OVERVIEW OF STOCK ASSESSMENT AND RECOMMENDED HARVEST STRATEGY FOR ST. MATTHEW ISLAND BLUE KING CRABS

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EXECUTIVE SUMMARY

The St. Matthew Island blue king crab (*Paralithodes platypus*) stock was declared "overfished" owing to low stock abundance in 1999. Accordingly, the Crab Plan Team and the Alaska Department of Fish and Game (ADF&G) need to evaluate alternative harvest strategies and develop a stock rebuilding plan. As part of this effort, we developed a four-stage catch-survey model to improve abundance estimates of this stock and evaluate alternative harvest strategies.

There is a great deal of uncertainty in St. Matthew Island blue king crab stock assessment, and the current status of this stock largely depends on the natural mortality rate in 1999. During the next two years, we should be able to determine the degree to which the sharp drop in abundance in 1999 is due to survey measurement errors or high natural mortality. Based on low estimated recruitment to the model during recent years, extremely low trawl survey abundance of all sizes and sexes in 1999, poor in-season fishery performance in 1998, and low catch rates from the ADF&G near-shore pot survey in 1999, the near-term outlook for this stock is not very promising.

We compared the status quo and four other alternative harvest strategies through computer simulations in terms of rebuilding time period, fishing opportunity, and mean annual yield. The status quo strategy has highest fishing opportunity, produces highest mean yield, but requires longest time to rebuild the stock. Moreover, with the current large fishing fleet, it may not be practical to manage the fishery with small guideline harvest levels (GHLs) as was possible with smaller fleets in the past; thus, it may not be possible to continue the status quo strategy. We propose a new harvest strategy that provides relatively short rebuilding times and incorporates a precautionary approach to fishery management by proportionally reducing harvest rates when abundance is below the long-term average and increasing the fishery threshold. When abundance is high, the proposed harvest strategy is identical to the status quo strategy. The proposed strategy also takes into account the manageability of the fishery at low GHLs.

The proposed harvest strategy includes four components:

(1) Minimum stock threshold: 2.9 million lbs of mature male (≥105 mm carapace length) biomass. This is 25% of the equivalent mature male biomass capable of producing maximum sustainable yield (B_{msy} for mature males = 11.6 million lbs).

(2) Minimum GHL: 2.5 million lbs.

(3) Directed mature male harvest rates:
- (i) 0.0 when mature male biomass (B) <2.9 million lbs,
- (ii) $[(B\text{-}2.9)/8.7]*0.1+0.1$ when $11.6> B \geq 2.9$ million lbs, and
- (iii) 0.2 when $B \geq 11.6$ million lbs.

(4) Cap of legal male harvest rate: 0.4.

PURPOSE

The purpose of this report is to provide the basis for a proposed new harvest strategy for the St. Matthew Island blue king crab fishery. We provide a brief history of the fishery and a summary of problems with the current management strategy. Then, we summarize the results from stock assessment modeling. Finally, we propose a new harvest strategy and summarize our analysis of it for this stock based on a catch-survey model.

HISTORY OF FISHERIES

The commercial pot fishery for St. Matthew Island blue king crabs started in 1977 (Otto 1990; Wilson and Morrison 1999). Less than 32 vessels participated in the fishery during the first five years (Table 1). The interest for this fishery increased sharply since 1981, and harvest peaked in 1983 when 164 vessels landed 9.5 million lbs with exvessel value of $25.8 million (Table 1). As the crab abundance declined, the number of vessels participating in the fishery decreased sharply and catch dropped to 1.0 million lbs in 1986 (Table 1). Annual catch was relatively stable from 1991 to 1998, ranging from 2.5 to 4.6 million lbs, and there were 117 to 131 vessels participating in the fishery each year during 1996-1998, the three most recent seasons (Table 1). The fishery was closed in 1999 due to the depressed stock condition. Because of high fishing effort, duration of the fishery is very short, ranging from 2.5 to 17 days per season from 1982 to 1998 (Table 1).

PROBLEMS AND APPROACHES

There are several problems facing the management of the St. Matthew Island blue king crab fishery. First, the fishery was closed for first time due to the depressed stock condition in 1999 since the fishery started in 1977. Estimated mature biomass, based on area-swept estimates of both males and females, was 4.8 million lbs, well below the overfished level (minimum stock size threshold, MSST) of 11.0 million lbs established in the federal fishery management plan for Bering Sea/Aleutian Islands king and Tanner crabs (NPFMC 1998); therefore, the stock was recently classified as "overfished" by the North Pacific Fishery Management Council (NPFMC 2000). According to the Magnuson-Stevens Fishery Conservation and Management Act (NMFS 1996), a rebuilding plan is needed to rebuild an overfished stock. Second, low stocks are not necessarily managed more conservatively than high stocks because the current 20% mature male harvest rate is fixed regardless of stock size, and the fishery threshold of 0.6 million mature males (Pengilly and Schmidt 1995) is very low. Alternative harvest rates, including reduced rates at low stock sizes, and thresholds need to be evaluated. Third, the current fishing fleet is very large for this small fishery, and it is very difficult to manage the fishery when guideline harvest levels (GHLs) are low. A minimum GHL is needed to maintain manageability of the fishery. Finally, bycatch of females and sublegal males in the directed fishery is high for this fishery, and approaches to reduce bycatch should be evaluated.

To address these problems, the Alaska Department of Fish and Game (ADF&G) proposes to revise the harvest strategy for the directed St. Matthew Island blue king crab fishery to rebuild this depressed stock. ADF&G's proposed new harvest strategy is closely based on the National Marine Fisheries Service (NMFS) technical guidance for implementing precautionary harvest strategies and rebuilding plans of Restrepo et al. (1998). We developed a four-stage catch survey analysis (CSA) to improve abundance estimates of St. Matthew Island blue king crabs. Then, based on the results of the CSA, we conducted computer simulations to evaluate the proposed and alternative harvest strategies for this stock.

