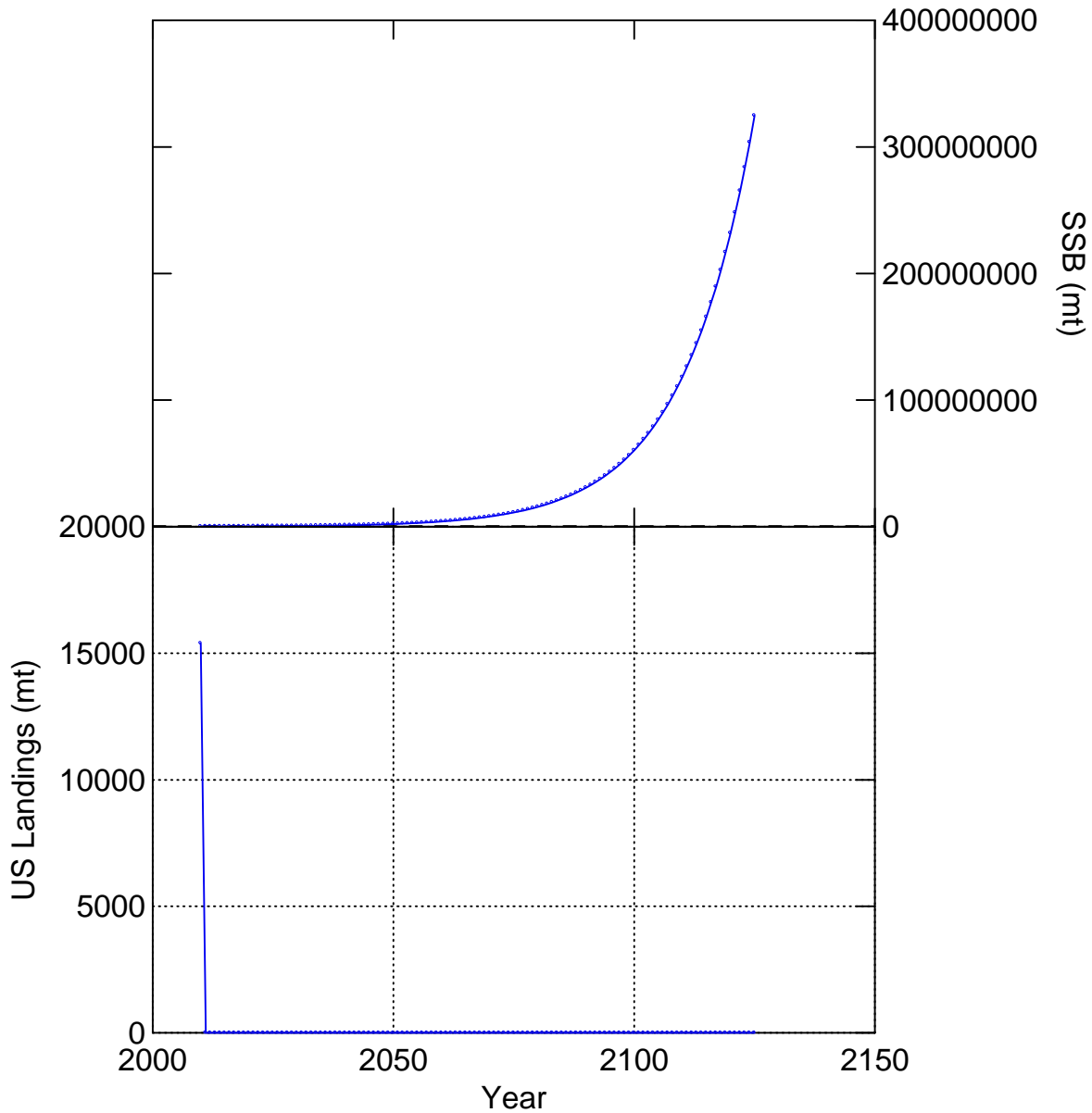
Fig. 6. Median longterm projection of female spawning stock biomass (mt) and projected US landings (mt) using a harvet policy of F=0.0   Expected annual population growth is 7% per year or a finite rate of increase of 1.07.   