A Bayesian stock assessment of lake whitefish (*Coregonus clupeaformis*) in Lake Huron and evaluation of total allowable catch options for 2007 Saugeen Ojibway Nations commercial harvest

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DRAFT

William Harford
Nawash Fisheries Assessment Biologist
nawash.fisheries@gmail.com

David Latremouille
Saugeen Fisheries Assessment Biologist
dlatremouille@saugeenfirstnation.ca

&

Stephen Crawford
Nawash Fisheries Management Biologist
Department of Integrative Biology, University of Guelph
Guelph, Ontario, N1G 2W1
scrawfor@uoguelph.ca

Report prepared for:

Chippewas of Nawash Unceded First Nation
R.R. #5, Wiarton, Ontario, Canada N0H 2T0

&

Saugeen First Nation
R.R. #1 Southampton Ontario, Canada N0H 2L0

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1 INTRODUCTION

This is the fourth technical report prepared by Saugeen Ojibway fisheries biologists and colleagues, regarding the biological condition of lake whitefish (*Coregonus clupeaformis*) populations supporting the Saugeen Ojibway Nations fisheries harvests. The first report (Crawford and Muir 2001) focused on key ecological uncertainties regarding (1) the discrimination of lake whitefish population(s) in Lake Huron, (2) the dynamics of the commercial fishing fleet, and (3) a simple model designed to assess regions of risk in the surplus production space defined by the commercial fishery data. The second report (Crawford et al. 2003) introduced the concepts of Decision Analysis-Adaptive Management (DAAM) as developed for the Saugeen Ojibway / Ontario MNR Plenary by Prof. Mike Jones (Michigan State University) and Prof. Tom Nudds (University of Guelph). The third report (Harford et al. 2006) focused on (1) the implementation of state-space surplus production models, (2) review of trends in biological samples drawn from commercial harvest and (3) identification of key uncertainties related to population distribution of lake whitefish.

The goal of this technical report is to build on previous technical evaluations to provide Saugeen Ojibway Nations Joint Council with the best available information with which to consider options for 2007 Total Allowable Catches (TACs) for their commercial fisheries. To achieve this goal, we have identified four specific objectives:

1. Describe general trends in commercial effort, harvest and CPUE (catch per unit effort);
2. Compile basic information on trends in biological samples drawn from the commercial harvest;
3. Incorporate parameter uncertainty in surplus production models by utilizing a Bayesian stock assessment framework; and,
4. Conduct a formal risks analysis for alternative TAC options for lake whitefish populations in Georgian Bay, Lake Huron.

The traditional waters of the Saugeen Ojibway represent approximately 10,600 square kilometers in surface area and cover the eastern main basin of Lake Huron extending to the Canada-United States border and the western half of Georgian Bay. During the 19th century, the Saugeen Ojibway were signatories to various treaties with the British Crown, including the 1836 Surrender of Southern Saugeen & Nawash Territories (Treaty No. 45 ½) and the 1854 Surrender of the Saugeen (Bruce) Peninsula (Treaty No. 72). However, the Saugeen Ojibway never surrendered their traditional waters (1847 Declaration of Queen Victoria), or their right to fish for food, ceremony or commerce, or their right to manage their own fisheries. This right was recognized in the *R v Jones-Nadjiwon* (1993) decision, and resulted in an agreement between the Saugeen Ojibway, the Ontario Ministry of Natural Resources and the Canadian Department of Indian Affairs to co-manage commercial fishing activity in the traditional waters.

Commercial assessment of the non-native fishery began in 1979 and assessments of the Saugeen Ojibway fishery began in 1995. The Saugeen Ojibway lake whitefish fishery is harvested entirely with gillnets. Management of this fishery requires decision-making in the face of considerable uncertainty about the abundance and biology of lake whitefish populations. In addition, Lake Huron lake whitefish fisheries have the potential for considerable economic growth under appropriate management policies (Tsiplova 2007).

The management issues faced by the Saugeen Ojibway fishery are consistent with those associated with developing fisheries (McAllister and Kirkwood 1998b, Walters 1998). A primary challenge is gaining an understanding of population dynamics, developing appropriate structural models and evaluating those models with suitable statistical methods (Walters 1998, Chen and Hunter 2003). Bayesian methods are particularly advantageous for developing fisheries where information about population dynamics and key population parameters are relatively limited (McAllister and Kirkwood 1998b). Bayesian approaches have recently been promoted for quantitatively considering uncertainty in stock assessments and risk analysis (Punt and Hilborn 1997, McAllister and Kirkwood 1998a, Harwood and Stokes 2003). Bayesian methods allow uncertainties about population parameters to be incorporated in the form of prior distributions, based on synthesis of existing information from commercial catch data and from similar fish populations (Ellison 1996, Hilborn and Liermann 1998). Bayesian methods are valuable for decision making under uncertainty because they combine the processes of accounting for uncertainty in parameter estimation with predicting the consequences of alternative management actions.

We applied a Bayesian approach for evaluating the consequences of alternative Total Allowable Catch (TAC) options for Saugeen Ojibway commercial harvests of lake whitefish in Georgian Bay, Lake Huron. Our analysis focused on addressing uncertainties in the specification of key population parameters for a Schaefer surplus production model. We used a relatively simple model of biomass dynamics to guide the development of future assessment procedures and as a precursor to research investigating structural model complexity (e.g. Punt and Smith 1999) and the associated justifications and trade-offs between the cost and value of additional research and fisheries-independent surveys (Walters 1998).

2 NAWASH FISHERIES MANAGEMENT REGIONS

The spatio-temporal distribution of whitefish that support the commercial harvests of the Saugeen Ojibway has been recognized as a key uncertainty in previous TAC reports prepared by the Chippewas of Nawash (Crawford et al. 2001; Crawford et al. 2003). Here we reiterate the importance of addressing this uncertainty by employing principles of decision analysis and adaptive management For the purpose of this report we considered the hypothesized distribution of whitefish populations at two spatial scales (Figures 2.1 and 2.2):

1. Basin
    - **“Main Basin”**, which is spatially equivalent to the Canadian waters of the Main Basin hypothesis
    - **“Georgian Bay”,** which is spatially equivalent to the Georgian Bay hypothesis
2. Region
    - **“Main Basin East”,** which is roughly spatially equivalent to the Western Bruce Peninsula hypothesis
    - **“Main Basin South”,** which is roughly equivalent to the Canadian waters of the Southwestern Main Basin hypothesis.
    - **“Main Basin South East”** (sometimes referred to as “Main Basin South + East”).

- **"Georgian Bay West",** for which there is considerable uncertainty, and very little empirical evidence, about the spatial extent of this hypothesized population.
- **"Georgian Bay South",** which is roughly spatially equivalent to the Southern Georgian Bay hypothesis.

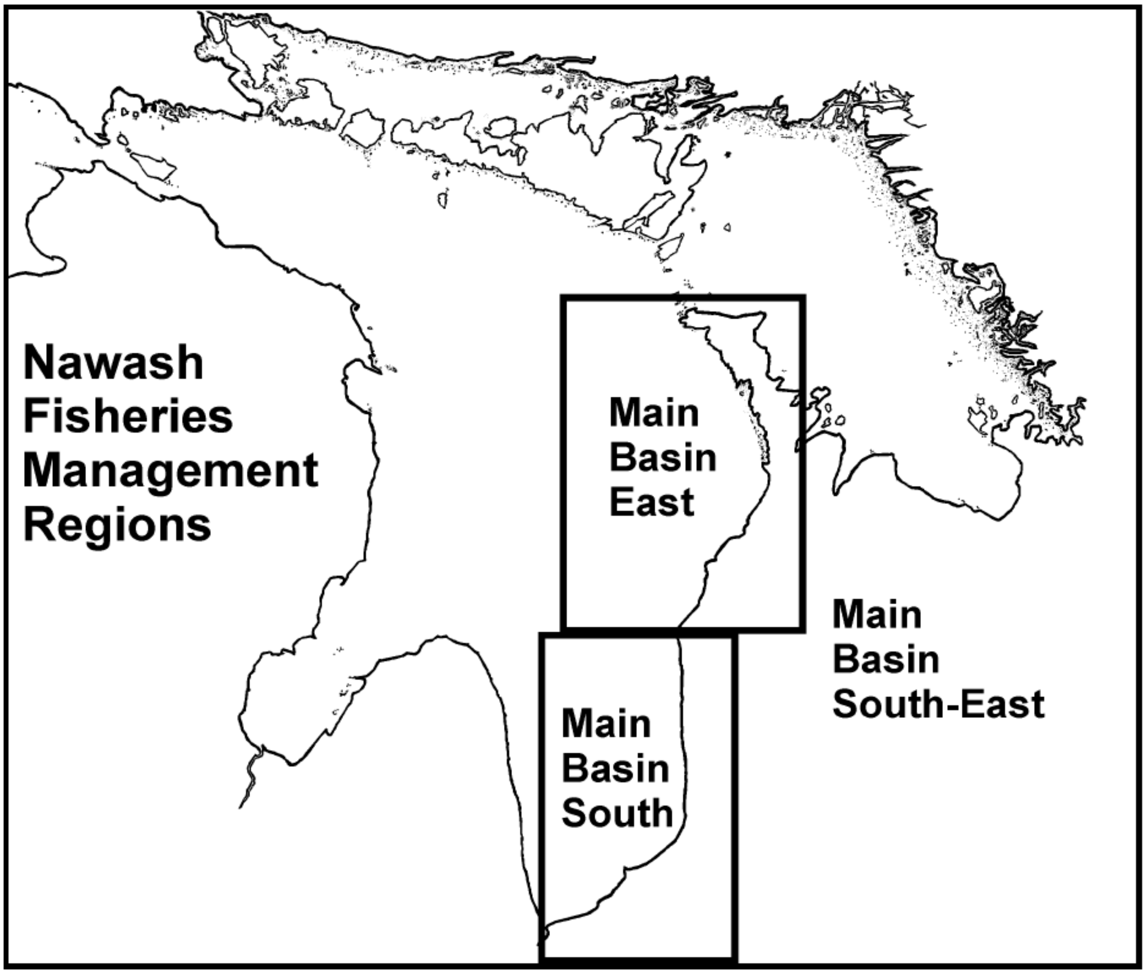


Figure 2.1. Map of Lake Huron showing the general regions in the Main Basin used by The Chippewas of Nawash Unceded First Nation as hypothesized lake whitefish populations, based on the available evidence. Due to great uncertainties regarding the spatio-temporal behaviour of lake whitefish in southern Main Basin, the region Main Basin South-East will be analysed separately from the two sub regions Main Basin East and Main Basin South.

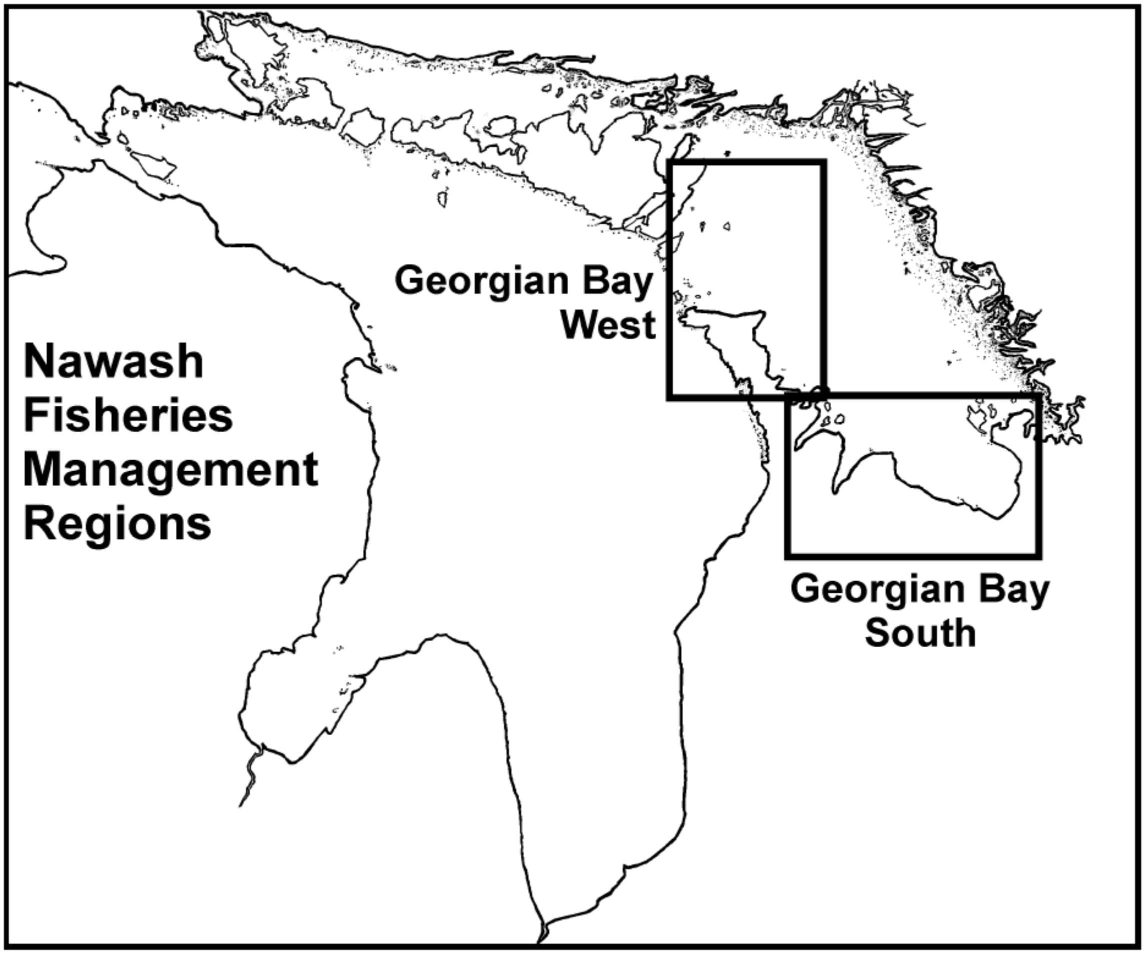


Figure 2.2. Map of Lake Huron showing the general regions in Georgian Bay used by The Chippewas of Nawash Unceded First Nation as hypothesized lake whitefish populations, based on the available evidence.

3 COMMERCIAL HARVEST AND CPUE

3.1 Main Basin

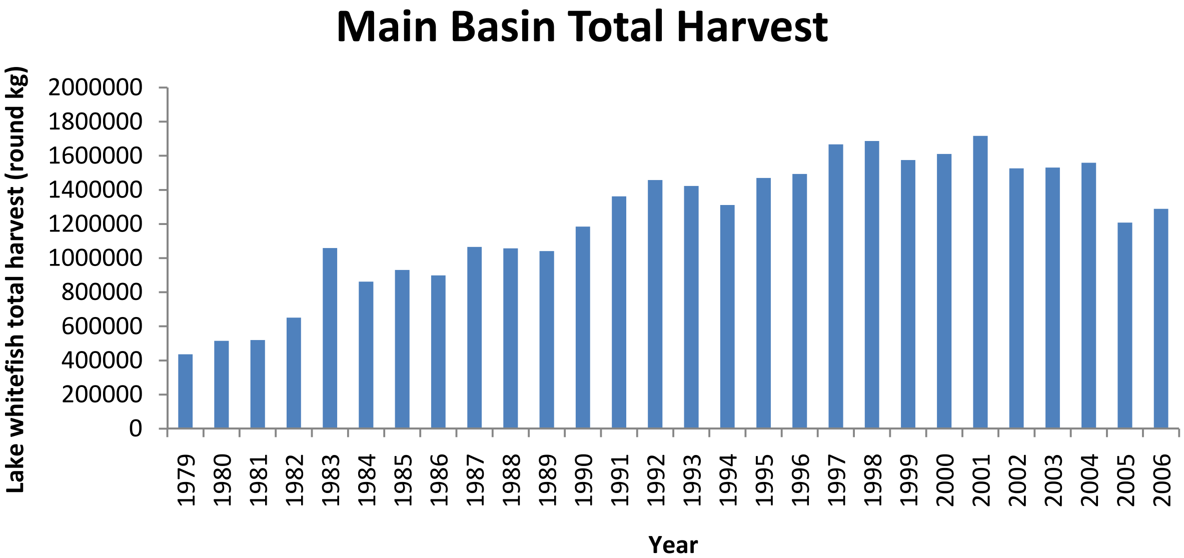


Figure 3.1 Examination of total harvest levels of Lake Whitefish in round kilograms (rkgs) for the entirety of the Canadian waters of Main Basin of Lake Huron for 1979 to 2006. Generally, total harvest levels have been increasing over the time frame examined. Overall, harvest levels steadily increased from 1979 to 2001, and then gradually declined thereafter.