CATCH-SURVEY ANALYSIS

Rationale to Develop the CSA

The annual trawl survey conducted by NMFS gathers essential data on the status of crab stocks in the eastern Bering Sea (Stevens et al. 2000). Yet, year-to-year changes in oceanographic conditions lead to changes in crab distributions and availability to survey gear. These changes may cause measurement errors that lead to unexpected shifts in area-swept abundance estimates unrelated to true changes in population size. Data from previous years' surveys and commercial catches provide valuable auxiliary information to help decipher real population changes from survey measurement errors. We developed a four-stage CSA to utilize multiple years of data and multiple data sources to estimate abundance more accurately than possible using current-year survey data alone. The exact same motivation led to similar age-structured analyses for most important fish stocks off Alaska and elsewhere around the world.

Overview of the CSA

The four-stage CSA extends the three-stage CSA by including pre-recruit-2 male crabs (90-104 mm carapace length, CL), those two molts from becoming legal size. The three-stage analysis includes pre-recruit-1 (105-119 mm CL), recruit (newshell 120-133 mm CL), and post-recruit male (>133 mm CL and oldshell 120-133 mm CL) crabs. Unlike the three-stage version of Zheng and Kruse (1999a) that was fitted to NMFS trawl survey data only, the new model was fitted to both NMFS trawl survey data from 1978 to 1999 and ADF&G pot survey data in 1995 and 1998. The additional data used in the new model are helpful for smoothing estimates of mature male crab abundance. Females are not modeled because too few are caught by the NMFS survey for analysis.

Because of extremely low survey abundance in 1999, poor in-season fishery performance in 1998, and low catch rates from the 1999 ADF&G near-shore pot survey, we suspect that natural mortality may have increased from 1998 to 1999. Because high natural mortality and survey measurement errors in a single year are confounded, we do not have information to estimate both simultaneously. To deal with this problem, we evaluated three different levels of natural mortality in 1999 (*M99*) by CSA and chose a level that produces a measurement error in 1999 comparable to those in the past. We assumed that *M99* was either: (1) the same, (2) three times as high, or (3) five times as high as mean *M* from 1978 to 1998.

Comparison of CSA and Area-swept Estimates

CSA estimates of abundance fitted well with NMFS survey area-swept estimates of abundance (Figure 1). Abundance of mature male legal crabs declined from the early 1980s to the mid-1980s and then increased and peaked in 1997. Compared to 1998, both mature and legal crab abundances showed substantial decline in 1999. CSA estimates of mature male abundance are lower than area-swept estimates in 1996-98 and higher in 1999.

Mortality assumption (2) results in a measurement error in 1999 comparable to the measurement errors from 1978 to 1998 (Figure 1). Assumption (3) fits the survey data best because it assumes high natural mortality and small measurement error, whereas assumption (1) fits the data poorest because it assumes constant natural mortality and high measurement error in 1999. Thus, we regard the results based on assumption (2) as the most likely scenario (base model) and used assumptions (1) and (3) for sensitivity analysis of alternative harvest strategies. Some model parameter values vary depending on these three different assumptions about *M99* (Table 2). Differences in parameter values among three scenarios are partially due to unavoidable confounding among parameters. Currently, we do not have additional data to solve the confounding problem. The high apparent natural mortality in 1999 will be re-estimated in the future when more survey data become available.

PROPOSED HARVEST STRATEGY

The proposed harvest strategy includes four components: a stock threshold, a minimum GHL, variable mature harvest rates, and a cap on legal male harvest rate. A stock abundance threshold was set to prevent against future instances of stock decline to "overfished" status. A minimum GHL was chosen because small GHLs are not manageable given the current size of the fishing fleet. A maximum legal harvest rate cap was set to prevent high removal rates of legal crabs when most mature males are sublegal size such as would be the case when a strong year class has yet to recruit to the fishery. The proposed strategy is closely based on NMFS technical guidance for implementing precautionary harvest strategies and rebuilding plans of Restrepo et al. (1998).

The four components of the proposed harvest strategy are:

(1) **Minimum stock threshold**: 2.9 million lbs of mature male (≥105 mm CL) biomass. This is 25% of the equivalent mature male biomass capable of producing maximum sustainable yield (B_{msy} for mature males = 11.6 million lbs).

(2) **Minimum GHL:** 2.5 million lbs.

(3) **Directed mature male harvest rates**:
  (iv) 0.0 when mature male biomass (*B*) <2.9 million lbs,
  (v) [(*B*-2.9)/8.7]*0.1+0.1 when 11.6> *B* ≥2.9 million lbs, and
  (vi) 0.2 when *B* ≥11.6 million lbs.

(4) **Cap of legal male harvest rate**: 0.4.

The proposed harvest strategy is illustrated in Figure 2. Application of the proposed harvest strategy to historical population abundance from 1978 to 1999 resulted in legal harvest rates generally less than the historical rates associated with the GHLs (Figure 3). All else being equal, the fishery would have been closed from 1984 to 1990 under the proposed harvest strategy due to the minimum GHL requirement in contrast to no historical closures during this period. However, GHL ranges were less than 2.5 million lbs during this period (Table 1), and these would not have been manageable anyway under the current fleet size; thus, the difference in fishery closures between proposed and historical harvest strategies are overstated in Figure 3. Also, because of lower harvest rates, the population abundance would have been higher under the proposed harvest strategy than the actual historical abundance, so the number of years with fishery closure might have been less than that indicated in Figure 3. That is, for purposes of Figure 3, we have not attempted to accumulate conservation benefits from the proposed strategy in one year in terms of improved stock conditions in the next year. We merely contrasted the proposed and the historical strategies given the historical stock assessment record.

EVALUATION OF ALTERNATIVE HARVEST STRATEGIES

Approach

The four-stage model was used in computer simulations to estimate rebuilding time periods and rebuilding probabilities for St. Matthew Island blue king crabs. Similar to the "rebuilt" definition for eastern Bering Sea Tanner crabs (*Chionoecetes bairdi*), we define the stock to be "rebuilt" when mature biomass achieves a level (B_{msy}) capable of producing maximum sustainable yield in two consecutive years. This "rebuilt" definition reduces chances of rebuilding caused by survey measurement errors or a single strong year class. Model parameters for simulations are summarized in Table 2. All parameter values in Table 2 are estimated from the assessment model and observer data except that natural mortality rates used in the simulations are 4% lower than those estimated in the assessment model. Natural mortality estimated from the assessment model includes bycatch mortality from the directed pot fishery. In the simulation model we modeled natural mortality and handling mortality separately, so M was reduced accordingly.