Horizontal dashed lines represent biomass target and threshold values of 159,288 mt and 79644 mt, respectively.
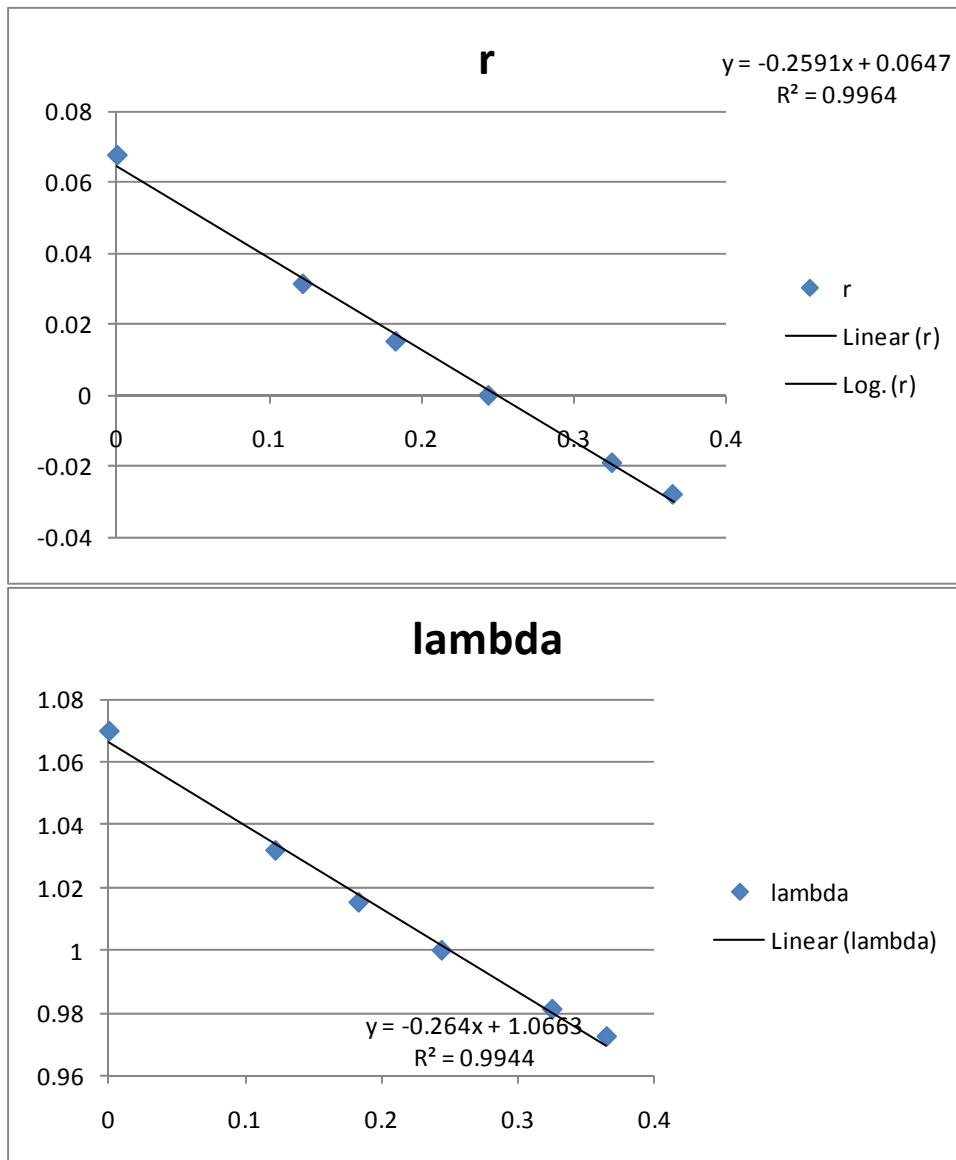
Fig. 7. Predicted instantaneous population growth rates and finite rate of increase for spiny dogfish as a function of fishing mortality rate. The first year survival rate is fixed at 0.68.