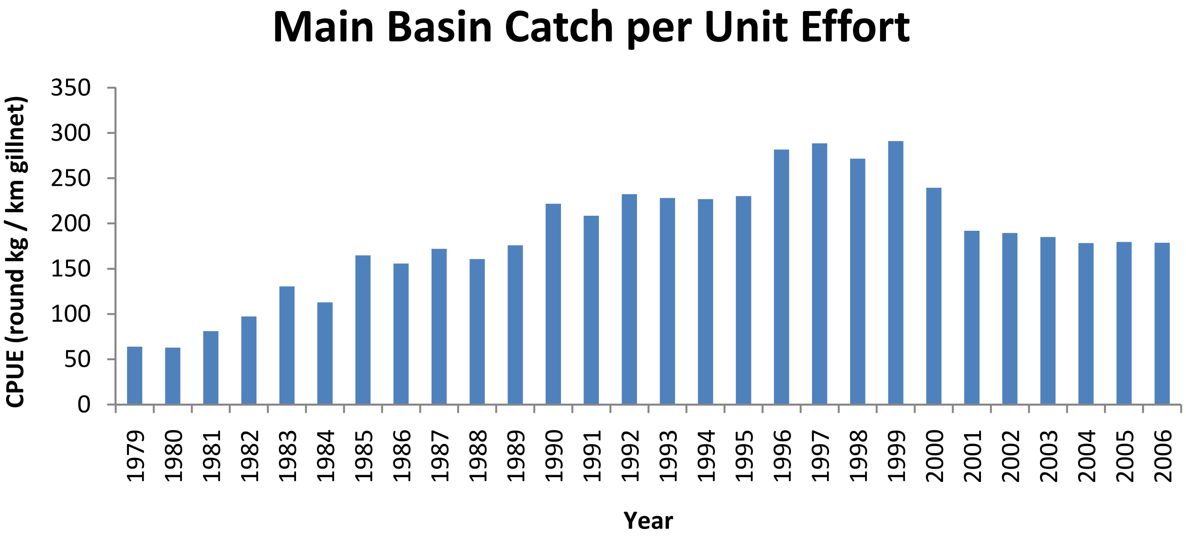


Figure 3.2 Examination of Catch per Unit Effort (rkgs/km of net) for the entirety of the Canadian waters of the Main Basin of Lake Huron for 1979 to 2006. Generally the Catch per Unit Effort steadily increased from 1979 to 1999, and then declined until 2003 and essentially hovered around the same level thereafter until 2006.

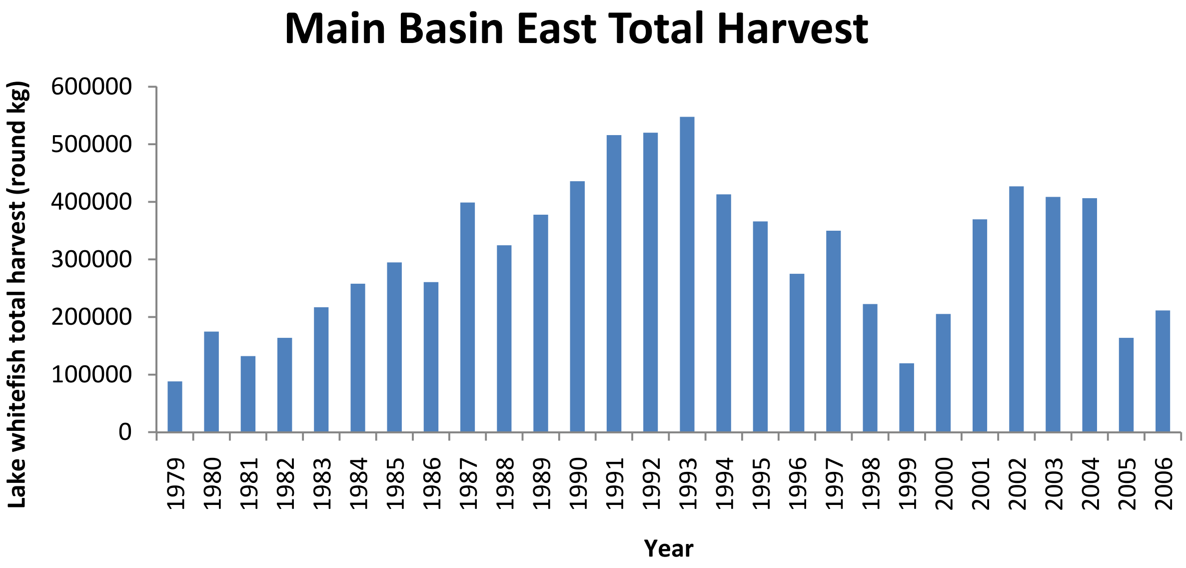


Figure 3.3 Examination of total harvest levels of Lake Whitefish in round kilograms (rkgs) in Main Basin East of Lake Huron for 1979 to 2006. In this case total harvest levels fluctuate between periods of increase and decrease. Harvest levels increase from 1979 to 1993, then decrease from 1994 to 1999. Increase in harvest level is seen again from 2000 to 2004, and then decreases throughout 2005 and 2006.

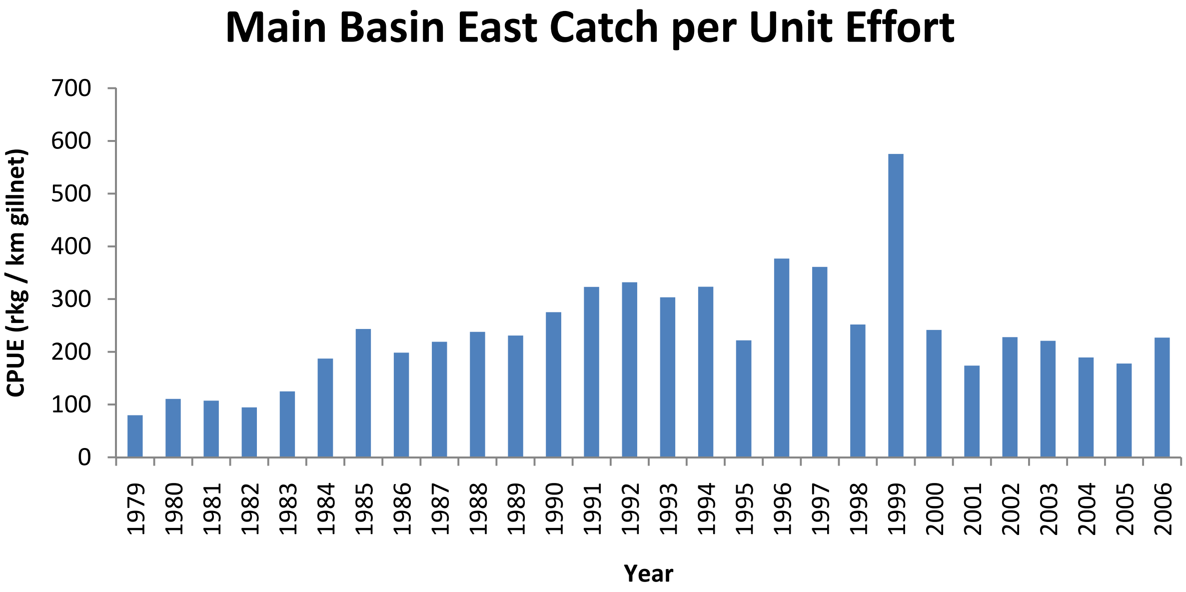


Figure 3.4 Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) in Main Basin East of Lake Huron for 1979 to 2006. As a general trend, catch per unit effort increases from 1979 to 1999, and then declines thereafter.

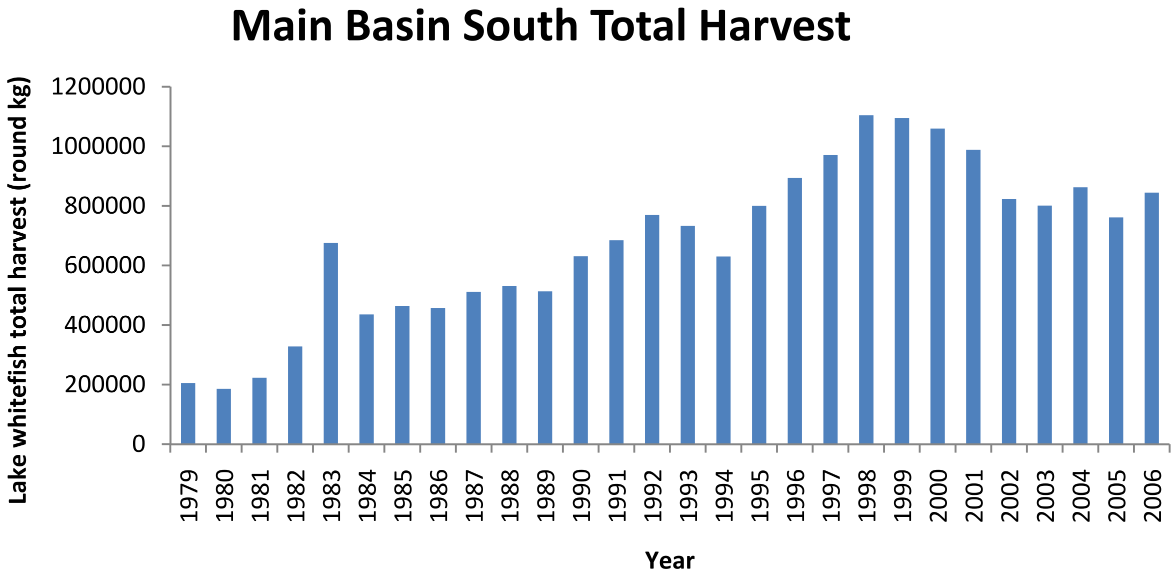


Figure 3.5 Examination of total harvest of Lake Whitefish in Main Basin South of Lake Huron in round kilograms (rkgs). As a general trend total harvest increases until 1999 then declines thereafter to 2006.

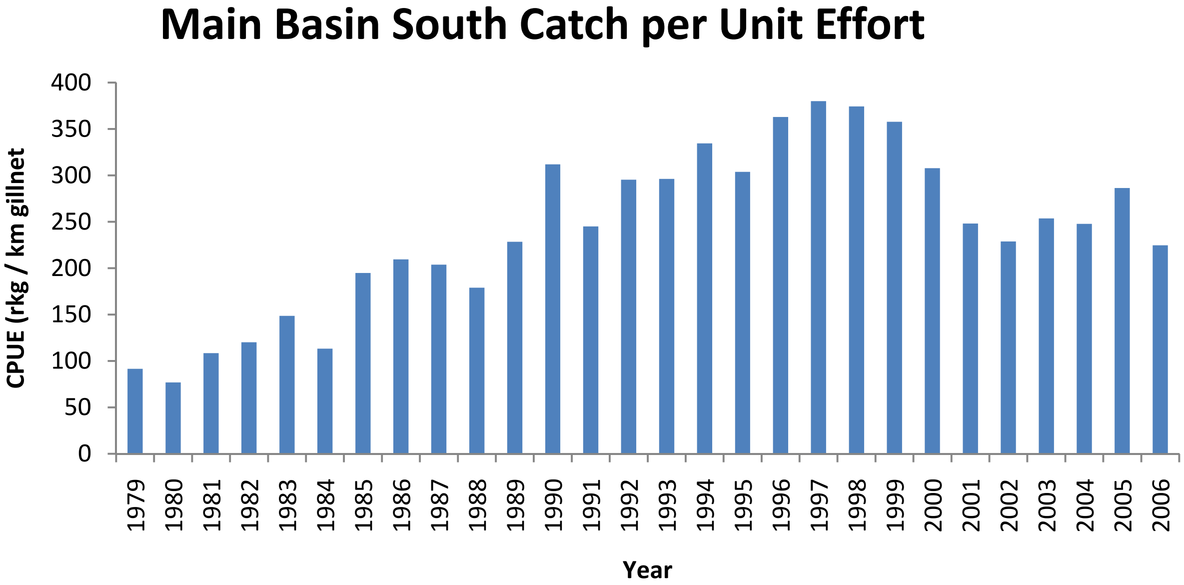


Figure 3.6 – Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) for Main basin South of Lake Huron. Generally, Catch per Unit Effort increases from 1979 to 1999, declines from 2000 to 2003, then moderately increases through 2004 and 2005, followed a slight decrease in 2006.

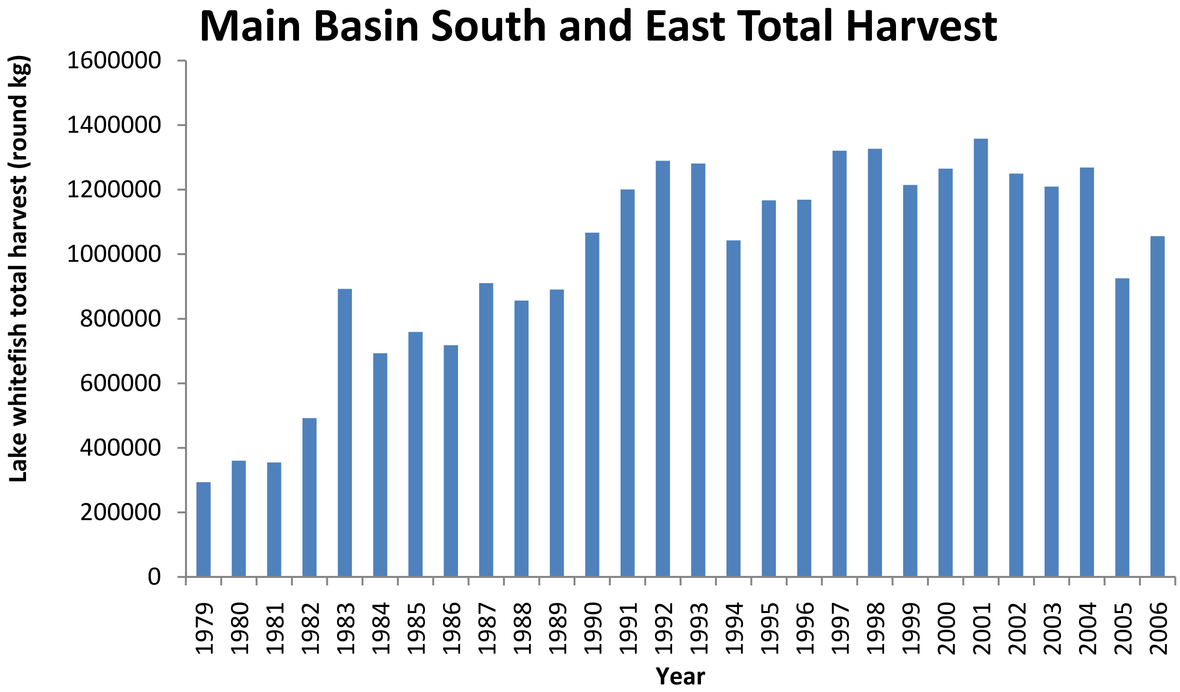


Figure 3.7 Examination of total harvest of Lake Whitefish in round kilograms from Main Basin South and East of Lake Huron's Canadian waters. Total harvest generally increases from 1979 to 1999 then declines thereafter.

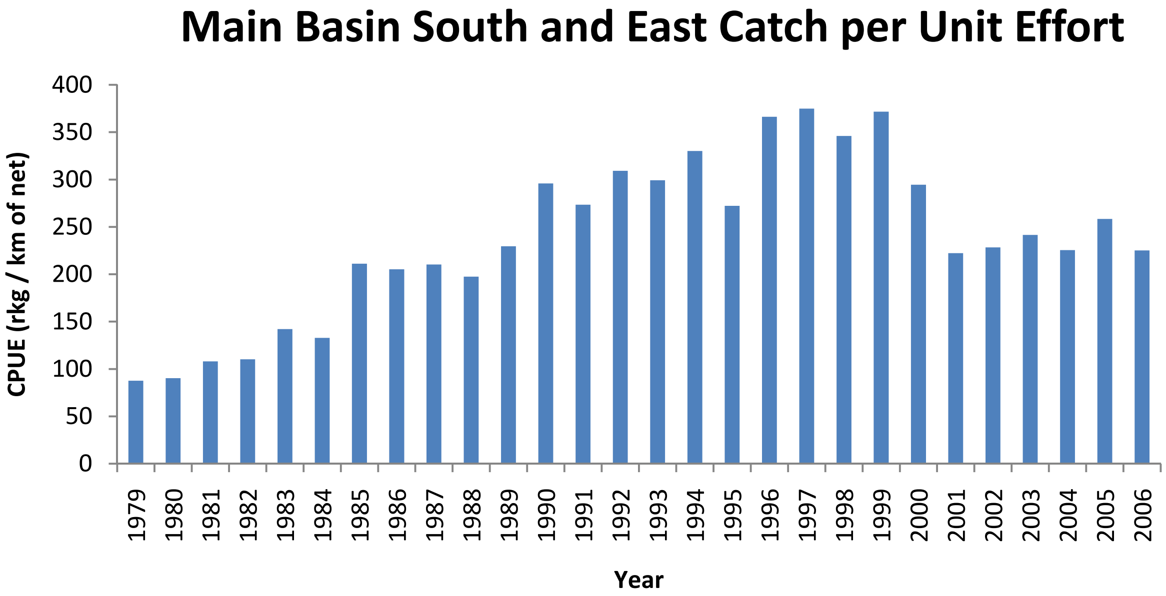


Figure 3.8 Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) for Main Basin South and East of Lake Huron's Canadian waters. As a general trend catch per unit effort increases from 1979 to 1999 then declines thereafter.