A stock-recruitment (S-R) relationship predicts likely recruitment of progeny from a given spawning stock size. Such a relationship can be created by density-dependent predation, cannibalism, and food or space limitation. Inability or difficulty to find mates at low densities can also result in a strong relationship at low spawning stock levels. The S-R relationship has important implications for harvest strategies. Unfortunately, because of lack of reliable female abundance data, we cannot establish an S-R relationship for St. Matthew Island blue king crabs right now. In our computer simulations, we have to model recruitment by randomly selecting the estimated male recruitment from the past, by assuming some sort of cycles in recruitment, or by assuming autocorrelation (i.e., that good year classes follow good ones, and bad year classes follow bad ones).

Recruitment to the model was assumed to enter the pre-recruit-2 size group. Based on a short time series from 1979 to 1999, model recruitment shows a semi-cyclic pattern with a low cycle for about 8 years (1981-88) and a period of high values for about 8 years (1989-96; Figure 4). This recruitment pattern is similar for the three assumptions of natural mortality in 1999, although the absolute values of recruitment are different under different assumptions because of association among natural mortality, catchability, and selectivity parameters (Figure 4 and Table 2).

The primary features of the simulation scenarios and options are as follows:

- The model was initialized with data on population status for 1999.

- Because of poor female data, only male crab data were used for stock assessment and simulation modeling. The current B_{msy} (22 million lbs, NPFMC 1998) is defined for both male and female blue king crabs. Based on the survey data from 1983 to 1997, we approximated the equivalent B_{msy} for mature male blue king crabs $\geq$105 mm CL as 11.6 million lbs.

- For each scenario and option, we simulated the population and fishery for 35 years with 1000 replicates. The average population status, rebuilding probability (the proportion of replicates at rebuilt status), loss of fishing opportunity (the proportion of replicates with fishery closure), and mean yield from the simulations were summarized to compare the alternative scenarios and options.

- Recruitment was modeled with three approaches: (1) random sampling from recruitment estimates from 1979 to 1999, (2) periodically semi-cyclic low recruitment (lasting randomly from 8 to 12 years) and high recruitment (lasting randomly from 6 to 10 years) with log-normally distributed noise, and (3) autocorrelated recruitment with recruitment equal to the mean level plus autocorrelated noise. We used assumption (1) as the base model and assumptions (2) and (3) for sensitivity studies.

- Handling mortality rate of captured, but discarded sublegal males was assumed to be 20% for the directed crab fishery. We also examined the sensitivities of the results to handling mortality rates of 0 and 50%.

- Because few St. Mathew Island blue king crabs were caught as bycatch from groundfish fisheries, no bycatch mortality from groundfish fisheries was included in the simulations.

- Standard deviation for log-normally distributed measurement error was assumed to be 0.2.

Four management options were compared in the simulations. We also examined the sensitivities of the results to minimum GHLs of 1.5 and 2.0 million lbs. The four management options are:

(1) No directed fishing mortality (i.e., the fishery is permanently closed).

(2) Proposed new harvest strategy described previously.

(3) Fixed mature harvest rate of 20% with a threshold of 2.9 million lbs of mature male biomass, a minimum GHL of 2.5 million lbs, and a legal harvest rate cap of 40%.

(4) Fixed mature harvest rate of 20% with a fishery threshold of 0.6 millions of mature male crabs (about 2 million lbs) and without a minimum GHL. This is the status quo strategy.

Results and Discussion

Simulated results are illustrated in Figure 5 and summarized in Table 3. With the base model, the rebuilding time periods at 50% probability are 5 years without a fishery (T_{min}), 6 years with the new harvest strategy (option 2), 7 years with the fixed mature harvest rate of 0.2 (option 3), and 12 years with the status quo strategy (option 4). The rebuilding time periods at 90% probability are 8 years without a fishery, 12 years with management option 2, and 25 years with management option 4. Because T_{min} is less than 10 years, the maximum rebuilding time period, T_{max}, should be 10 years (Restrepo et al. 1998). Due to the minimum GHL, the fishery might be closed about 40% or more of the time within a 20-year horizon. Management option 3 has slightly higher mean yield than management option 2, but option 2 is more precautionary. The status quo strategy has highest fishing opportunity, produces highest mean yield, and requires longest time to rebuild the stock. However, with the current large fishing fleet, it may not be possible to manage the fishery with small GHLs.

If the stock-recruitment relationship is density-dependent, the conservation benefits of management option 2 would be relatively higher than estimated because we assumed that recruitment is density-independent in this study. However, rebuilding time periods at 50% probability would not greatly be affected by the assumption of density-independent stock-recruitment relationship because any management actions taken now to protect the spawning stock will not have any effects on recruitment until 6 to 8 years later owing to the time from mating to recruitment. Unfortunately, data are not available to test for a stock-recruitment relationship for this crab stock.

Rebuilding time periods and probabilities also depend on assumptions on future recruitment, minimum GHL, and handling mortality rate (Table 3). As expected, at 50% rebuilding probability, rebuilding time periods are generally shortest for scenarios with randomly selected recruitment because recruitment has been high more than half of the time (Figure 4). Rebuilding time periods are longest for scenarios with autocorrelated recruitment because the stock recently entered a period of declining recruitment (Figure 4) and autocorrelation continues that trend. For high rebuilding probabilities, rebuilding time periods are shortest for scenarios with semi-cyclic recruitment because the cycle deterministically turns to high recruitment after a certain number of years. High minimum GHL shortens rebuilding time periods, increases the proportion of years with fishery closures, and decreases mean yield. Closing the fishery until the population is rebuilt considerably shortens time to rebuild with a high rebuilding probability. Assumptions about 1999 natural mortality slightly affect the rebuilding time periods, proportions of fishery closure, and mean yield.

Handling mortality rate for blue king crab bycatch from the directed fishery is not very well known. Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island is very high and total bycatches were often twice as high as or higher than total legal crab catch (Moore et al. 2000). In our study of the red king crab (*Paralithodes camtschaticus*) fishery in Bristol Bay, increased handling mortality in our model resulted in lower optimal harvest rates and higher optimal threshold levels (Zheng et al. 1997). For the Bristol Bay Tanner crab fishery, we found that handling mortality had similar, but less pronounced, effects because of low catchability for females (Zheng and Kruse 1999b). In this study, we considered two extreme handling mortality rates of 0 and 50% in our sensitivity analysis. Overall, higher handling mortality rates increase rebuilding time periods and decrease mean yield, but it appears that a handling mortality rate within our examined range does not greatly impact rebuilding time periods under the proposed harvest strategy.