Table 1. Estimates of population growth rate for varying levels of F and So

Description	*So*	*F*	*ln(λ)*	*λ*
Fmsy proxy for Linear Model	0.68	0.2439	0	1
F=0.0 To estimate maximum growth rate	0.68	0	0.067364	1.07
75% of Fmsy Proxy	0.68	0.182925	0.015151	1.01527
50% of Fmsy Proxy	0.68	0.12195	0.031274	1.03177
Old Fmsy Proxy based on Life History model	0.68	0.325	-0.01891	0.98127
Old Target F based on Life History Model	0.68	0.207	0.008989	1.00892

Table 2. Summary statistics for population biomass, total catch and estimated USA landings in
   2150 for a population stabilized at Bmsy and F=Fmsyproxy. A fishing mortality rate of
   0.235 from 2010 to 2129 and followed by the threshold F= 0.2439 from 2130 to 2259.

	USA Landings(mt)	Total Catch(mt)	SSB (mt)
Minimum	6,597	14,972	98,451
Maximum	15,908	33,445	219,921
Median	11,220	24,146	158,770
Mean	11,224	24,152	158,815
Standard Dev	2,088	4,143	27,243
Percentile			
1%	6,890	15,552	102,266
5%	7,741	17,242	113,375
10%	8,412	18,574	122,131
20%	9,332	20,399	134,135
25%	9,699	21,127	138,921
30%	10,033	21,790	143,278
40%	10,646	23,005	151,270
50%	11,220	24,146	158,770
60%	11,796	25,287	166,276
70%	12,408	26,503	174,269
75%	12,744	27,168	178,642
80%	13,111	27,897	183,437
90%	14,041	29,741	195,566
95%	14,721	31,092	204,445
99%	15,599	32,832	215,890

Table. 3. Summary of predicted catch statistics and SSB in 2011 given F=Fmsyproxy

	USA Landings	Total Catch	SSB
Minimum	6,513	16,274	113,608
Maximum	14,638	31,266	259,245
Median	10,547	23,718	185,921
Mean	10,550	23,724	185,976
Standard Dev	1,823	3,363	32,664
Percentile			
1%	6,768	16,745	118,179
5%	7,510	18,115	131,495
10%	8,096	19,196	141,991
20%	8,899	20,677	156,382
25%	9,219	21,268	162,119
30%	9,510	21,805	167,342
40%	10,046	22,793	176,933
50%	10,547	23,718	185,921
60%	11,049	24,644	194,918
70%	11,584	25,631	204,505
75%	11,877	26,171	209,748
80%	12,197	26,762	215,492
90%	13,009	28,261	230,050
95%	13,603	29,356	240,691
99%	14,368	30,768	254,408

Draft Working Paper for Predissemination Peer Review Only

Table 4. Summary of predicted catch statistics and SSB in 2011 given F=75% Fmsyproxy

	USA Landings	Total Catch	SSB
Minimum	4,711	12,327	113,608
Maximum	10,886	23,720	259,245
Median	7,777	17,984	185,921
Mean	7,779	17,988	185,976
Standard Dev	1,385	2,555	32,664
Percentile			
1%	4,905	12,685	118,179
5%	5,469	13,726	131,495
10%	5,914	14,547	141,991
20%	6,524	15,673	156,382
25%	6,768	16,122	162,119
30%	6,989	16,530	167,342
40%	7,396	17,281	176,933
50%	7,777	17,984	185,921
60%	8,158	18,688	194,918
70%	8,565	19,437	204,505
75%	8,787	19,848	209,748
80%	9,031	20,297	215,492
90%	9,648	21,436	230,050
95%	10,099	22,268	240,691
99%	10,681	23,341	254,408

Draft Working Paper for Predissemination Peer Review Only

APPENDIX 1. Sampling Distribution of Biomass and Fishing Mortality

The sampling distributions of biomass and fishing mortality are approximated by integrating over the factors which constitute the primary sources of uncertainty. These factors include the sampling variability in the NEFSC spring bottom trawl survey, the size of the area swept by an average tow, and the uncertainty in the discard estimates. The sample means and variances for each of these factors were used to parameterize their respective normal distributions. Sampling theory suggests that the survey means should be asymptotically normal. We exploit this feature to simplify the estimation of the sampling distribution of biomass and fishing mortality.

The sampling distribution of each of the Fs described above was evaluated by integrating over each of the normal distributions for average number $\overline{X}$, survey footprint $\boldsymbol{a}$, and total discards for gill nets and trawls, and recreational catch, $\boldsymbol{D_G}, \boldsymbol{D_T}$, and $\boldsymbol{D_R}$ respectively. The density $\overline{X}$ and footprint a parameters were evaluated over 500 equal probability intervals, while the sampling distribution D_G, D_T, and D_R were evaluated over 20 equal probability intervals.