3.2 Georgian Bay

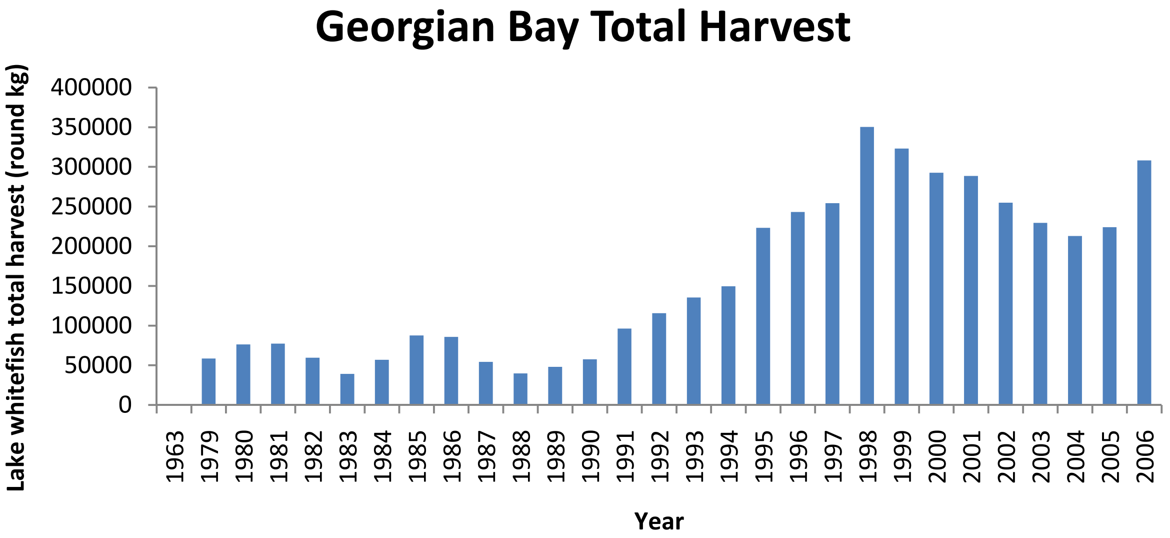


Figure 3.9 Examination of total harvest of Lake Whitefish in round kilograms from the entirety of Georgian Bay for 1963 to 2006. It should be noted that there were no commercial fishing records for the region from 1964 to 1970, thus there are no analyses for this time period. In this case the level of total harvest undergoes alternating periods of increase and decrease. From 1979 to 1998 a relatively steady increase in harvest is seen. From 1999 to 2004 a steady decline in harvest is witnessed. Total harvest again increases in 2005 and 2006 over previous levels.

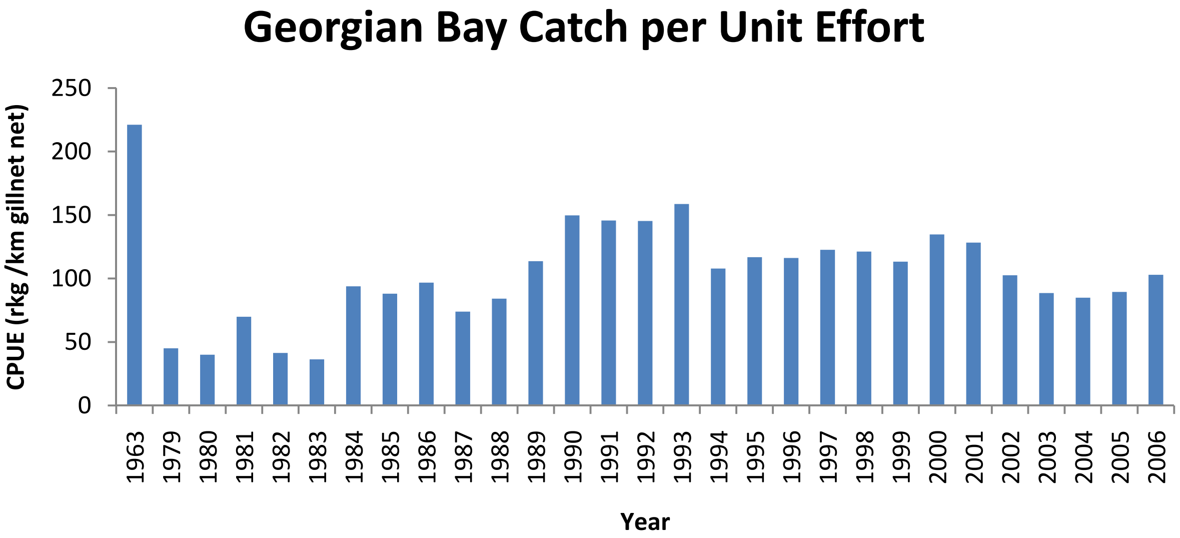


Figure 3.10 Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) for the entirety of Georgian Bay from 1963 to 2006. It should be noted that there were no commercial fishing records for the region from 1964 to 1970, thus there are no analyses for this time period. From 1979 to 1993 a relatively steady increase in CPUE is seen. From 1994 to 1999 a decline in CPUE is seen. An increase is seen again in 2000 and 2001, followed a gradual decrease in 2002 through 2005. CPUE then increases again in 2006.

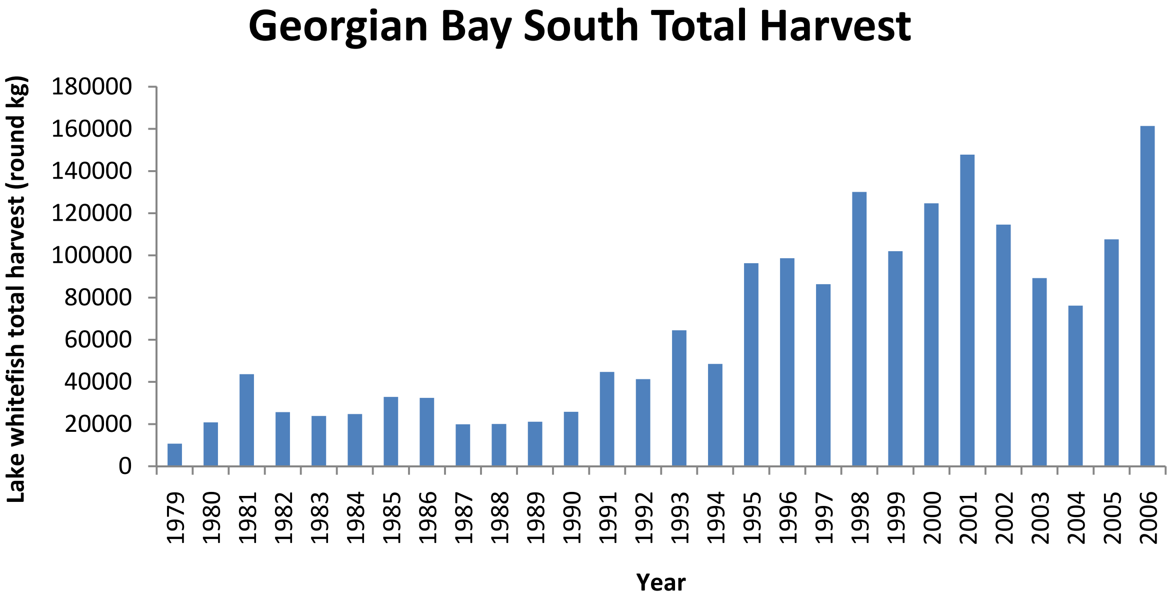


Figure 3.11 Examination of total harvest of Lake Whitefish in round kilograms for Georgian Bay South from 1979 to 2006. Periods of both increase and decrease are seen. A general increase is seen in the time period of 1979 to 2001, followed by a decrease from 2002 to 2004. A gradual increase is seen again in 2005 and 2006.

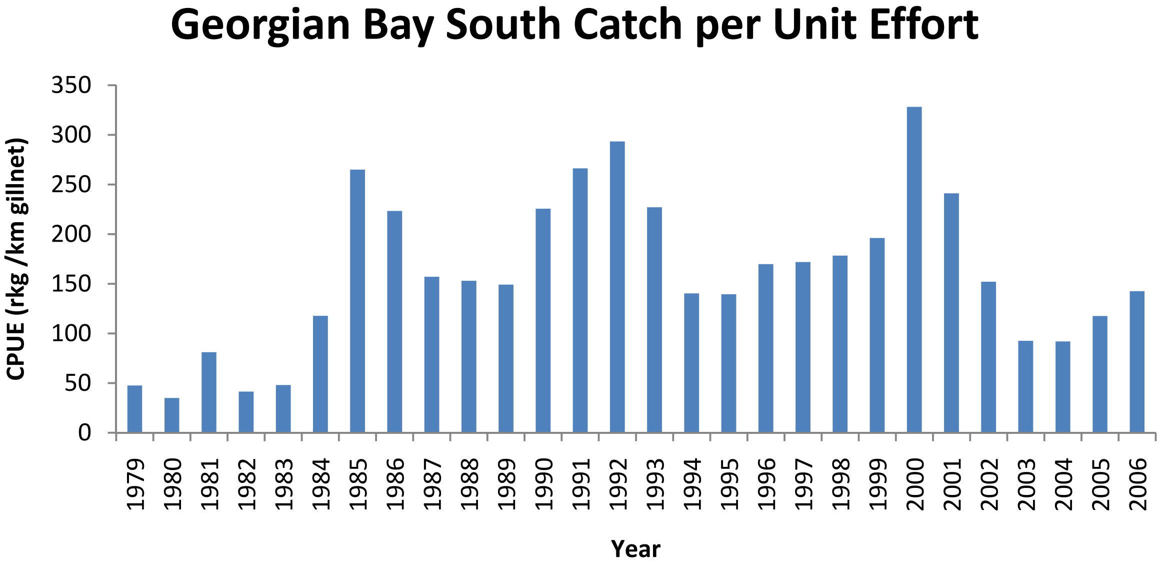


Figure 3.12 Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) for Georgian Bay South for 1979 to 2006. The distribution for Georgian Bay South is characterized by various periods of increase and decrease. From 1979 to 1985 an increase in CPUE is seen, followed by a decrease from 1986 to 1989. Another increase is seen from 1990 to 1992, with the next decrease from 1993 to 1995. The next period is characterized by an increase from 1996 to 2000, with CPUE decreasing from 2001 to 2003, and then increasing again from 2004 through to 2006.

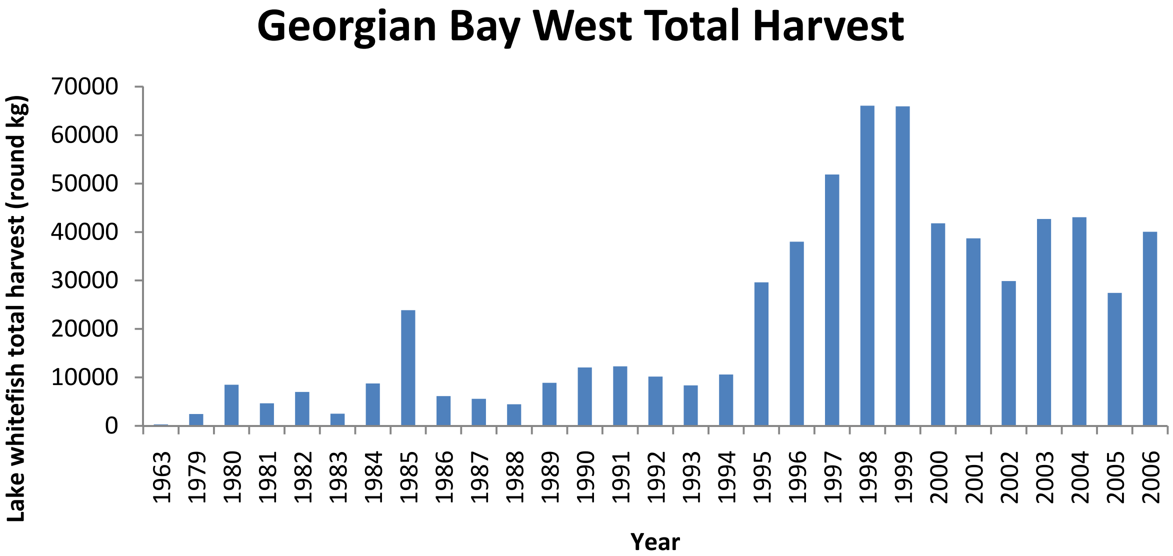


Figure 3.13 Examination of total Lake Whitefish harvest in round kilograms from Georgian Bay West for 1963 to 2006. It should be noted that there were no commercial fishing records for the region from 1964 to 1970, thus there are no analyses for this time period. In terms of a general trend harvest levels have generally increased from 1979 to 1998 and then decreased thereafter. From 1999 onward harvest levels decreased to about three quarters of the highest levels seen in Georgian Bay West in 1997 and 1998.

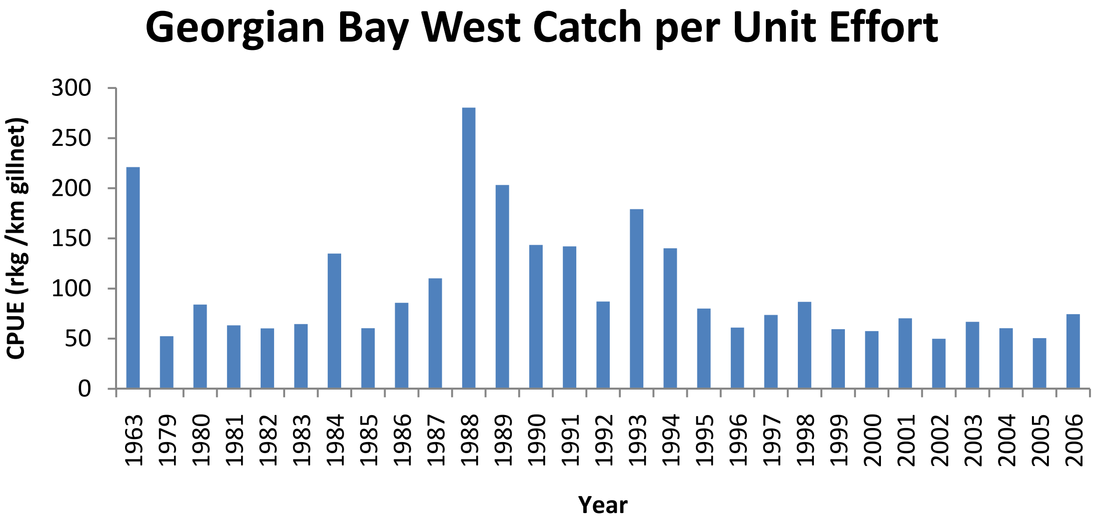


Figure 3.14 Examination of Catch per Unit Effort (CPUE) (rkgs/km of net) for Georgian Bay West for 1963 to 2006. It should be noted that there were no commercial fishing records for the region from 1964 to 1970, thus there are no analyses for this time period. From 1979 to 1988 a gradual increase in CPUE is seen. From 1989 through to 2006 CPUE declines.

4 SURPLUS PRODUCTION MODELLING

4.1 Methods

4.1.1 *Bayesian framework for evaluating total allowable catch options*

Pervasive uncertainties in stock assessments are most explicitly addressed in decision-making by representing uncertainties as alternative hypotheses, and determining the relative weight of evidence (probability) in support of each hypothesis (Punt and Hilborn 1997, Peterman and Anderson 1999). Assessment of Georgian Bay lake whitefish began with first identifying key ecological uncertainties and alternative hypotheses representing each uncertainty. Key uncertainties regarding the assessment of Georgian Bay lake whitefish are:

i. Population distribution uncertainty, which arises from the cryptic nature of population structure of continuously distributed species (Taylor and Dizon 1999, Martien and Taylor 2003) and when information among sources is inconsistent or complex;
ii. Structural model uncertainty resulting from an incomplete understanding population dynamics (Punt and Hilborn 1997, Punt and Smith 1999, Harwood and Stokes 2003);
iii. Process error inherent in annual biomass dynamics resulting from demographic and environmental variation (Harwood and Stokes 2003, Peterman 2004);
iv. Observation error, which consists of measurement error and sampling error and is a consequence of the inaccuracy and imprecision of observations (Mace and Sissenwine 2002, Harwood and Stokes 2003);
v. Parameter specification uncertainty due to poor understanding of population dynamics.