Overall, under our base model, T_{min} is 5 years, and T_{max} is 10 years. If the current trend of poor recruitment continues as would be the case under the autocorrelated recruitment scenario, T_{min} will be 8 years, and T_{max} will still be 10 years. Either way, the target rebuilding time periods (T_{target}) with the new proposed harvest strategy are within these T_{min} and T_{max} bounds as required by the Magnuson-Stevens Fishery Conservation and Management Act.

CONCLUDING REMARKS

There is a great deal of uncertainty in St. Matthew Island blue king crab stock assessment. The current summer trawl survey cannot reach the shallow areas near the island, where a large majority of females and small males concentrate. Pot surveys can supplement trawl surveys by surveying the shallow areas, but so far only two comparable pot surveys were conducted. Development of the four-stage CSA to utilize more survey data helps improve abundance estimates but cannot eliminate the uncertainty. The current status of the St. Matthew Island blue king crab stock largely depends on the natural mortality in 1999. During the next two years, we should be able to determine the degree to which the sharp drop in abundance in 1999 is due to either survey measurement errors or high natural mortality. Based on low estimated recruitment to the model during the recent years, extremely low trawl survey abundance of all sizes and sexes in 1999, poor in-season fishery performance in 1998, and low catch rates from the ADF&G near-shore pot survey in 1999, the near-term outlook for this stock is not very promising.

The proposed harvest strategy aims to address many problems currently facing the management. First, it promotes stock rebuilding through reducing rebuilding time periods. Among likely scenarios, rebuilding time periods are considerably shorter with the proposed strategy than with the status quo strategy. Second, it takes a precautionary approach to fishery management by proportionally reducing harvest rates when abundance is below the long-term average and increasing the fishery threshold (Restrepo et al. 1998). When abundance is high, the proposed harvest strategy is identical to the status quo strategy. Finally, it takes into account manageability by imposing a minimum GHL. The minimum GHL not only ensures the manageability but also serves as a means to reduce harvest and bycatch when abundance is low. Due to high recruitment variation, uncertainty on stock assessment, and potentially occasional high natural mortality, it appears that no harvest strategy can completely prevent stock collapse, but a precautionary approach will reduce the chance of prolonged stock collapse.

The proposed harvest strategy does not address at least one issue mentioned in the section, Problems and Approaches: high bycatch of females and sublegal males in the directed fishery. In a separate report, potential gear modifications (escape rings) and area closures to protect females and sublegal males are proposed and evaluated as supplementary management options. Those measures, plus the proposed harvest strategy (this report), together constitute the complete proposed rebuilding plan.

ACKNOWLEDGMENTS

We thank Doug Pengilly, Wayne Donaldson, and Shareef Siddeek for their review comments. This paper is funded in part by cooperative agreement from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Table 1. Economic performance of the commercial blue king crab fishery in the St. Matthew Island Section of the Northern District of the Bering Sea, 1977-1999. Data are obtained from Wilson and Morrison (1999).

Year	Number of Vessels	Number of Pots Registered	Number of Pots Pulled	Catch per Pot Pulled	Season (days)	GHL (mill.lbs)	Catch[1] (mill.lbs)	Exvessel (mill.$)
77	10	NA	17370	16	40	NA	1.20	1.2
78	22	NA	43754	10	50	NA	1.98	1.9
79	18	NA	9877	5	40	NA	0.21	0.1
80[2]	NA	NA	NA	NA	50	NA	NA	NA
81	31	2960	58550	18	37	1.5-3.0	4.63	4.2
82	96	21894	165618	12	16	5.6	8.85	17.7
83	164	38000	133944	14	17	8.0	9.45	25.8
84	90	14800	73320	11	7	2.0-4.0	3.77	6.5
85	79	13000	51606	9	5	0.9-1.9	2.43	3.8
86	38	5600	22093	10	5	0.2-0.5	1.00	3.2
87	61	9370	28440	8	4	0.6-1.3	1.08	3.1
88	46	7780	10160	30	4	0.7-1.5	1.33	4.0
89	69	11983	30853	8	2.5	1.7	1.17	3.5
90	31	6000	26264	15	6	1.9	1.73	5.7
91	68	13100	37104	20	4	3.2	3.37	9.0
92	174	17400	56630	10	2.5	3.1	2.47	7.4
93	92	5895	58647	11	6	4.4	3.00	9.7
94	87	5685	60860	14	7	3.0	3.76	15.0
95	90	5970	48560	14	5	2.4	3.17	7.1
96	122	8010	91205	7	8	4.3	3.08	6.7
97	117	7650	81117	12	7	5.0	4.65	9.8
98	131	8561	89500	7	11	4.0	2.87	5.3
99	0	0	0	0	0	0	0	0

[1]Commercial catch includes deadloss.
[2]Data in 1980 are confidential.

Table 2. Parameters for a four-stage model used to estimate rebuilding time periods and probabilities through computer simulations for St. Matthew blue king crabs. All parameters are estimated from the assessment model and observer data except that natural mortality rates are 4% lower than those estimated in the assessment model.

Parameter	Natural Mortality in 1999 3**M*	1**M*	5**M*
Natural Mortality (*M*) during 1978-98	0.35	0.26	0.31
Trawl Catchability: Pre-recruit 2	0.38	0.53	0.41
Trawl Catchability: Pre-recruit 1	0.79	0.95	0.83
Trawl Catchability: Legals	1.00	1.00	1.00
Pot Selectivity: Pre-recruit 2	0.23	0.29	0.20
Pot Selectivity: Pre-recruit 1	0.61	0.71	0.58
Pot Selectivity: Legals	1.00	1.00	1.00
Molting Probability: Pre-recruit 2	1.00	1.00	1.00
Molting Probability: Pre-recruit 1	0.91	0.92	0.90
Autocorrelation Coefficient	0.70	0.70	0.70
Recruitment Deviate in 1999	-1.00	-1.00	-1.00
St. Dev. for Autocorrelated R	0.54	0.54	0.54
Low Recruitment Cycle Length (yr)	8-12	8-12	8-12
High Recruitment Cycle Length (yr)	6-10	6-10	6-10
Cycle Magnitude (ln scale)	0.82	0.82	0.82
St. Dev. for Cyclic Recruitment	0.28	0.28	0.28
St. Dev. for Mean Recruitment	0.24	0.24	0.24
Abundance in 1999 (millions of crabs)			
Pre-recruit 2	0.64	0.46	0.59
Pre-recruit 1	0.47	0.60	0.32
Recruits	0.41	0.63	0.27
Post-recruits	0.69	1.35	0.45