Let Φ = Normal cumulative distribution function. The inverse of Φ, denoted as Φ^{-1} allows the evaluation of a set of values over a specified range, say α_{min} and α_{max}, over equal probability intervals. The value of the random variable X associated with the α level is defined as:

$$X'_{t,\alpha} = \Phi^{-1}(\alpha \mid \overline{\overline{X}}, \overline{S}_t^2) \qquad (1.1)$$

The step size between successive values of α was set as $\delta_1 = 1/500$ (0.975-0.025), where α_{min} =0.025 and α_{max}=0.975. An equivalent approach was used for evaluation of the footprint parameter a where a~$N(\mu_a, \sigma_a^2)$. The total discard estimate D~$N(\mu_D, \sigma_D^2)$ was approximated by dividing the 95% confidence interval into 20 equal probability values (δ_2=1/20). Discard means and variances were estimated for each gear and sex.

This property can be illustrated for the biomass estimates by rewriting Eq. 2 and 3 as

Draft Working Paper for Predissemination Peer Review Only

$$B'(l) = N'(l)W(l) = I'(l)\left(\frac{A}{a'}\right)W(l) = \overline{X}_\alpha' \, p_s(l)\left(\frac{A}{a_\alpha'}\right)W(l) \qquad (1.2)$$

where the prime mark indicates that value is drawn from a normal distribution (Eq. 1.1) corresponding the α probability level. The expected value of **B'(l)** is obtained by summing over the sampling distributions of **X** and **a** as follows
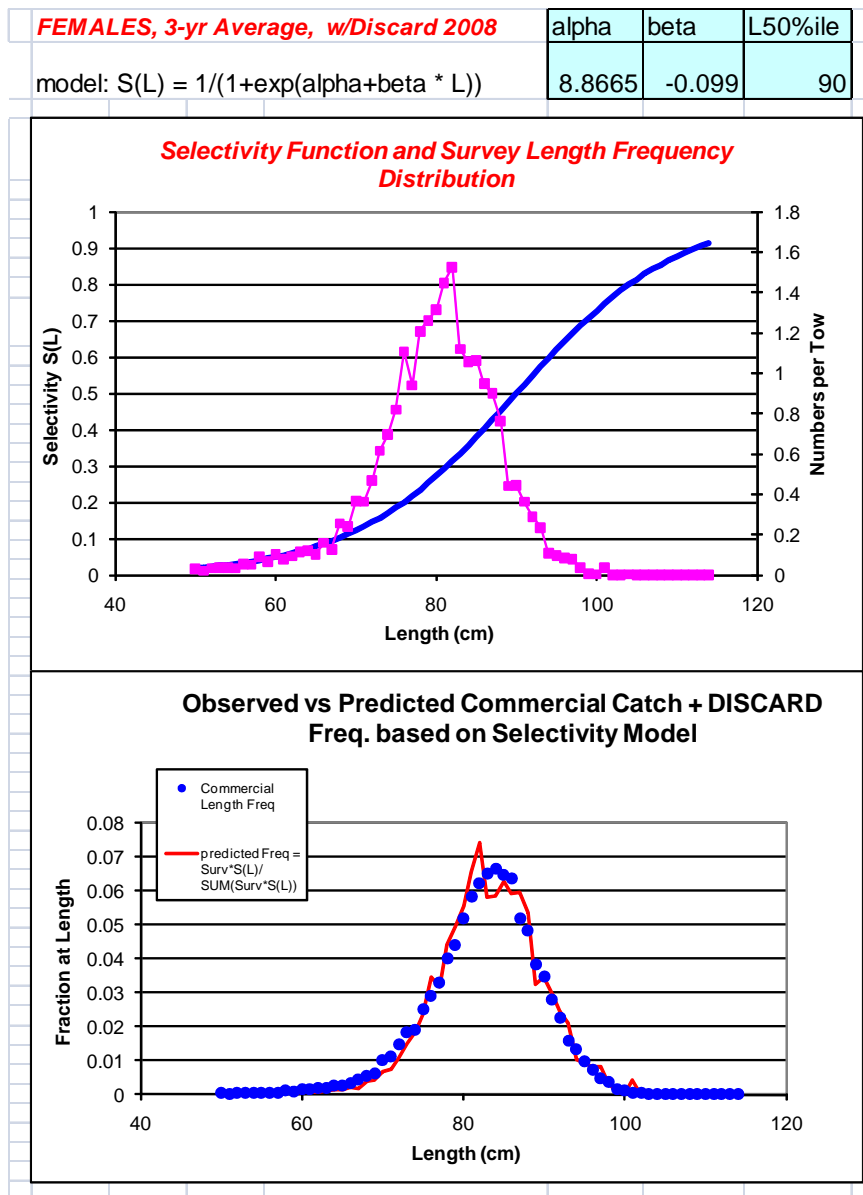
$$E[B'(l)] = \sum_{\alpha=\alpha_{min}}^{\alpha_{max}} \sum_{\beta=\beta_{min}}^{\beta_{max}} \left(\overline{X}_\alpha' \, p_s(l)\left(\frac{A}{a_\beta'}\right)W(l)\delta_\alpha\delta_\beta \right) \qquad (1.3)$$