Population distribution uncertainty was addressed qualitatively, due to a lack of probability weightings associated with each hypothesized population distribution. Stock assessments and risk analyses were conducted according to two hypothesized population distributions: (i) a single Georgian Bay Population; and, (ii) two distinct populations with at least partial overlap with the Traditional Waters of the Saugeen Obijway, referred to as Georgian Bay West (GB-W) and Georgian Bay South (GB-S).

We resolved to thoroughly investigate the benefits and limitations of a simple surplus production model of population dynamics before considering more complex structural models. The Shaefer surplus production function formed the basis of the operating model:

$$B_t = B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1} \qquad (1)$$

where t is the year, B is population biomass, r is the intrinsic rate of increase, K is the carrying capacity and C is catch biomass. Annual catch is treated as a fixed constant. The observation equation was an index of relative biomass based on CPUE:

$$I_t = qB_t \qquad (2)$$

where is I_t is CPUE calculated as the total catch (round kg) divided by the total fishing effort (kilometres of gillnet) and q is the catchability coefficient.

A Bayesian state-space model was used to incorporate process error (σ^2) and observation error (τ^2) in fitting the stock assessment model. State-space models provide a suitable framework for incorporating both types of stochasticity. A full description of methods for implementing a

Bayesian state-space surplus production model is described by Meyer and Millar (1999b) and Millar and Meyer (2000). Briefly, state-space models relate time series observations (observed CPUE from commercial harvest) to unobserved states (B_t) by a stochastic observation model for I_t given B_t (Meyer and Millar 1999a). Deterministic versions of the state and observation equations are shown in equations 1 and 2, respectively. Annual biomass estimates are treated as unknown states and process error was explicitly incorporated in the population dynamics through specification of their conditional distribution given previous states, unknown model parameter and observed total annual harvest (Meyer and Millar 1999a). To aid in model implementation, biomass was re-parameterized as a proportion of carrying capacity ($P_t = B_t/K$), as recommended by Millar and Meyer (2000). Further, catch observations, carrying capacity and biomass expressed in thousands of kilograms.

Computationally intensive methods associated with Bayesian statistical inference were employed using WinBUGS (Bayesian inference Using Gibbs Sampler) software. Complete statistical methodology for implementing Bayesian state-space models using WinBUGS is presented in Meyer and Millar (1999b) and Lunn et al. (2000). Posterior distributions for population parameters, unknown states $P_1,\ldots, P_N$ and performance indices were generated from 260 000 iterations of the model, where the initial 10 000 iterations were discarded as a 'burn-in' period, and every 25th sample of the following 250 000 was saved, resulting in 10 000 values for each parameter of interest.

4.1.2 *Specification of priors and sensitivity analysis*

Priors probability distributions were specified based on our viewpoint that informative *base-case* priors combined with an analysis of the sensitivity of results to alternative prior distributions provides a comprehensive approach to addressing uncertainty in parameter estimation. For alternative approaches to prior specification see Kass and Wasserman (1996), Wolfson et al. (1996) and Millar (2002). Considerable difficulties persist to constructing priors, including the appropriate conveyance of uncertainty through the use of noninformative and informative priors. Noninformative priors may be used to express total ignorance in parameter values; however, they may not be noninformative with respect to other quantities of interest, including policy performance measures (Punt and Hilborn 1997, Millar 2002). Informative priors may be used to incorporate information from earlier stock assessments and from similar populations (e.g. Hilborn and Liermann 1998, McAllister et al. 2001), which represents an important step in recognizing what has been learned, while still embracing uncertainty. However, incorporating prior information and expert judgment must be done cautiously due to the potential effects of biased or overly narrow priors on measures of policy performance (McAllister and Kirkwood 1998b). Punt and Hilborn (1997) argue that information elicited from a group of experts is one of the stronger methods for developing priors; however, other authors note that experts tend to be overly confident and fail to fully recognize uncertainty (Walters and Ludwig 1994, Wolfson et al. 1996).

Alternative hypotheses and associated evidence weightings for population model parameters r, K, P_1 (initial biomass as a proportion of K), σ^2 and τ^2 were constructed as *base-case* informative priors. Intrinsic rate of increase r was considered to be an exchangeable parameter, thus information from other lake whitefish populations was used to construct a prior for all three hypothesized populations. Best guess estimates for r from deterministic surplus production models range from (0.22-0.5) for Lake Superior, Lake Michigan and Lake Huron populations

(Jensen 1976). To more fully consider the possibility that lake whitefish populations in Georgian Bay are more or less productive than reported for other populations we constructed a log-normal prior based on the assumption that 95% of plausible values occur between 0.1 and 0.9:

$$r \sim dlnorm(-1.2,3.3)I(0.01,2)$$

where $dlnorm(\mu, \rho)$ refers to a log-normal distribution with mean μ and precision ρ and $I(min,max)$ are bounding parameters. *Base-case* prior distributions for carrying capacity K were considered population specific. Prior probabilities were informed by parameter estimates generated from maximum likelihood methods used in Harford et al. 2006. Estimates for K were selected from models that had the strongest statistical fits (maximum likelihood estimates) and were judged to be biologically relevant. A log-normal prior distribution for K for each hypothesized population was constructed based on 95% of observations occurring within the range of values generated from maximum likelihood estimates:

GB-S: $K \sim dlnorm(8,3)I(300,12000)$
GB-W: $K \sim dlnorm(6.5,1)I(50,10000)$
GB: $K \sim dlnorm(9,4)I(2500,28000)$

A diffuse log-normal prior was used for P_1 based on 95% of observations occurring between 0.1 and 0.9.

Observation error variance τ^2 arises from variability associated with sampling commercial landings, which are then used as an index of relative abundance. A reasonable range for observation error as a coefficient of variation (CV) on CPUE is from 0.1 – 0.3 (Hilborn and Liermann 1998, Walters 1998). We selected to follow the example from Meyer and Millar (1999b) and constructed priors for each hypothesized population where 95% of observations occur between a CV of 0.05 and 0.15:

GB-S: $\tau^2 \sim dnorm(9.2,0.07)I(0.1,20)$
GB-W: $\tau^2 \sim dnorm(11.3,0.04)I(0.1,24)$
GB: $\tau^2 \sim dnorm(57.2,0.002)I(0.1,120)$

Process error variance σ^2 will arise due to environmental and demographic variability. In the absence of a formal examination of stock-recruitment relationships, we calculated the observed variance of age-5 recruitment as a proportion of the total annual catch. Recruitment to the fishery typically begins at age 3 or 4, based on scale age estimates from commercial landings; however, we more confidently assume that full recruitment has occurred by age 5. Since age-5 recruitment VAR includes observations error, density-dependent effects on recruitment and process error, it was considered the 97.5th percentile and 0.25*VAR the 2.5th percentile of a normally distributed prior:

GB-S: $\sigma^2 \sim dnorm(100.7,0.001)I(35,165)$
GB-W: $\sigma^2 \sim dnorm(100,0.001)I(35,165)$
GB: $\sigma^2 \sim dnorm(156,0.0004)I(1,300)$

A noninformative uniform prior was selected for *q* based on previous work by McAllister et al. (1994), Walters and Ludwig (1994), Punt et al. (1995) and Millar and Meyer (2000).

Posterior distributions may be highly influenced by the shape of the prior and by priors centered on inaccurate values (McAllister and Kirkwood 1998b). When data are not too informative the shape of posterior distribution is highly influenced by the prior distribution (Ellison 1996, Peterman 2004). Conversely, when data are informative the nature of the prior will have relatively little effect on the posterior distribution. Managers must be informed when posterior inference and risk associated with management options changes according to the choice of priors (Punt and Hilborn 1997, Meyer and Millar 1999b). The sensitivity of resulting posterior distributions and performance indices measures to the choice of prior distributions was evaluated as follows:

- For *r* and *K* we selected alternative priors that were positively and negatively biased relative to *base*-case priors. Alternative priors were generated that had mean values 100% higher and 50% lower than *base-case* priors, similar to the approach of McAllister and Kirkwood (1998b). Combinations of negatively and positively biased priors for *r* and *K* were investigated due to observation from Harford et al. (2006) that several models with reasonable fits were characterized as having either low *r* and high *K*, or high *r* and low *K*. This suggests that *r* and *K* may not be independent and may have a combined effect on posterior inference.
- For σ^2 and τ^2 we selected alternative priors that were positively biased relative to *base-case* priors. We investigated the risk of alternative management actions when uncertainty about recruitment (σ^2) is increased, thus recruitment anomalies are more likely, and when uncertainty about the reliability of CPUE estimates is increased. Process error was increased by constructing distributions based on age-5 recruitment variance where 2*VAR was the 97.5th percentile and VAR the 2.5th percentile of a normally distributed prior. Observation error was increased by constructing priors for each hypothesized population where 95% of observations occur between a CV of 0.1 and 0.3.

Sensitivity of posterior inference was investigated for GB-S and GB-W populations and the risk associated with alternative TACs was investigated for a moderate and high TAC level over a 10-year projection period.

4.1.3 *Performance Indices*

Consequences of alternative constant harvest TAC options were forecasted over 1 and 10 year projection periods for each hypothesized population distribution. We identified one performance target and two indicators of risk based on the belief that traditional performance targets such as MSY are unobtainable and inappropriate, given the overall uncertainty associated with the state of the fishery and the feasibility of regulating a fishery with the necessary responsiveness and accuracy to achieve such a target (Roughgarden 1998, Hatton et al. 2006). Performance of each TAC option was measured as proximity to a target within surplus-production state space specified as 3/4*K* on the biomass axis and 1/2*MSY* on the surplus production axis (Roughgarden 1998, Matchett 2007).

Risk associated with alternative TAC options was based on indices of population growth trajectory and long-term sustainability. Following an approach similar to that presented by Hatton et al. (2006), surplus-production state-space was divided into regions representing discrete levels of population biomass and surplus production (Figure 4.1). Regions were identified as high, medium and low risk of population collapse. High risk regions were characterized by low population size relative to carrying capacity and high harvest levels relative to productivity. Medium risk regions were characterized by small population size relative to carrying capacity and low harvest levels, or large population size and high harvest levels. Low risk regions were characterized by a population that larger than 1/2*K* and medium to high harvest levels. Probabilities were assigned to each risk region representing degree of belief in the trajectory of population growth as a consequence of each TAC option. A second index of risk was based on a more direct measure of the risk of population collapse, defined simply as the probability of population biomass declining below 1/4*K* as a consequence of each TAC option.

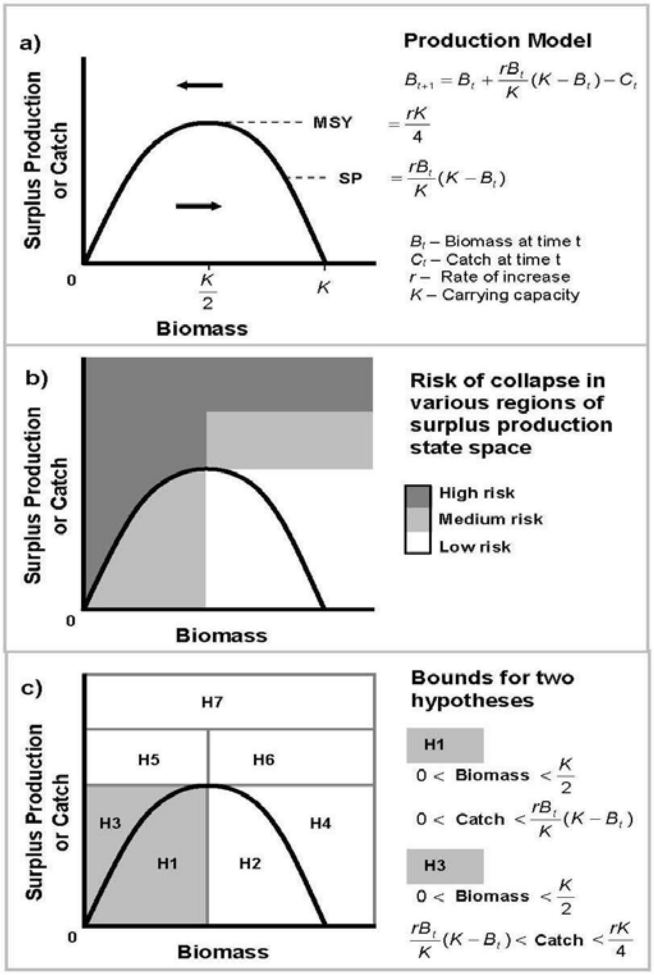


Figure 4.1. (a) Relationship between surplus production (SP) plotted against biomass (B_t). This curve arises from the production model which includes discrete logistic growth and is extended to include catch (C_t), as shown.

4.2 Results

4.2.1 *Georgian Bay South*

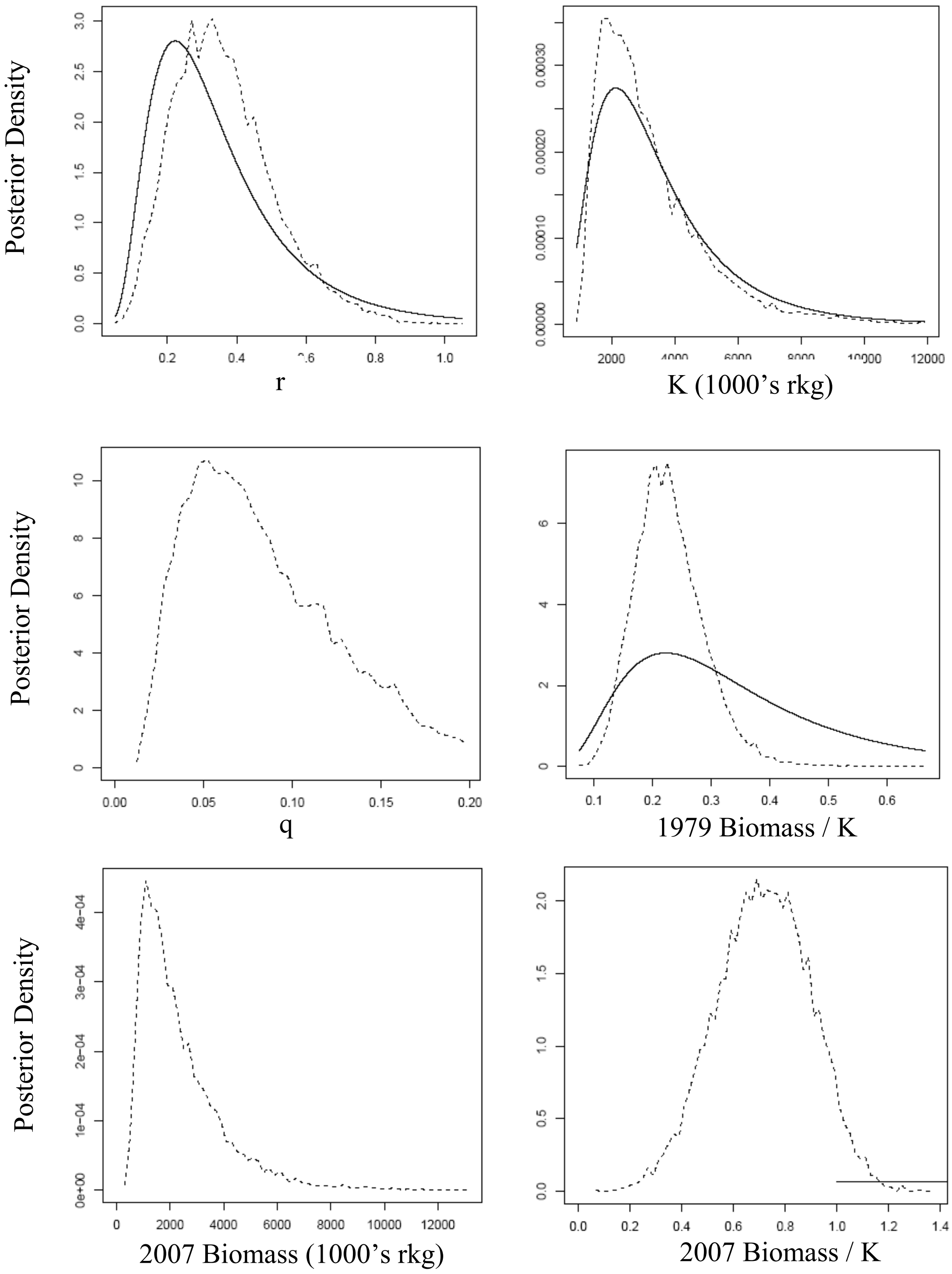


Figure 4.2. Prior distributions (__) and posterior distribution (- - - -) of model parameters r, K, q and population characteristics from surplus production models for Georgian Bay South.

Table 4.1. Summary of model parameters and population characteristics from surplus production models for Georgian Bay South.