Parameters for Three Scenarios

	Mean W(lbs)	Growth Matrix: From Pre-recruit 2	Pre-recruit 1
Pre-recruit 2	1.47	0.11	0.00
Pre-recruit 1	2.33	0.83	0.11
Recruits	3.51	0.06	0.83
Post-recruits	4.83	0.00	0.06

Table 3. Comparisons of mean number of years required to achieve ≥10%, 50% and 90% rebuilding probabilities (RP) and mean proportions of years with fishery closure and mean annual yields (million lbs) within 5, 10 and 20 years after the year 1999 under four management options with different levels of GHL threshold (TH, million lbs) and different assumptions of recruitment dynamics, natural mortality in 1999 (*M99*), and handling mortality rates (HM). The first four rows in bold font are the results from the base model.

Scenarios				Years at RP ≥			Fishery Closure			Mean Annual Yield		
M99	TH	HM	Option	10%	50%	90%	5-yr	10-yr	20-yr	5-yr	10-yr	20-yr
Randomly Selected Recruitment												
3*M	**2.5**	**0.2**	**1**	**4**	**5**	**8**	**1**	**1**	**1**	**0**	**0**	**0**
3*M	**2.5**	**0.2**	**2**	**4**	**6**	**12**	**0.66**	**0.50**	**0.42**	**1.148**	**1.711**	**2.009**
3*M	**2.5**	**0.2**	**3**	**4**	**7**	**13**	**0.64**	**0.48**	**0.40**	**1.195**	**1.755**	**2.051**
3*M	**0**	**0.2**	**4**	**6**	**12**	**25**	**<0.01**	**<0.01**	**<0.01**	**1.953**	**2.275**	**2.478**
1*M	2.5	0.2	1	2	4	6	1	1	1	0	0	0
1*M	2.5	0.2	2	3	6	12	0.53	0.45	0.41	1.553	1.871	2.039
1*M	2.5	0.2	3	3	6	14	0.50	0.42	0.38	1.619	1.916	2.078
5*M	2.5	0.2	1	4	5	7	1	1	1	0	0	0
5*M	2.5	0.2	2	4	6	11	0.67	0.49	0.39	1.113	1.783	2.140
5*M	2.5	0.2	3	4	6	12	0.65	0.47	0.37	1.156	1.826	2.177
3*M	2.5	0.0	1	4	5	8	1	1	1	0	0	0
3*M	2.5	0.0	2	4	6	11	0.65	0.47	0.39	1.190	1.838	2.176
3*M	2.5	0.0	3	4	6	12	0.63	0.45	0.36	1.243	1.884	2.226
3*M	2.5	0.5	1	4	5	8	1	1	1	0	0	0
3*M	2.5	0.5	2	4	7	14	0.68	0.54	0.48	1.076	1.545	1.788
3*M	2.5	0.5	3	4	8	16	0.66	0.52	0.45	1.119	1.582	1.824
3*M	1.5	0.2	1	4	5	8	1	1	1	0	0	0
3*M	1.5	0.2	2	4	8	17	0.42	0.27	0.20	1.481	1.984	2.256
3*M	1.5	0.2	3	4	9	20	0.30	0.18	0.11	1.669	2.122	2.375
3*M	2.0	0.2	1	4	5	8	1	1	1	0	0	0
3*M	2.0	0.2	2	4	7	14	0.56	0.40	0.32	1.310	1.855	2.144
3*M	2.0	0.2	3	4	8	17	0.49	0.33	0.25	1.452	1.972	2.250
Semi-cyclic Recruitment												
3*M	2.5	0.2	1	6	7	8	1	1	1	0	0	0
3*M	2.5	0.2	2	7	8	9	0.93	0.53	0.46	0.221	1.758	1.999
3*M	2.5	0.2	3	7	8	9	0.90	0.51	0.44	0.281	1.789	2.033
3*M	0	0.2	4	8	9	11	<0.01	<0.01	<0.01	1.325	2.226	2.496
Autocorrelated Recruitment												
3*M	2.5	0.2	1	5	8	15	1	1	1	0	0	0
3*M	2.5	0.2	2	5	10	22	0.84	0.67	0.54	0.536	1.311	1.911
3*M	2.5	0.2	3	5	10	23	0.83	0.65	0.52	0.570	1.344	1.943
3*M	0	0.2	4	6	13	32	0.01	0.01	0.01	1.502	1.999	2.468