The sampling distribution of **B'(l)** can be constructed by noting that the each element within the brackets of the rhs of Eq. 1.3 has a probability weight of $\delta_\alpha\delta_\beta = (1/500)(1/500)$.

The sampling distribution of F in Eq. 5 is a straightforward extansion of Eq. 1.3 with summation terms corresponding to average number $\overline{X}$, survey footprint **a,** and total discards for gill nets and trawls, and recreational catch, D_G, D_T, and D_R respectively. This approximation of the multidimensional integration provides reasonable assurance that the sampling distribution of the F will be appropriately estimated.

Draft Working Paper for Predissemination Peer Review Only

Appendix 1 Extra: Selectivity function for 2006-2008

Comparison of size composition of commercial catch (landings + Discards) for
male and female spiny dogfish with the NEFSC spring survey for 2006-2008. Both catch and
survey frequencies represent 3-yr moving averages. Summary of estimated selectivity pattern
for male and female spiny dogfish. Selectivity at length L is modeled as sel(L)=1/(1+exp(a + b
L)) where sel(F) is the fraction of the spiny dogfish population vulnerable to the commercial
fishery (both landings and discards). Size composition of the commercial fishery is based on
analyses of port sampling and at-sea observer sampling, 1989-2008. Selectivity blocks are based
on a 3-yr moving average, eg. 2006-2008.

FEMALES, 3-yr Average, w/Discard 2008	alpha	beta	L50%ile
model: S(L) = 1/(1+exp(alpha+beta * L))	8.8665	-0.099	90

Selectivity Function and Survey Length Frequency Distribution

Observed vs Predicted Commercial Catch + DISCARD Freq. based on Selectivity Model

- Commercial Length Freq
- predicted Freq = Surv*S(L)/ SUM(Surv*S(L))

Draft Working Paper for Predissemination Peer Review Only

Appendix 2. Summary of model projections using the Ricker model estimates in Rago and Sosebee (2010).

As an exploratory exercise, the Ricker stock recruitment model was used to predict recruitment. The relative catchability of the pups compared to adult spiny dogfish must ultimately be estimated via a dynamic model. For the purposes of this exercise, the expected female SSB and yield were estimated for a variety of scaling factors on recruits. To initially rescale the population it was assumed that the Fmsy proxy for the linear model would be approximate Fmsy estimate from the Ricker model. The predicted Ricker model recruitment was adjusted by a factor of 0.74829 (rather than the expected 0.5 for a 50:50 sex ratio) to obtain a predicted equilibrium SSB of 157,791 (row 1 below). Thus an adjustment factor of 0.74829 resulted in an Bmsy estimate of 157,791 or approximately 159,288 mt the proxy value of Bmsy (See Rago and Sosebee 2010). The following table summarizes the effects of further searches for maximum total yield. Note the high sensitivity of the total yield estimate and SSB to changes in F. In the vicinity of this rescaling the maximum yield of 24042 mt is obtained at a fishing mortality rate of 0.257925 and a predicted SSBmsy of 149,538 mt. This analysis is by means definitive but it does suggest that modest consistency between the Bmsy proxy from the linear model and a Bmsy estimate from the Ricker model.