Parameter	Mean	SD	25%	Median	75%
B_{2007} (x1000 rkg)	2371	1580	1255	1930	3032
P_{2007}	0.71	0.18	0.59	0.72	0.84
r	0.36	0.14	0.26	0.34	0.45
K (x1000 rkg)	3210	1700	1981	2753	3971
q	0.08	0.04	0.05	0.07	0.11
P_{1979}	0.23	0.06	0.19	0.22	0.26

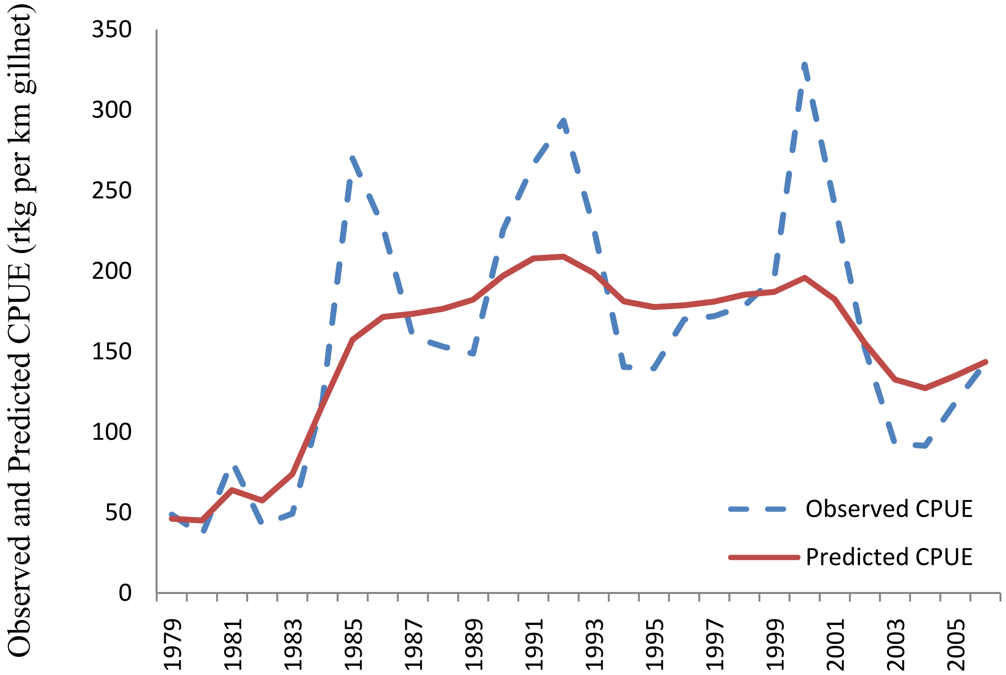


Figure 4.3. Observed CPUE and predicted median CPUE obtained from the surplus production state-space model for Georgian Bay South.

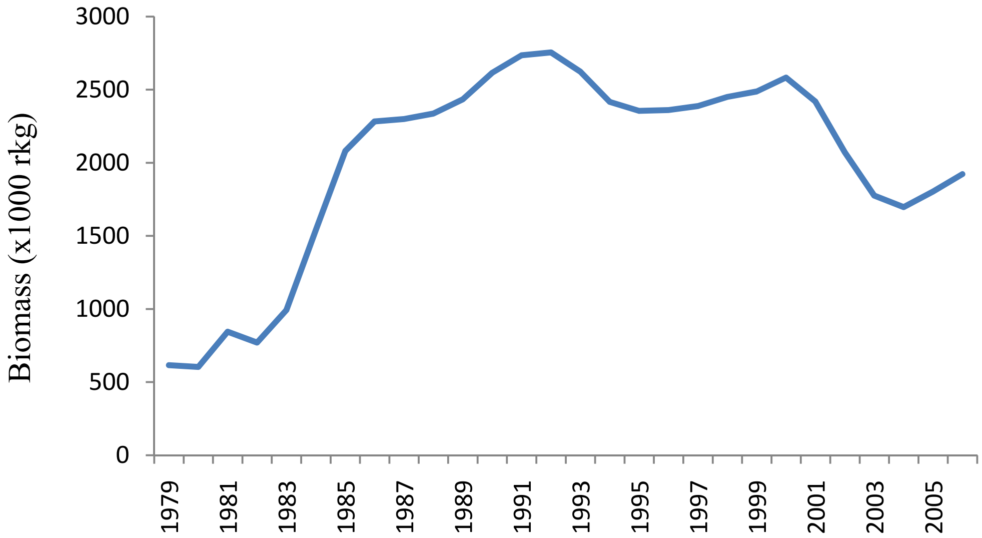


Figure 4.4. Median annual biomass estimates obtained from surplus production state-space model for Georgian Bay South.

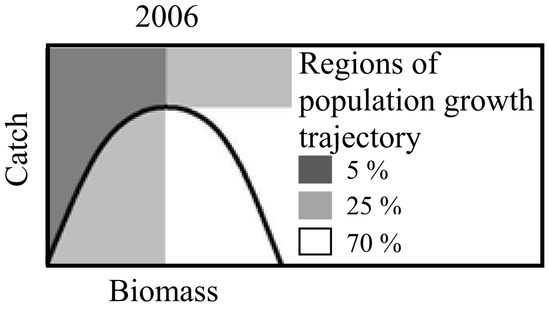
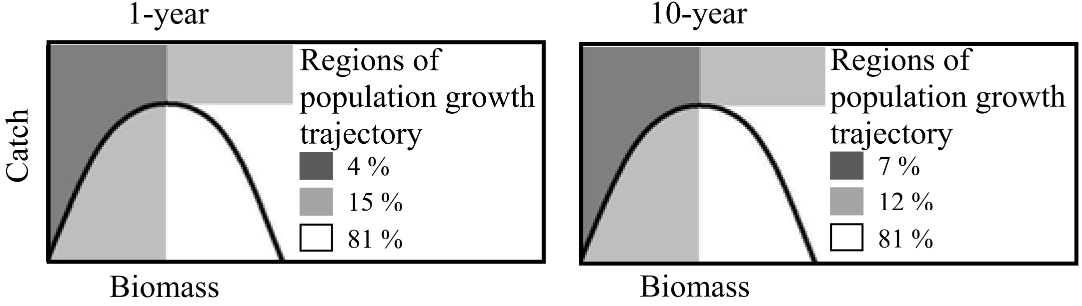
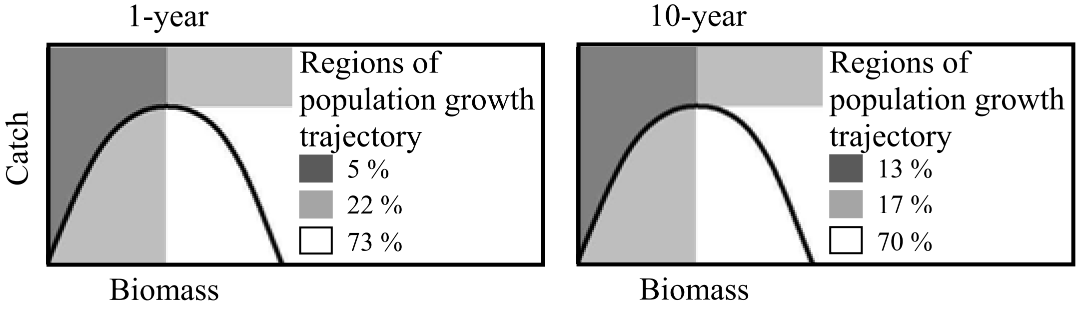


Figure 4.5. Regions of population growth trajectory based on estimates obtained from surplus production state-space models for Georgian Bay South.

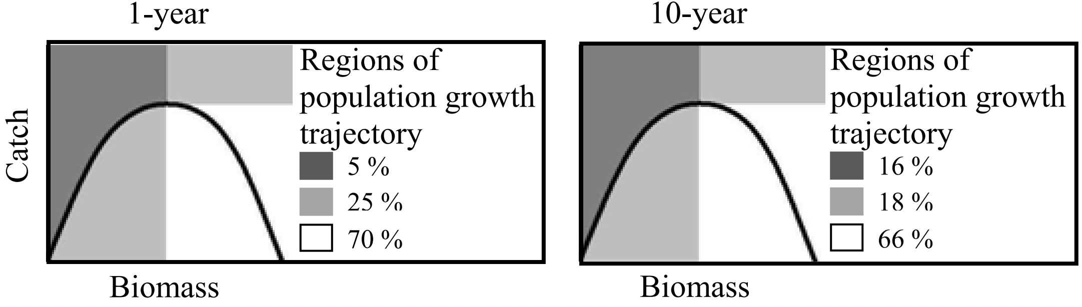
120 000 rkg



160 000 rkg



180 000 rkg



190 000 rkg

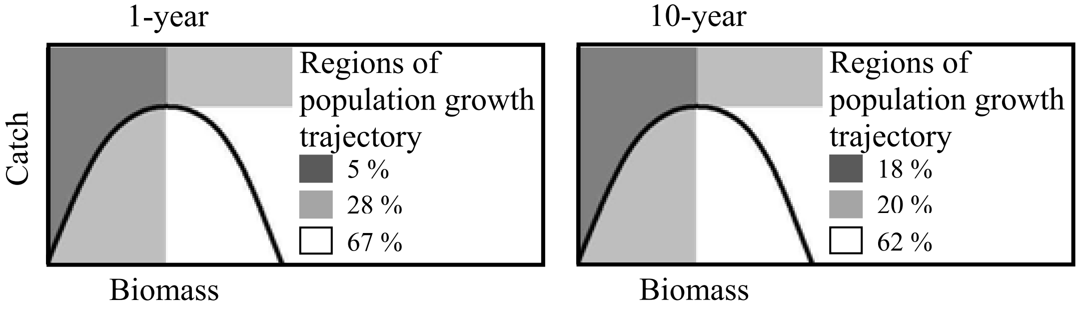
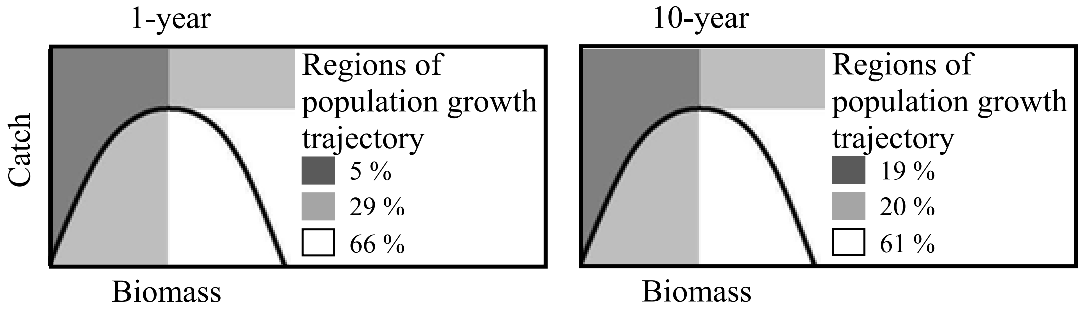


Figure 4.6 Probabilities associated with population growth trajectories for alternative TACs based on estimates obtained from surplus production state-space models for Georgian Bay South.

200 000 rkg



240 000 rkg

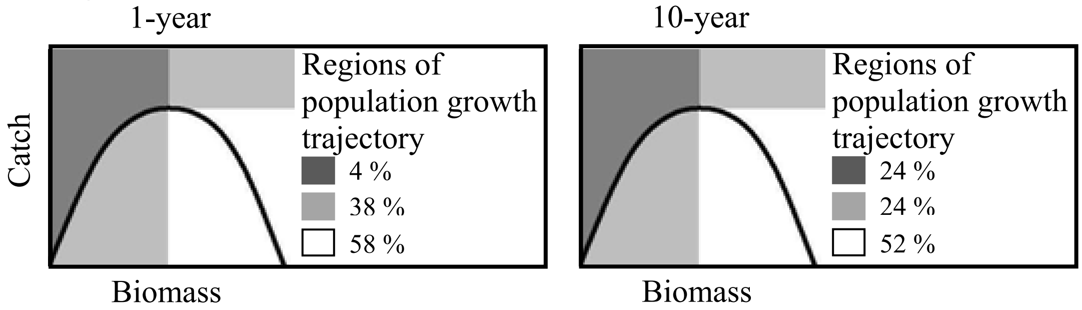


Figure 4.6 cont. Probabilities associated with population growth trajectories for alternative TACs based on estimates obtained from surplus production state-space models for Georgian Bay South.

Table 4.2. Performance indices for alternative TAC options for Georgian Bay South.

TAC Option	SP Target 2006	SP Target 1-year	SP Target 10-year	Risk P<0.25K 1-year	Risk P<0.25K 10-year
120 000 rkg	315	350	437	0.01	0.04
160 000 rkg	315	344	462	0.01	0.06
180 000 rkg	315	352	493	0.01	0.07
190 000 rkg	315	353	503	0.01	0.08
200 000 rkg	315	356	521	0.01	0.09
240 000 rkg	315	372	575	0.01	0.12

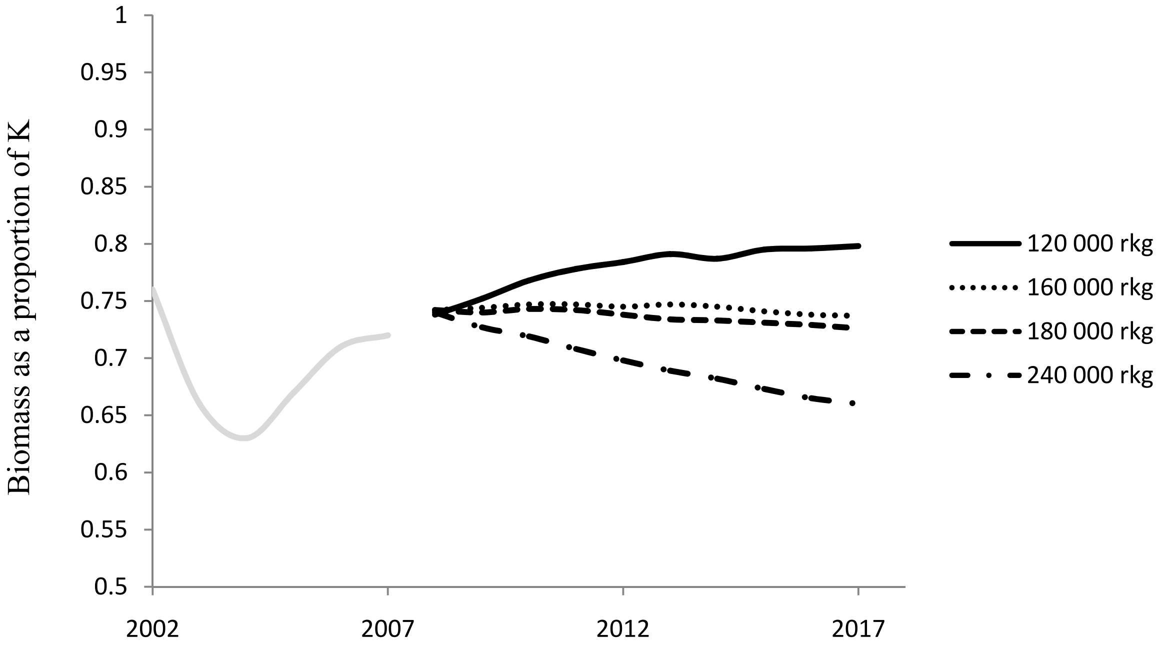


Figure 4.7. Retrospective and predicted biomass as a proportion of carrying capacity (K) for selected TAC levels for Georgian Bay South.