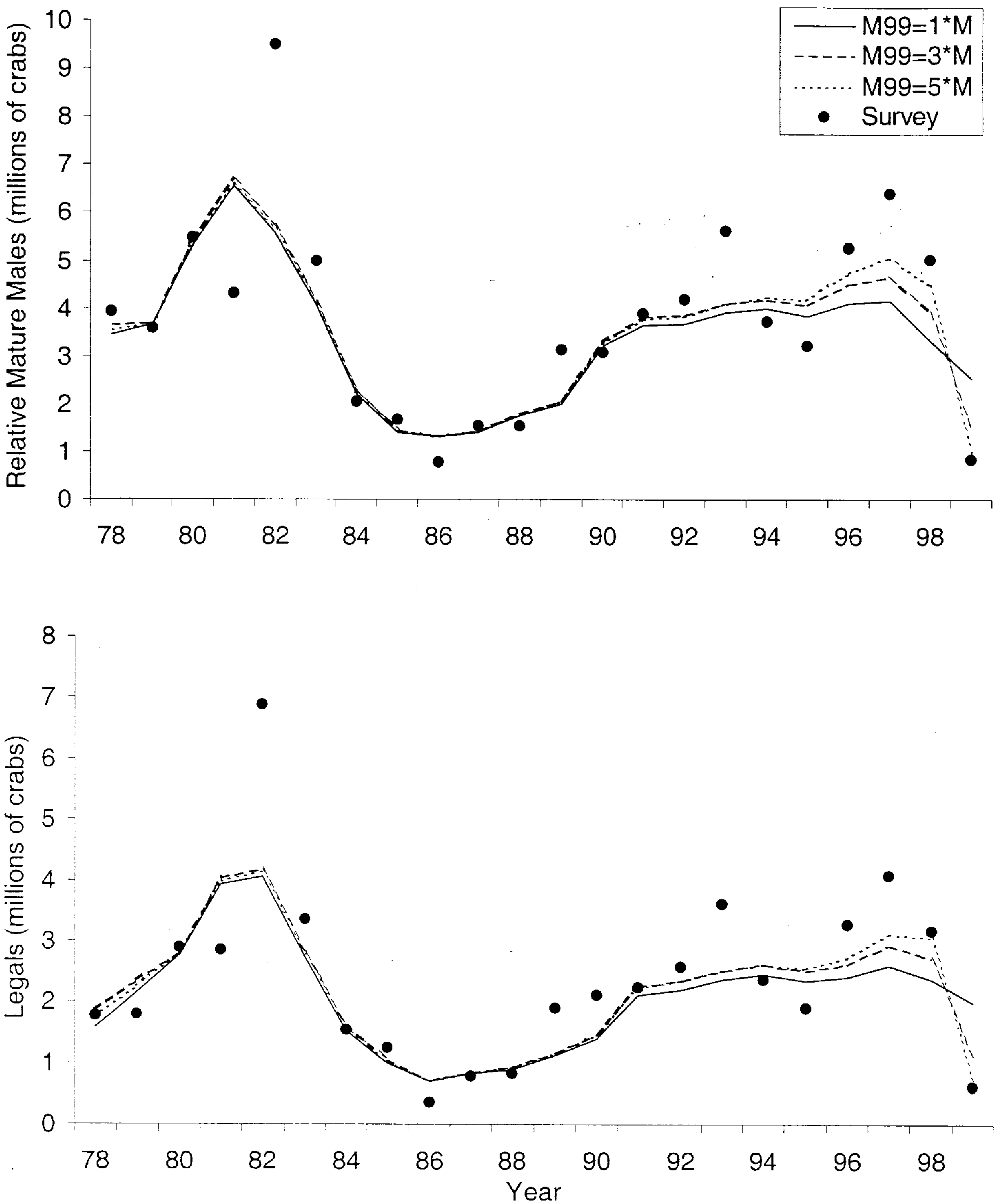

Figure 1. Comparison of abundance estimates of St. Matthew mature (top panel) and legal (bottom panel) male blue king crabs from area-swept estimates and catch-survey analysis. Three assumptions were made for natural mortality in 1999 (*M99*).

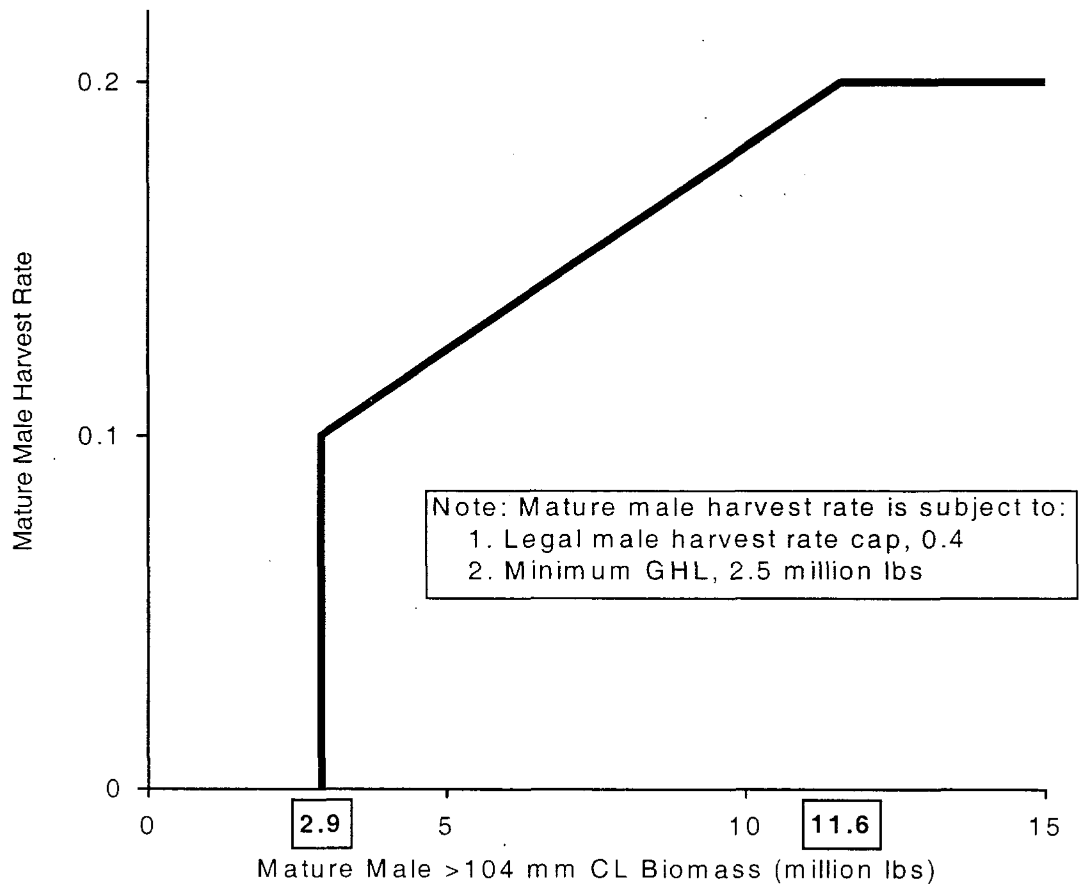

Figure 2. The proposed new harvest strategy for the St. Matthew blue king crab stock.