Adj Factor	F	SSB	Ytot
0.74829	0.2439	157791	23994
0.74829	0.2	126194	23639
0.74829	0.3	185479	23225
0.74829	0.27195	141533	23995
0.74829	0.257925	149538	24042

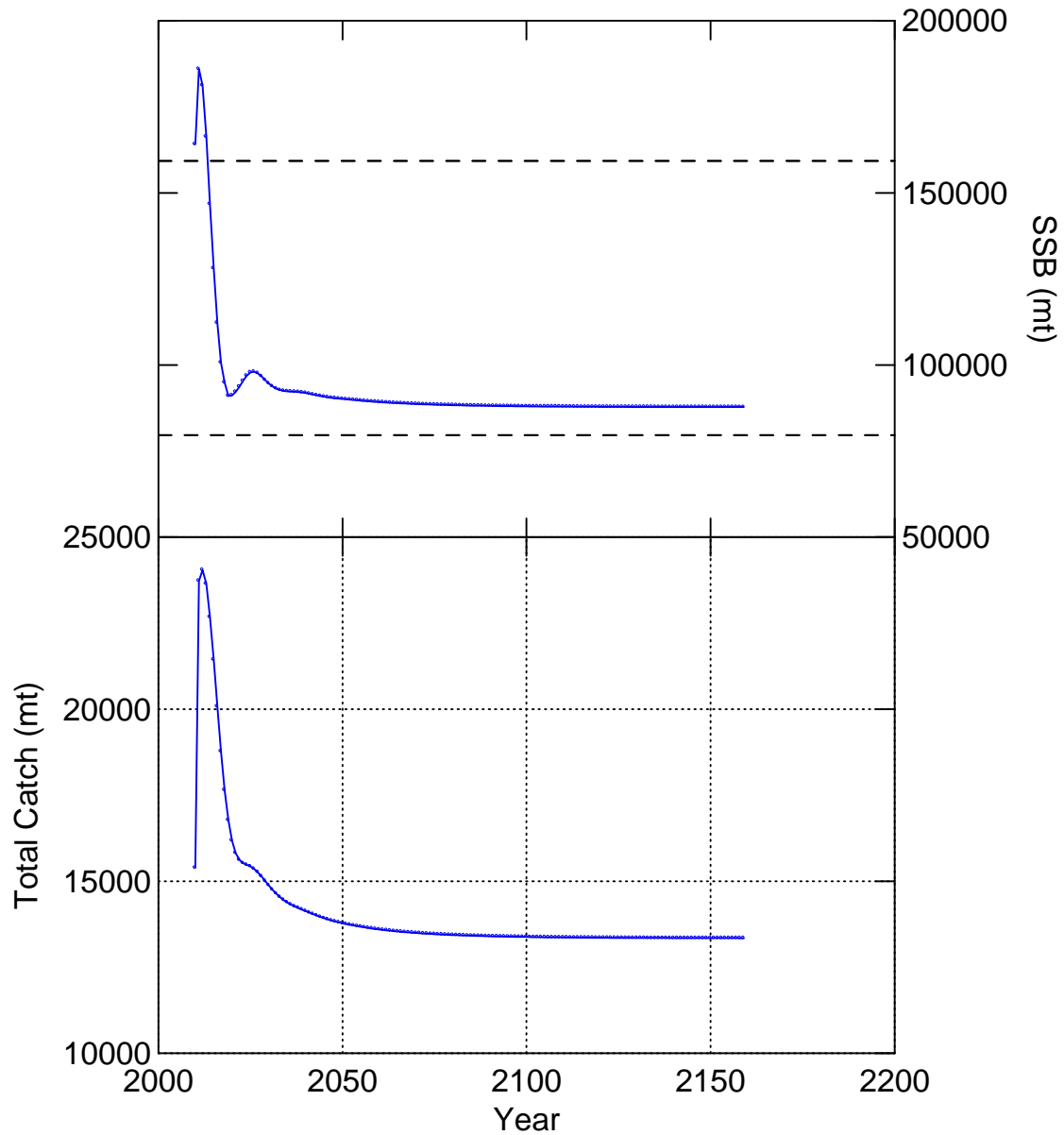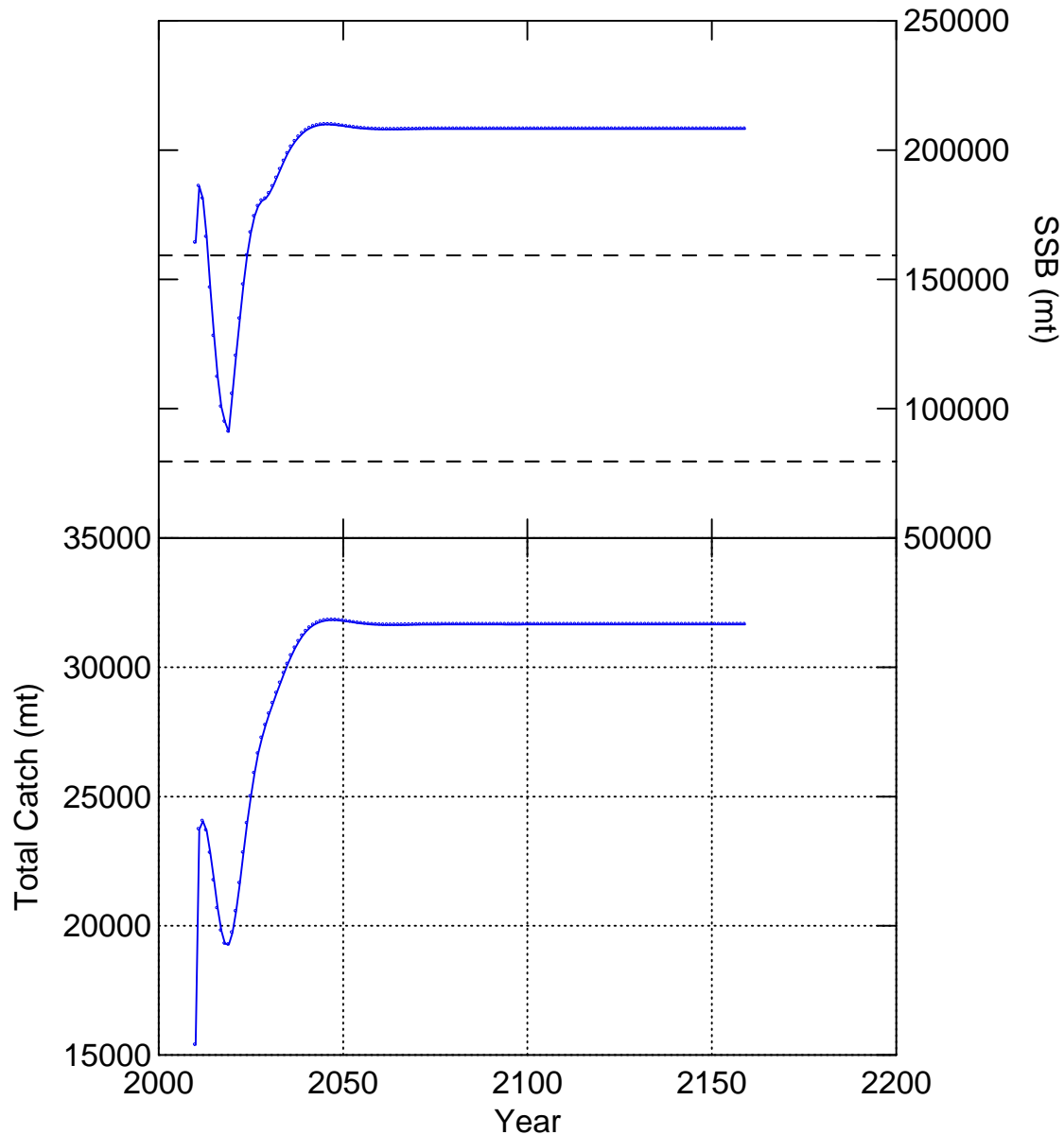# Longterm Projection at F=Fmsyproxy with S-R function at 0.5X