4.2.2 *Georgian Bay West*

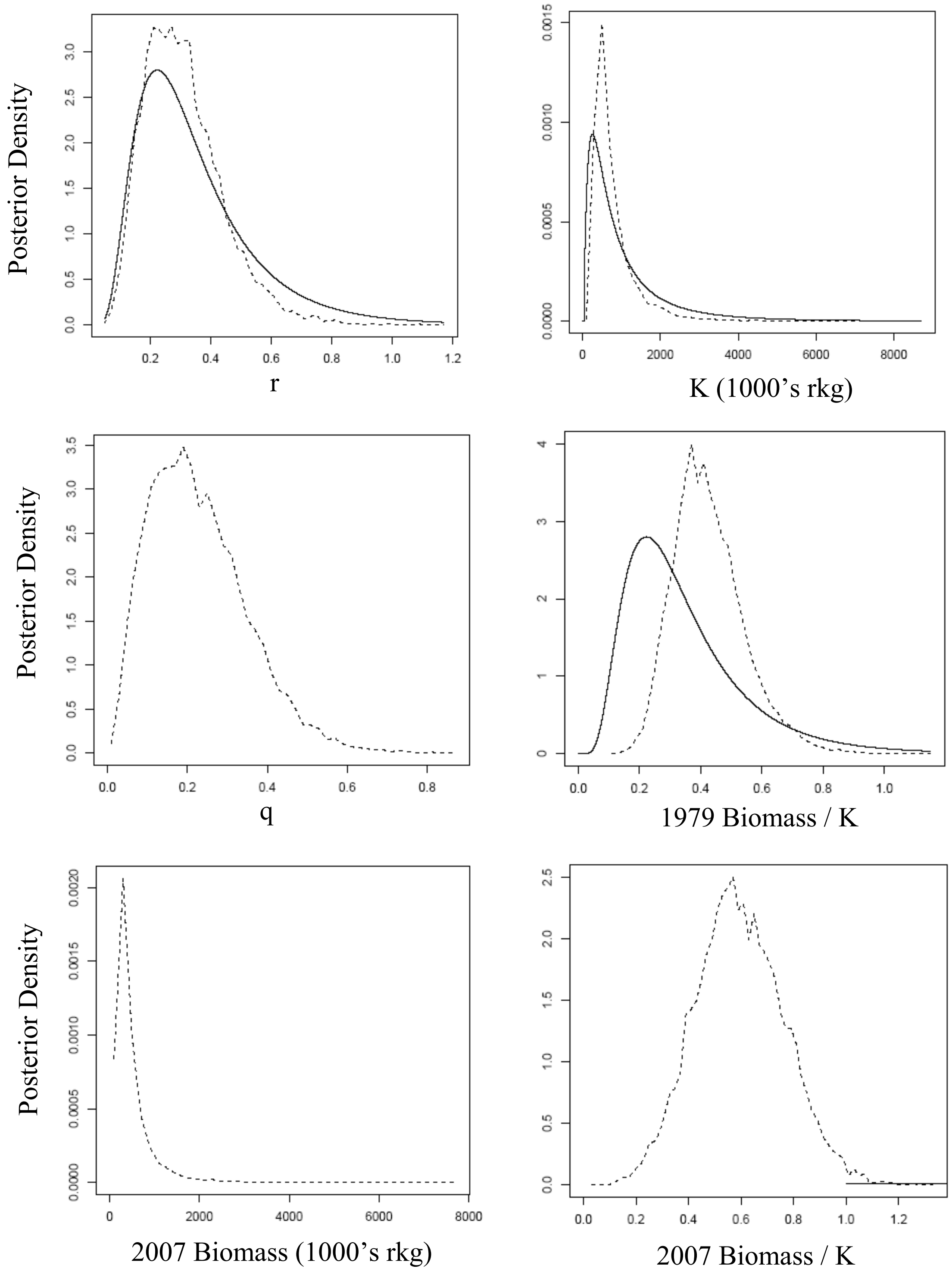


Figure 4.8. Prior distributions (__) and posterior distribution (- - - -) of model parameters r, K, q and population characteristics from surplus production models for Georgian Bay West.

Table 4.3. Summary of model parameters and population characteristics from surplus production models for Georgian Bay West.

Parameter	Mean	SD	25%	Median	75%
B_{2007} (x1000 rkg)	486	470	234	350	561
P_{2007}	0.59	0.17	0.48	0.59	0.71
r	0.31	0.13	0.21	0.29	0.38
K (x1000 rkg)	799	644	431	602	923
q	0.23	0.12	0.13	0.21	0.30
P_{1979}	0.43	0.12	0.34	0.41	0.49

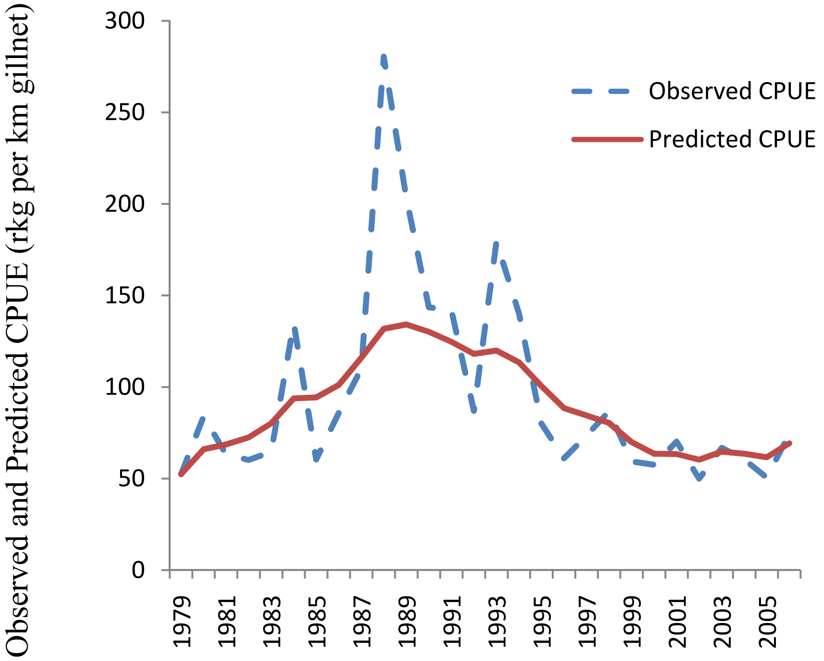


Figure 4.9. Observed CPUE and predicted median CPUE obtained from the surplus production state-space model for Georgian Bay West.

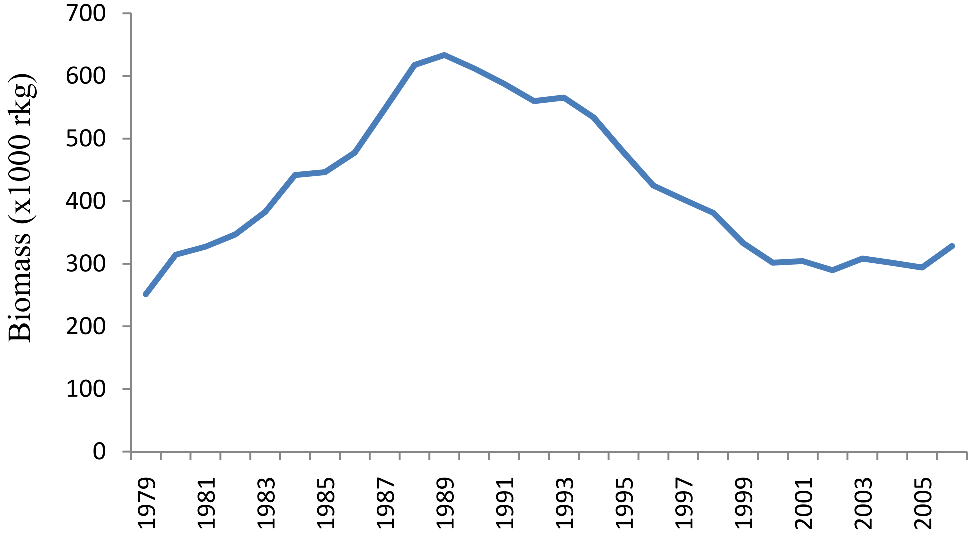


Figure 4.10. Median annual biomass estimates obtained from surplus production state-space model for Georgian Bay West.

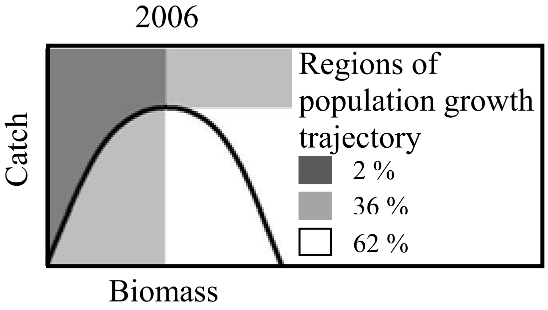


Figure 4.11. Regions of population growth trajectory based on estimates obtained from surplus production state-space models for Georgian Bay West.

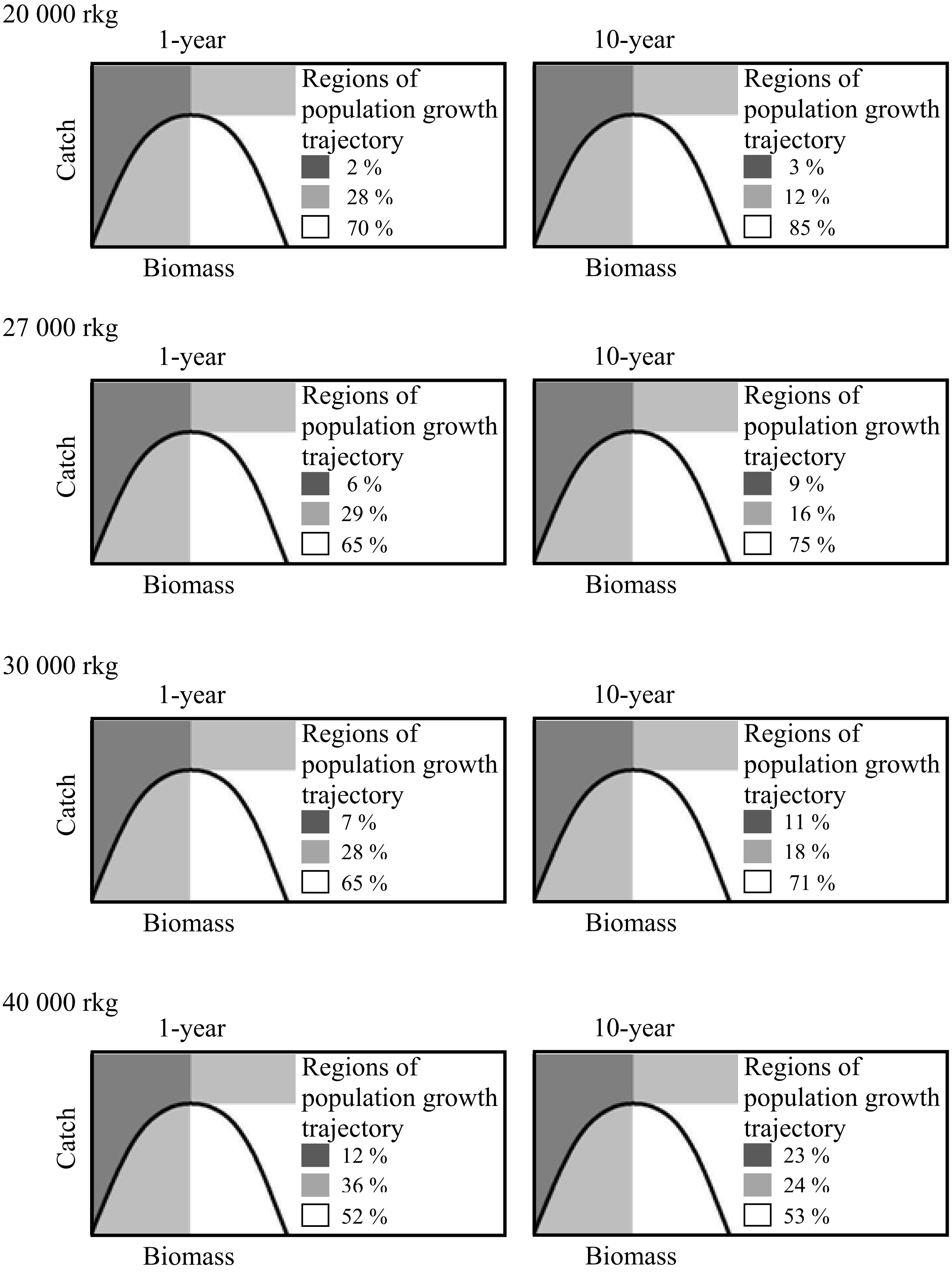


Figure 4.12. Probabilities associated with population growth trajectories for alternative TACs based on estimates obtained from surplus production state-space models for Georgian Bay West.

Table 4.4. Performance indices for alternative TAC options for Georgian Bay West

TAC Option	SP Target 2006	SP Target 1-year	SP Target 10-year	Risk P<0.25K 1-year	Risk P<0.25K 10-year
20 000 rkg	118	104	93	0.02	0.04
27 000 rkg	118	104	97	0.02	0.06
30 000 rkg	118	103	103	0.02	0.07
40 000 rkg	118	100	124	0.01	0.11

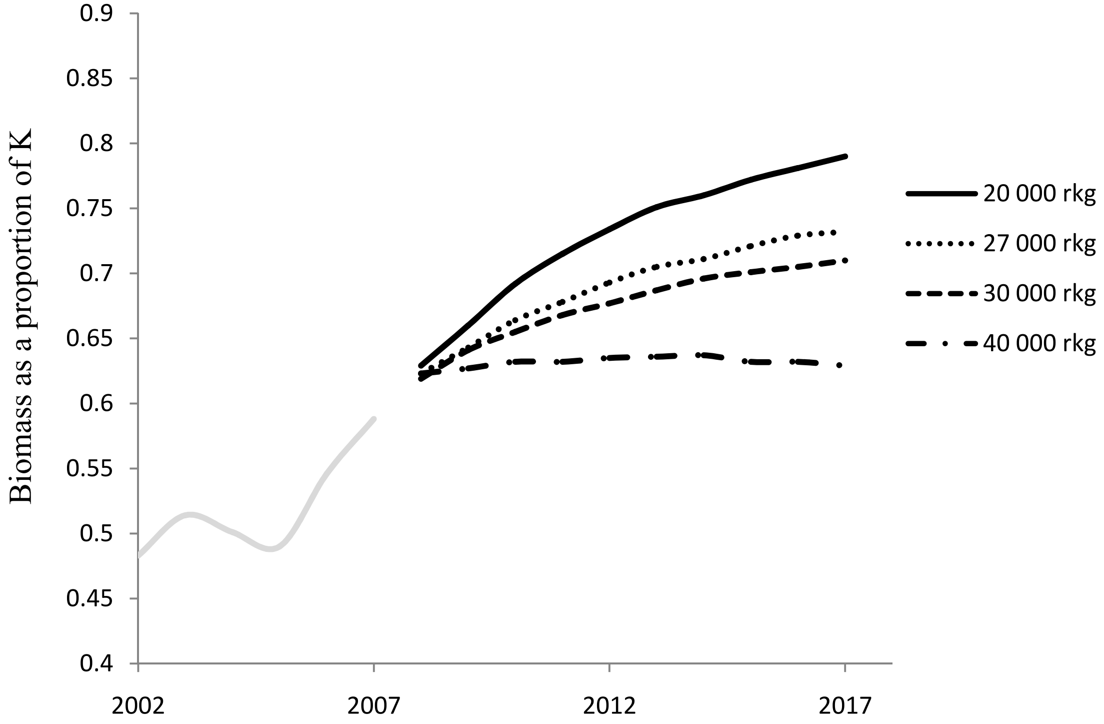


Figure 4.13. Retrospective and predicted biomass as a proportion of carrying capacity (K) for selected TAC levels for Georgian Bay West.

4.2.3 *Georgian Bay*

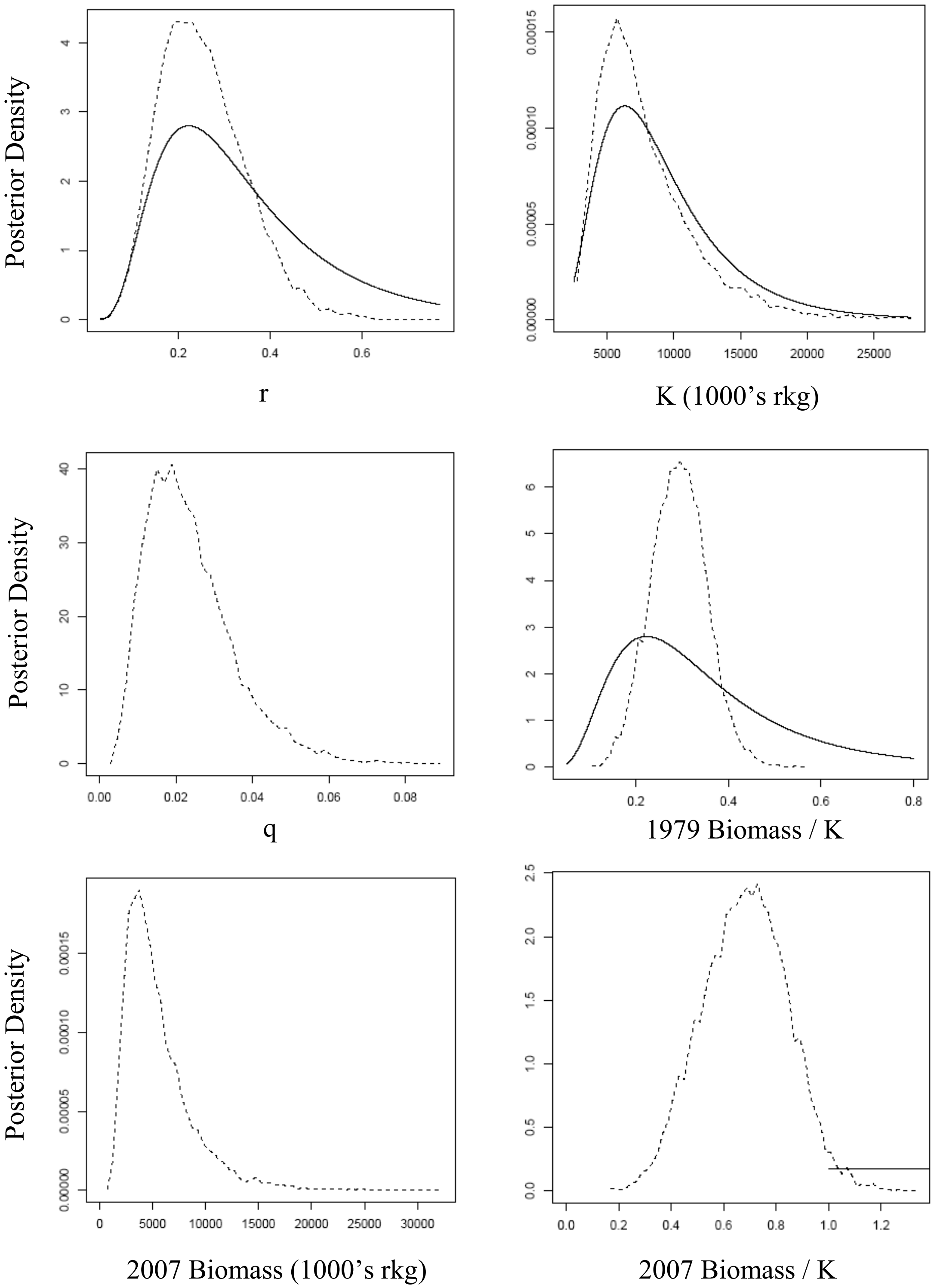


Figure 4.14. Prior distributions (__) and posterior distribution (- - - -) of model parameters r, K, q and population characteristics from surplus production models for Georgian Bay.