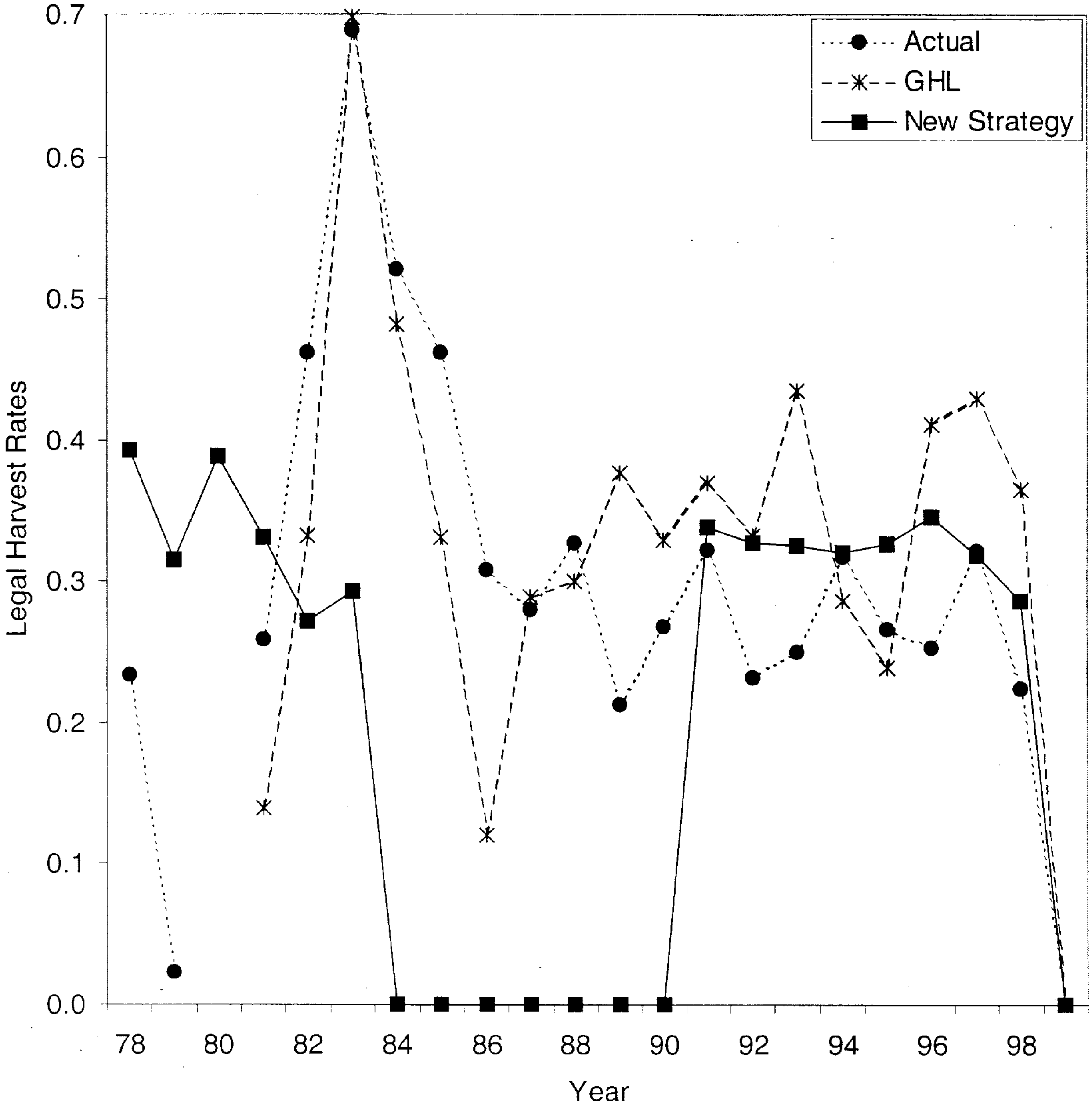

Figure 3. Comparison of historical (GHL midpoint and actual) legal harvest rates and legal harvest rates resulting from the proposed new harvest strategy from 1978 to 1999 for St. Matthew blue king crabs. Male abundance was estimated by a four-stage catch-survey analysis with natural mortality in 1999 being three times as high as the mean value from 1978 to 1998. Because of lower harvest rates, the population abundance would have been higher under the proposed harvest strategy than the historical abundance, so the number of years with fishery closure might have been less than indicated in this figure.