Fig. A2.1 Predicted median trajectory for population subjected to F=0.2439 and recruitment predicted by Ricker stock recruitment function. Predicted recruits are estimated to have a 50:50 sex ratio.

Draft Working Paper for Predissemination Peer Review Only

Longterm Projection at F=Fmsyproxy with S-R function at 1.0X

Fig. A2.2 Predicted median trajectory for population subjected to F=0.2439 and recruitment predicted by Ricker stock recruitment function. Predicted recruits are adjusted upward by a factor of 2. This rescales the predicted recruitment consistent with a relative catchability of juveniles to adults of ½.

Draft Working Paper for Predissemination Peer Review Only

Longterm Projection at F=Fmsyproxy with S-R function at 0.74829X

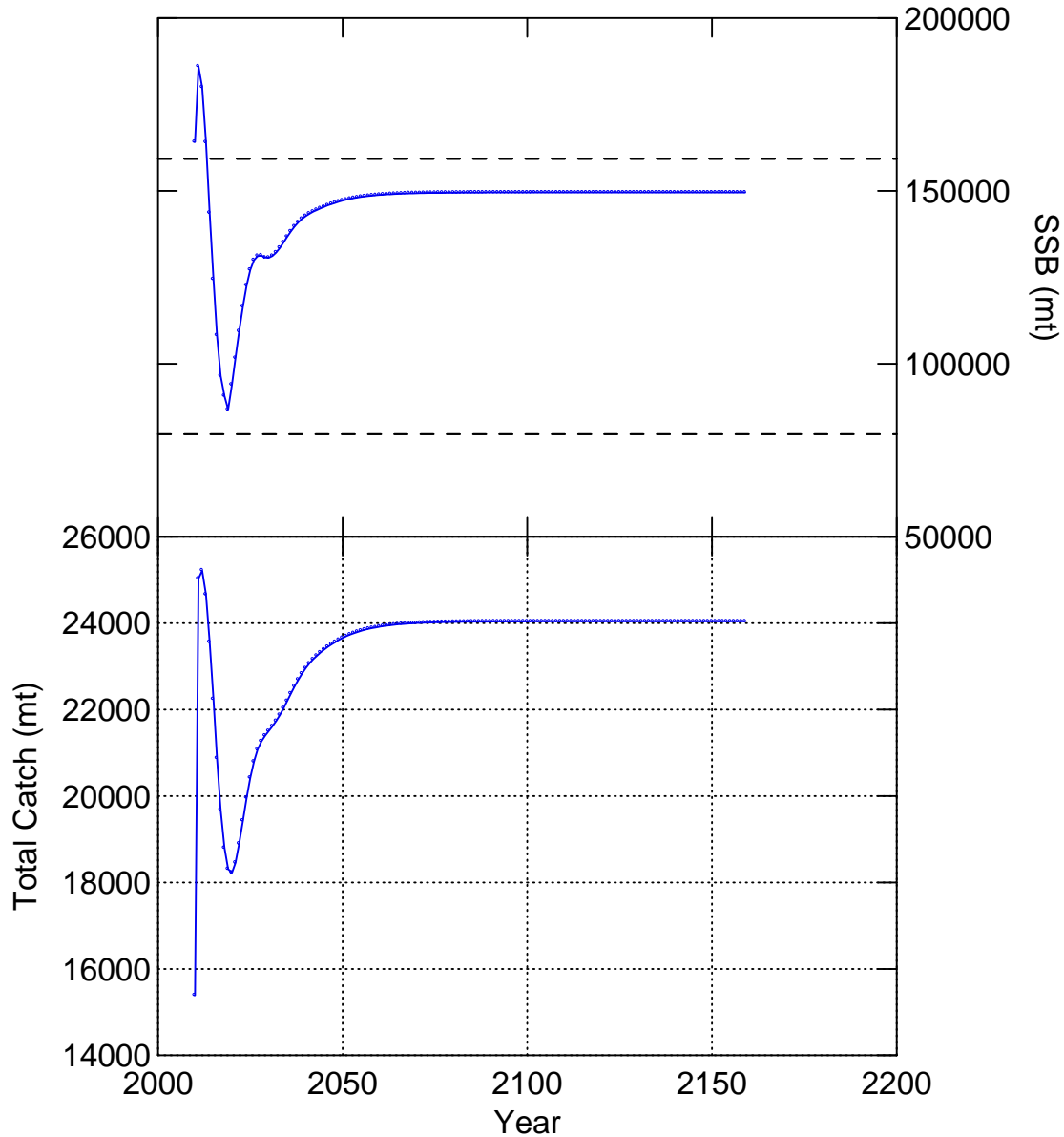

Fig. A2.3. Predicted median trajectory for population subjected to an estimated Fmsy=0.258 and recruitment predicted by Ricker stock recruitment function. Predicted recruits are adjusted upward by a factor of 1.496. Predicted USA landings would be 24,042 mt. This rescales the predicted recruitment consistent with a relative catchability of juveniles to adults of 0.748.

Draft Working Paper for Predissemination Peer Review Only