Table 4.5. Summary of model parameters and population characteristics from surplus production models for Georgian Bay.

Parameter	**Mean**	**SD**	**25%**	**Median**	**75%**
B_{2007} (x1000 rkg)	5506	3244	3278	4666	6810
P_{2007}	0.68	0.16	0.60	0.68	0.80
r	0.25	0.09	0.18	0.24	0.31
K (x1000 rkg)	7929	3753	5303	6988	9616
q	0.02	0.01	0.01	0.02	0.03
P_{1979}	0.29	0.06	0.25	0.29	0.33

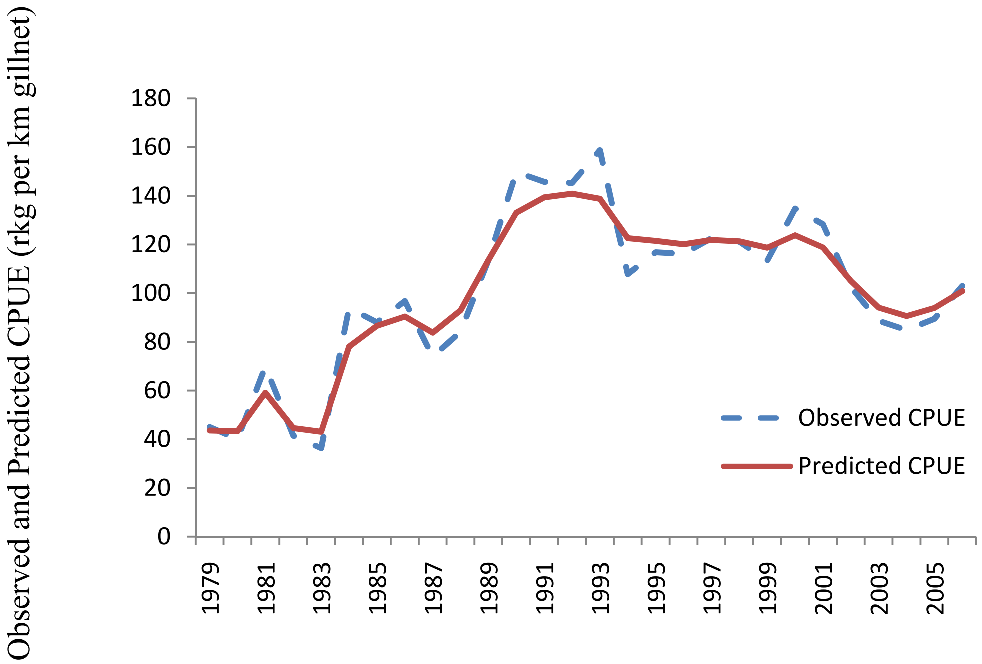


Figure 4.15. Observed CPUE and predicted median CPUE obtained from the surplus production state-space model for Georgian Bay.

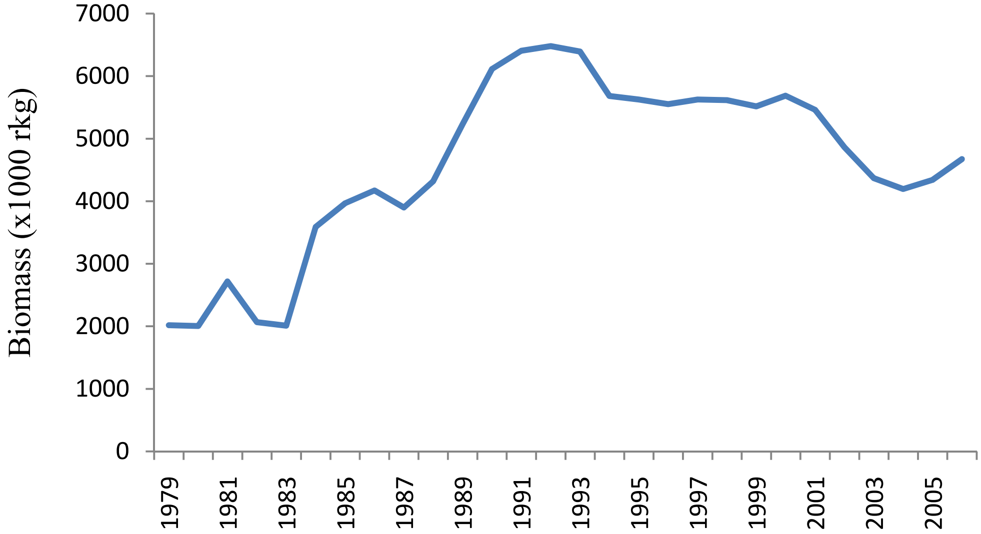


Figure 4.16. Median annual biomass estimates obtained from surplus production state-space model for Georgian Bay.

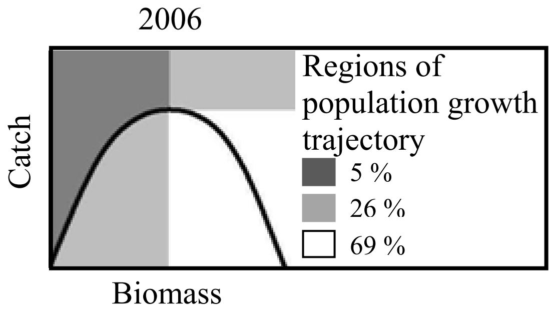


Figure 4.17. Regions of population growth trajectory based on estimates obtained from surplus production state-space models for Georgian Bay.

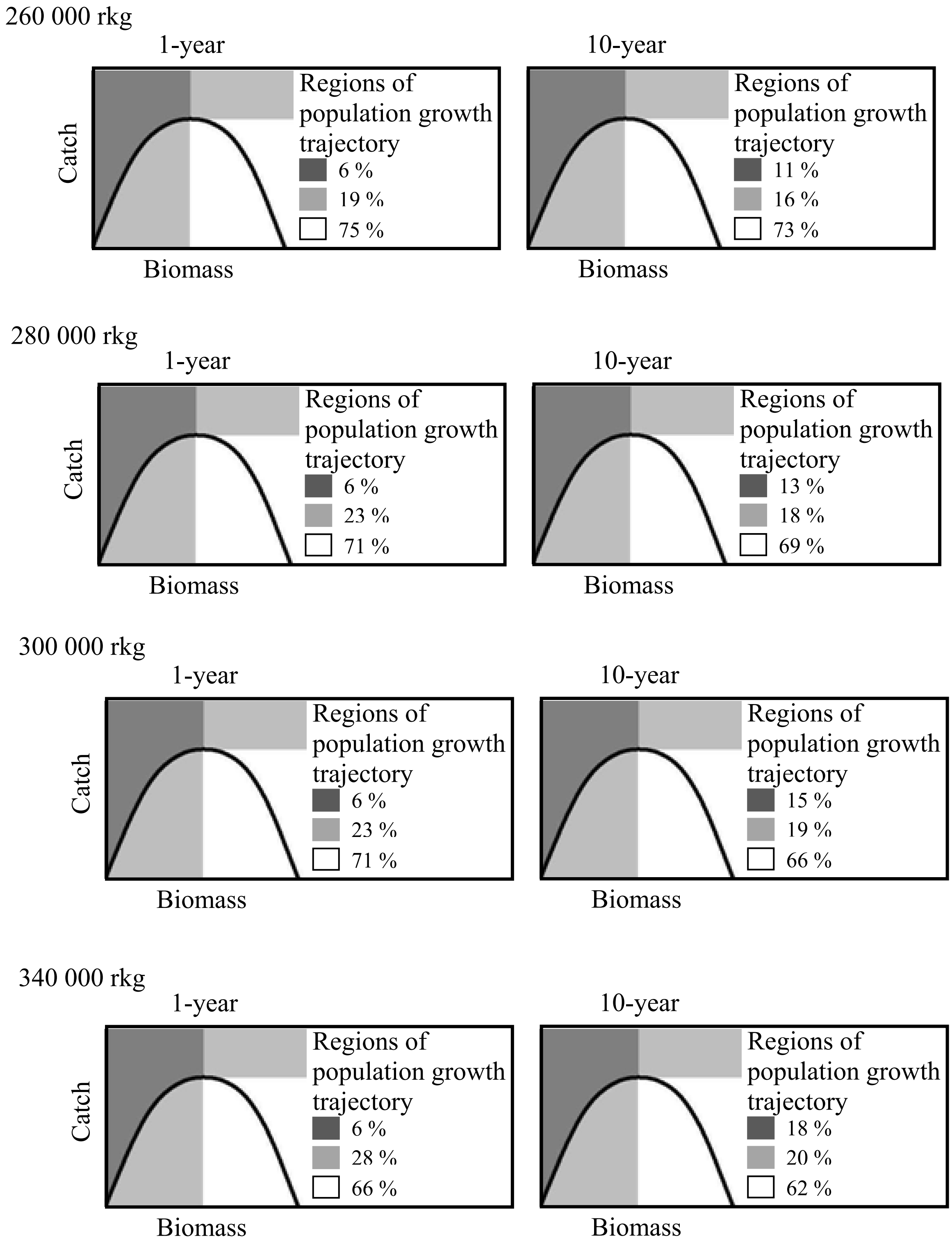


Figure 4.18. Probabilities associated with population growth trajectories for alternative TACs based on estimates obtained from surplus production state-space models for Georgian Bay.

Table 4.6. Performance indices for alternative TAC options for Georgian Bay.

TAC Option	SP Target 2006	SP Target 1-year	SP Target 10-year	Risk P<0.25K 1-year	Risk P<0.25K 10-year
260 000 rkg	722	836	1110	0	0.05
280 000 rkg	722	833	1109	0	0.06
300 000 rkg	722	821	1146	0	0.07
340 000 rkg	722	804	1210	0	0.08

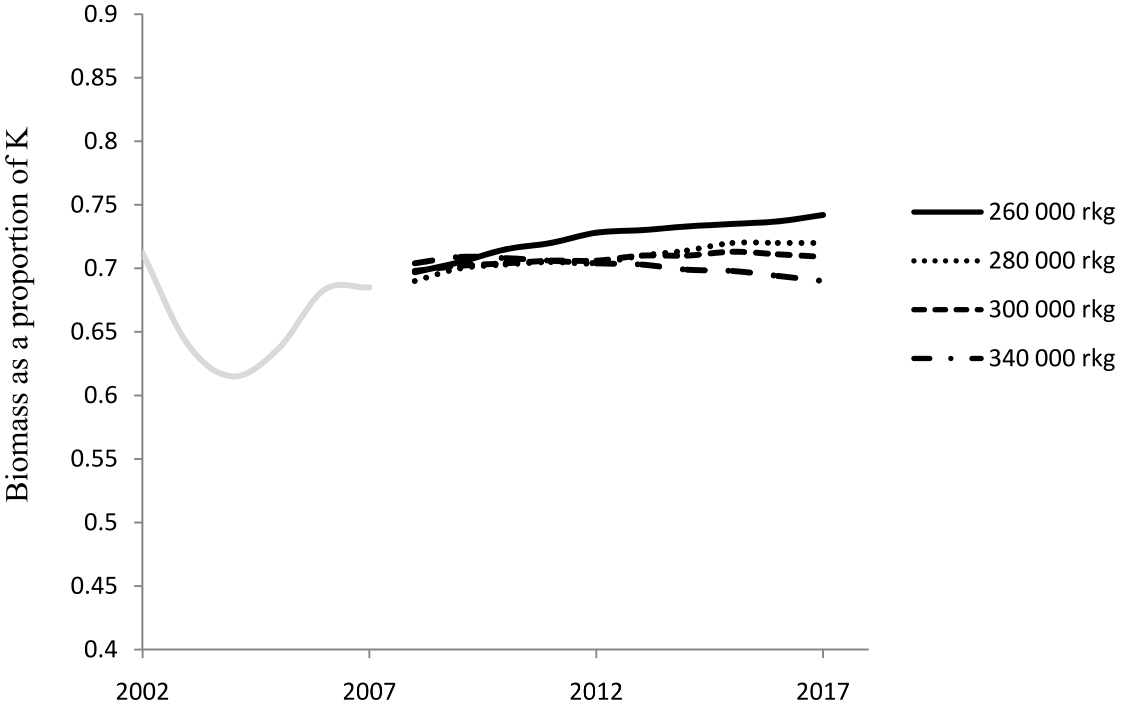


Figure 4.19. Retrospective and predicted biomass as a proportion of carrying capacity (K) for selected TAC levels for Georgian Bay.

5 IMPLICATIONS FOR FISHERIES MANAGEMENT

5.1 2007 TAC options for Saugeen Ojibway Nation Territories Joint Council

Summary for Saugeen Ojibway Joint Council presented October 15th, 2007

File can be found in 2007 TAC Summary – IMPLICATIONS FOR FISHERIES MANAGEMENT.doc

5.2 Key Uncertainties and future work

Our purpose for investigating a Bayesian stock assessment using a relatively simple surplus production model was to identify benefits and limitations of the model to guide future research and to identify strategic priorities for future stock assessments. Four priorities for future work were identified.

The first priority is to develop an explicit set of management objectives and improve performance measures used to rank management options, including an investigation of quantitative decision making rules. A common challenge of developing fisheries is the need to develop decision tools that explicitly and quantitatively incorporate uncertainty in decision-making. While decision analysis has been widely promoted for incorporating uncertainty in decision-making (Peterman and Peters 1998, Peterman and Anderson 1999), developing fisheries may lack an explicit set of management objectives against which management options can be ranked. Management objectives can serve to guide the actions of both scientists and managers and lead to more informed choices because management options are weighed across a range of objectives, representing a diverse mix of values (McDaniels 1995, Sladek Nowlis 2004). This is particularly important in a management context, where multiple jurisdictions are co-managing resources and represent a diverse set of user-groups; such is the case for Lake Huron.

The second priority is to conduct a simple decision analysis to explicitly incorporate ecological uncertainties that limit our ability to predict the outcomes of various management actions. Two uncertainties of immediate importance are uncertainty in population parameter estimation and uncertainty in the population distributions used to manage commercial harvests. Decision Analysis is a process of risk management that provides decision makers with informed choices (Peterman and Peters 1998). This approach explicitly incorporates risk and uncertainty in decision making by representing uncertain states of nature as competing hypotheses. Several outcomes are generated for each management option and are weighted by degree of belief (probabilities) in each hypothesized state of nature (Keeney 1982, Peterman and Anderson 1999). The consequences of each management option are then calculated as the weighted average of predicted outcomes for each state of nature (Peterman and Peters 1998, Peterman and Anderson 1999).

The third priority is to quantitatively consider uncertainty about population boundaries by assigning probabilities to alternative hypotheses about population distribution of lake whitefish in Main Basin and Georgian Bay. Concurrent research has been proposed to refine a suite of alternative hypotheses and assign probabilities to each of these hypotheses using genetics and mark-recapture techniques. An important aspect of this research is development of Bayesian methods to assign probabilities to alternative hypotheses, and secondarily the need for Bayesian methods for iteratively updating what is already known in the form of probabilities. Updating probabilities from several types of scientific information (e.g. genetics, mark-recapture, morphology, etc.) will sequentially reduce uncertainty about population distribution and allow information from different techniques to be integrated. Further, population distribution hypotheses represented as alternative states of nature, with associated probabilities can then be incorporated into a formal decision analysis.