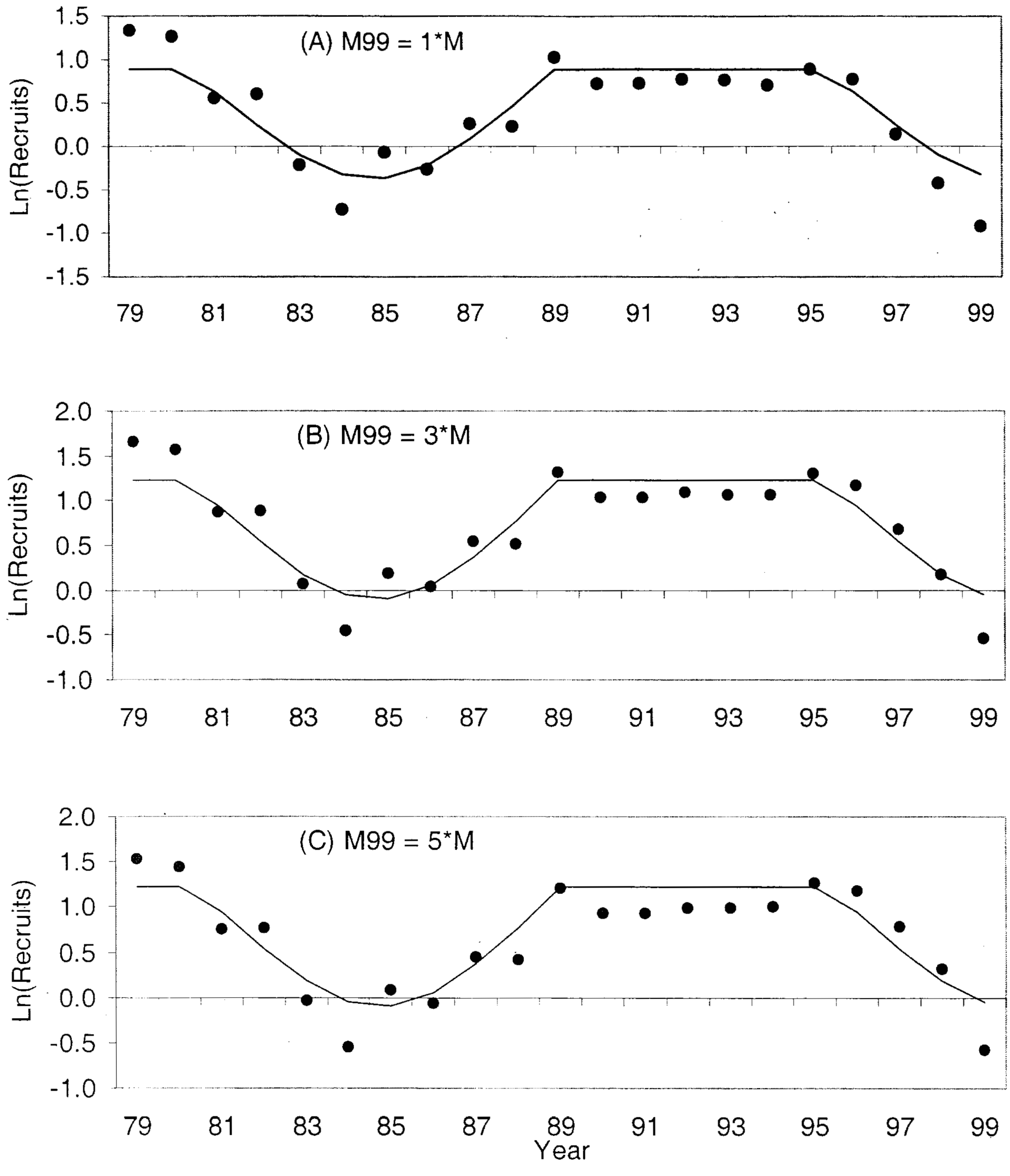

Figure 4. Logarithm of male recruitment to the model and the fit of semi-cyclic recruitment. Year is year of recruitment to the model as pre-recruit-2 males. Recruitment was estimated by a four-stage catch-survey analysis with three assumptions of instantaneous natural mortality in 1999 (*M99*) shown in panels A, B, and C.

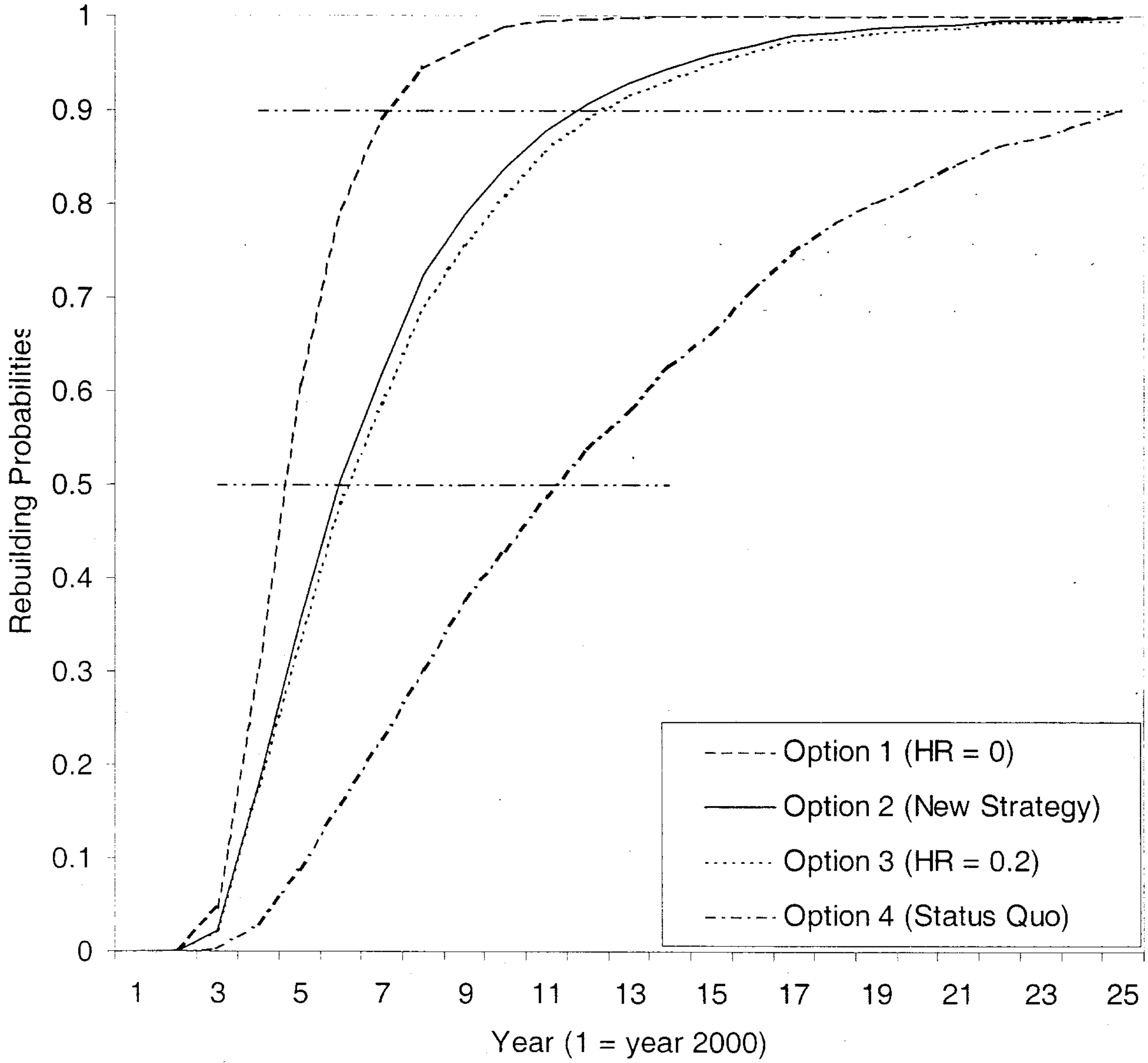

Figure 5. Estimated rebuilding probabilities for four harvest strategy options under the assumption of randomly selected recruitment for St. Matthew blue king crabs. Parameters used in the simulations were estimated with an assumption that natural mortality in 1999 was three times as high as the mean from 1978 to 1998. Year 1 corresponds to 2000.