The fourth priority is to investigate the role model complexity and parsimony in quantitative stock assessments. Several authors have noted the importance of considering structurally different models (Sainsbury 1988, Punt and Hilborn 1997, Punt and Smith 1999); however, is it also critical to evaluate the relative weight of evidence in support of alternative models (McAllister and Kirkwood 1998b, McAllister and Kirchner 2002). The results from our surplus production model indicated a modest fit between observed and predicted CPUE for all three hypothesized populations. However, predicted CPUE estimates were unable to capture the highest and lowest observed values, suggesting that investigating alternative and more complex models would be valuable. Ebener et al. (2005) suggested surplus production models are better suited to populations where recruitment is not highly variable. Based on our results, recruitment of whitefish in Lake Huron may not to be strongly linked to stock biomass. Statistical catch-at-age modelling is now commonly used for assessment of Lake Huron lake whitefish (Ebener et al. 2005). Structural model uncertainty may be addressed by examining the tradeoffs between model complexity (number of parameters) and model fit. Developing models in a progression from simple to complex will allow the most informative models to be identified, without model over parameterization. A further challenge to implementing age-structured models is the use of age estimates from scales and otoliths. Our current focus for ageing research is to generate a correction factor between scales and otoliths, as well as quantify the effects of ageing errors (precision) on population modelling.

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Appendix 1. Summary of age distribution of catch

Main Basin East

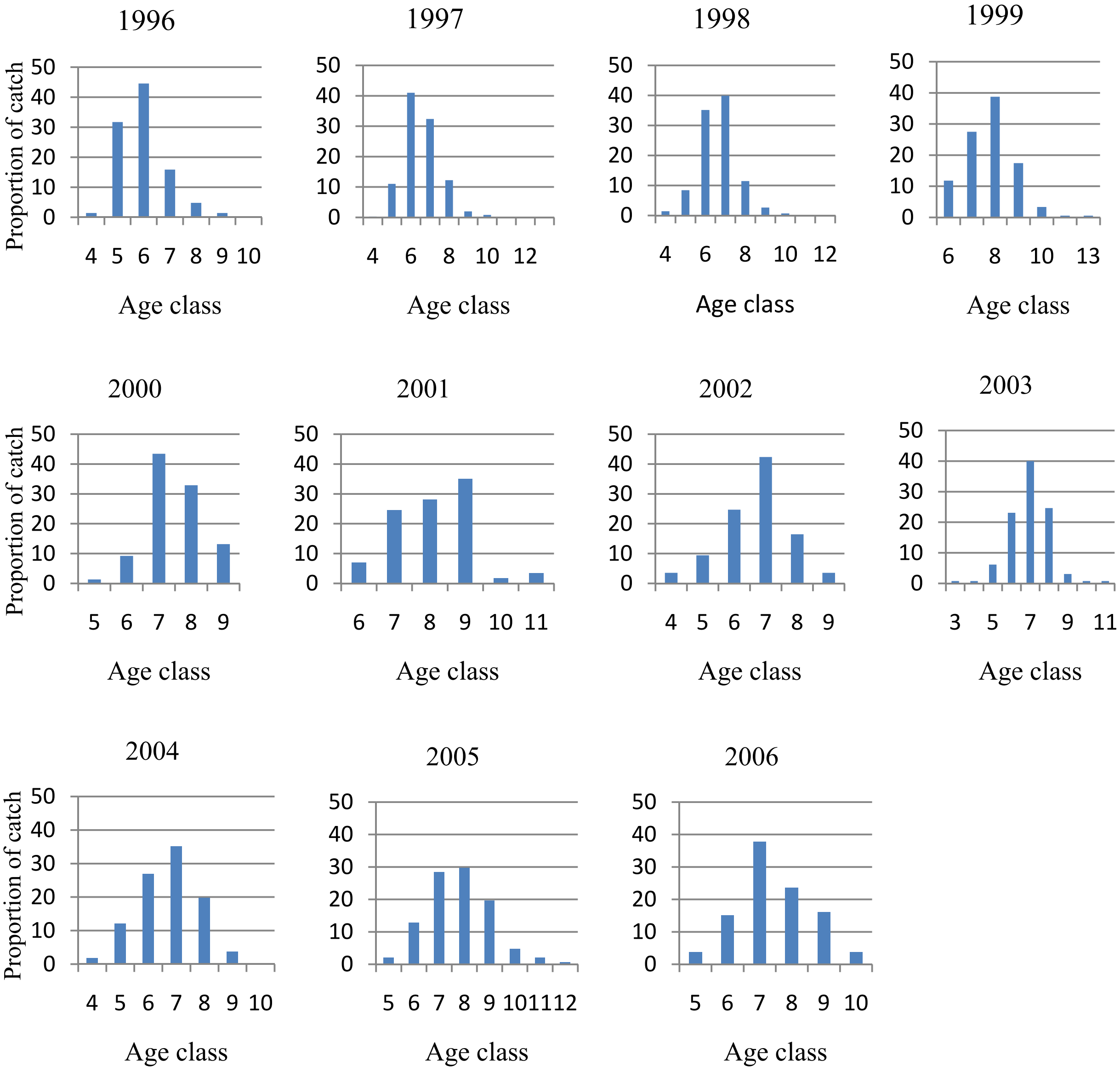


Figure A1.1. Age distribution of lake whitefish from commercial harvest from Main Basin East.

Main Basin South

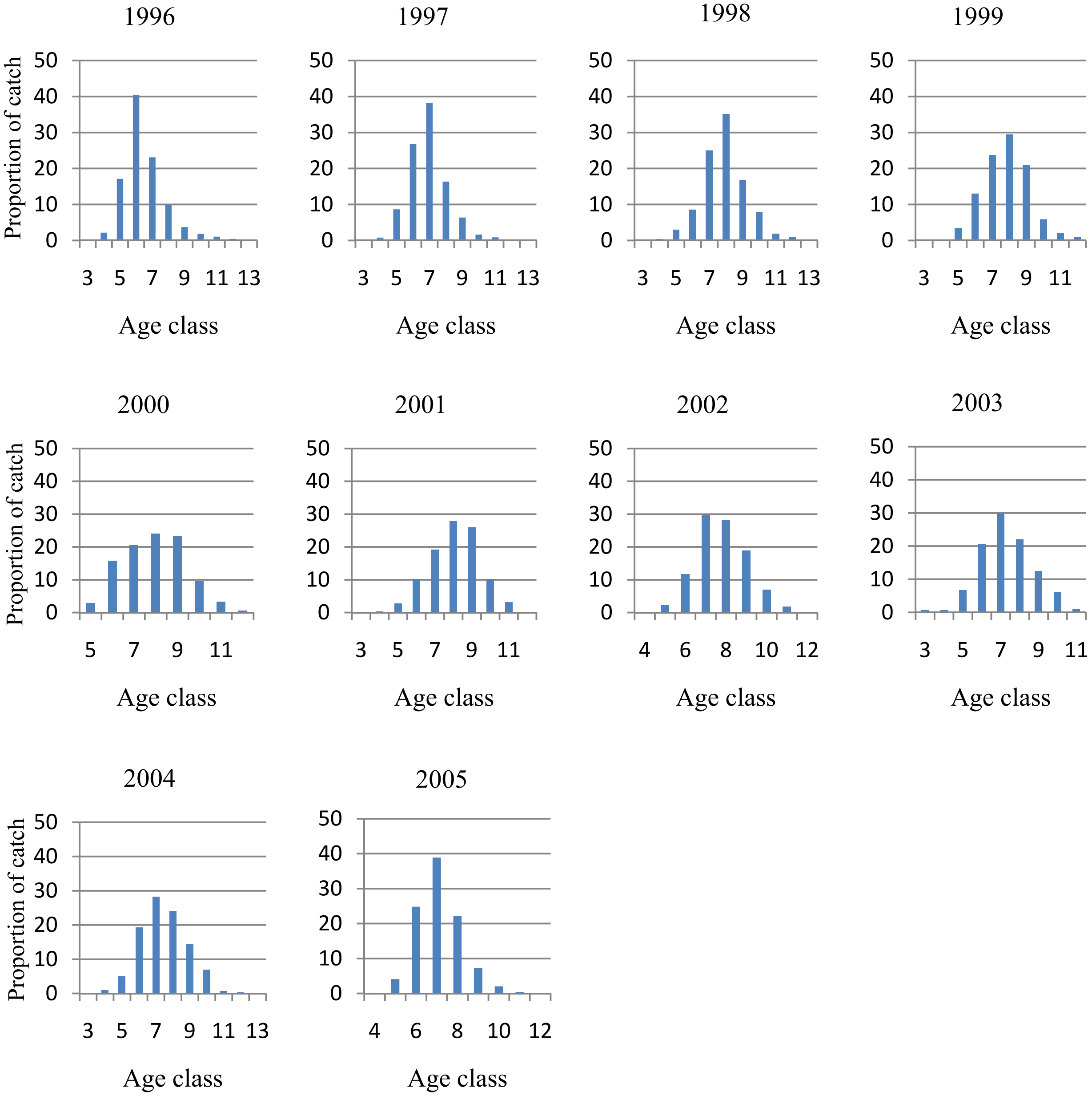


Figure A1.2. Age distribution of lake whitefish from commercial harvest from Main Basin South.

Georgian Bay South

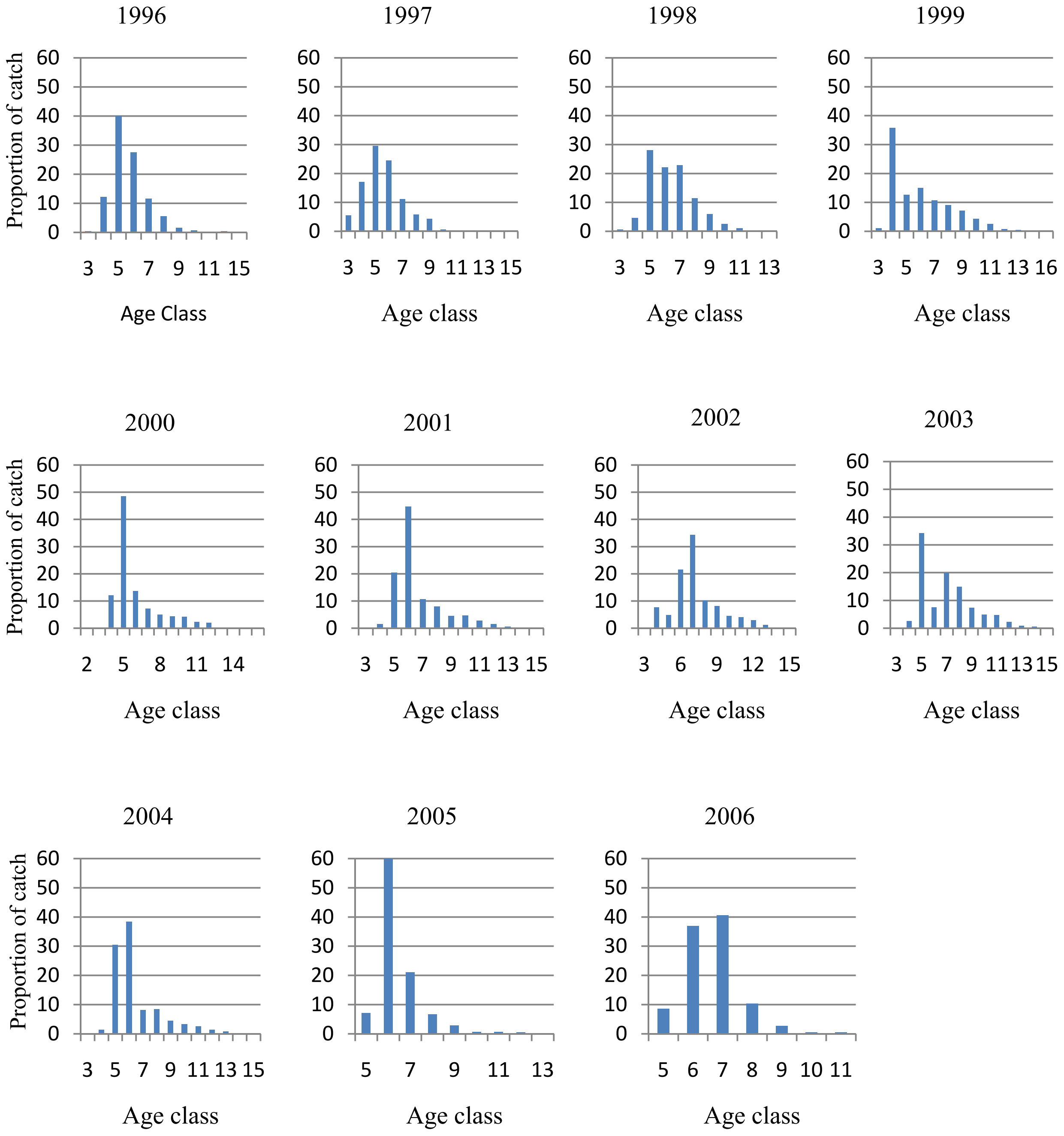


Figure A1.3. Age distribution of lake whitefish from commercial harvest from Georgian Bay South.

Georgian Bay West

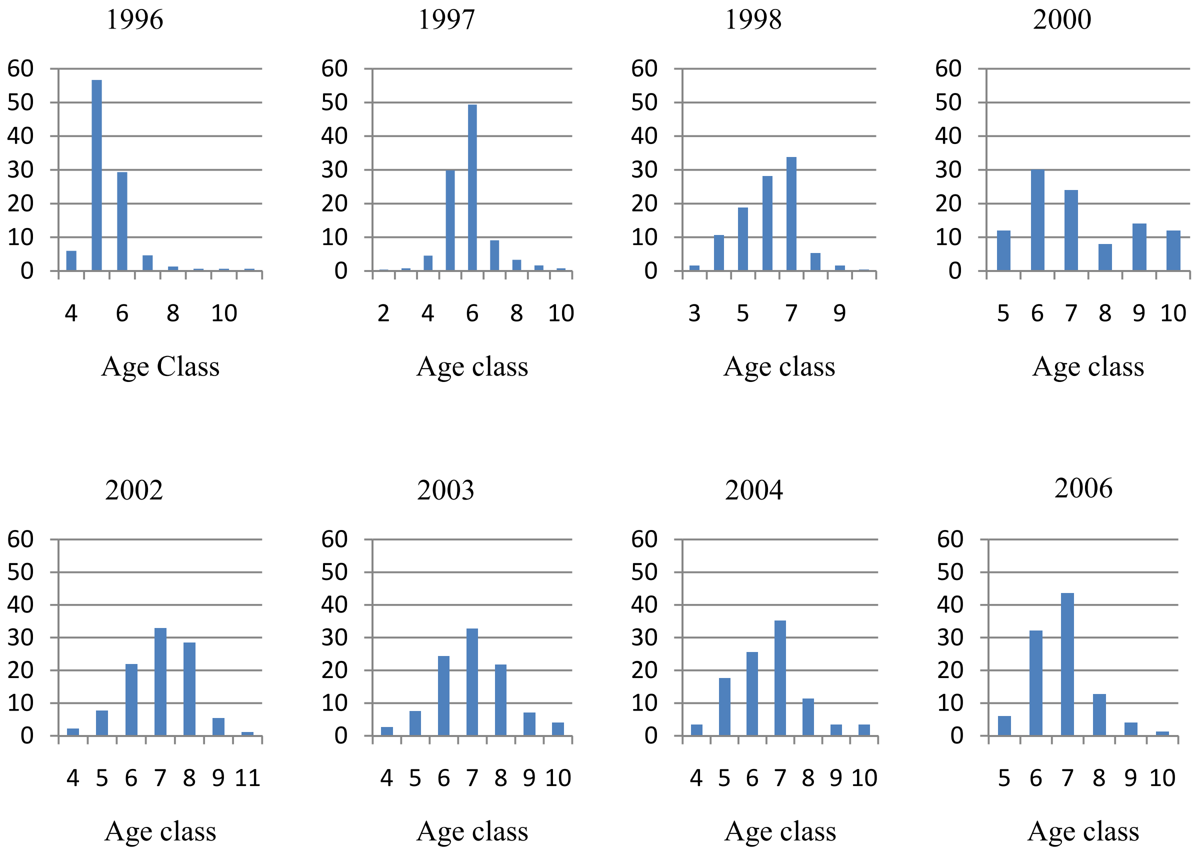


Figure A1.4. Age distribution of lake whitefish from commercial harvest from Georgian Bay West. Age distributions for years 1999, 2001, 2005 are not presented due to small sample size of aged individuals.

Appendix 2. Summary of length and weight of catch

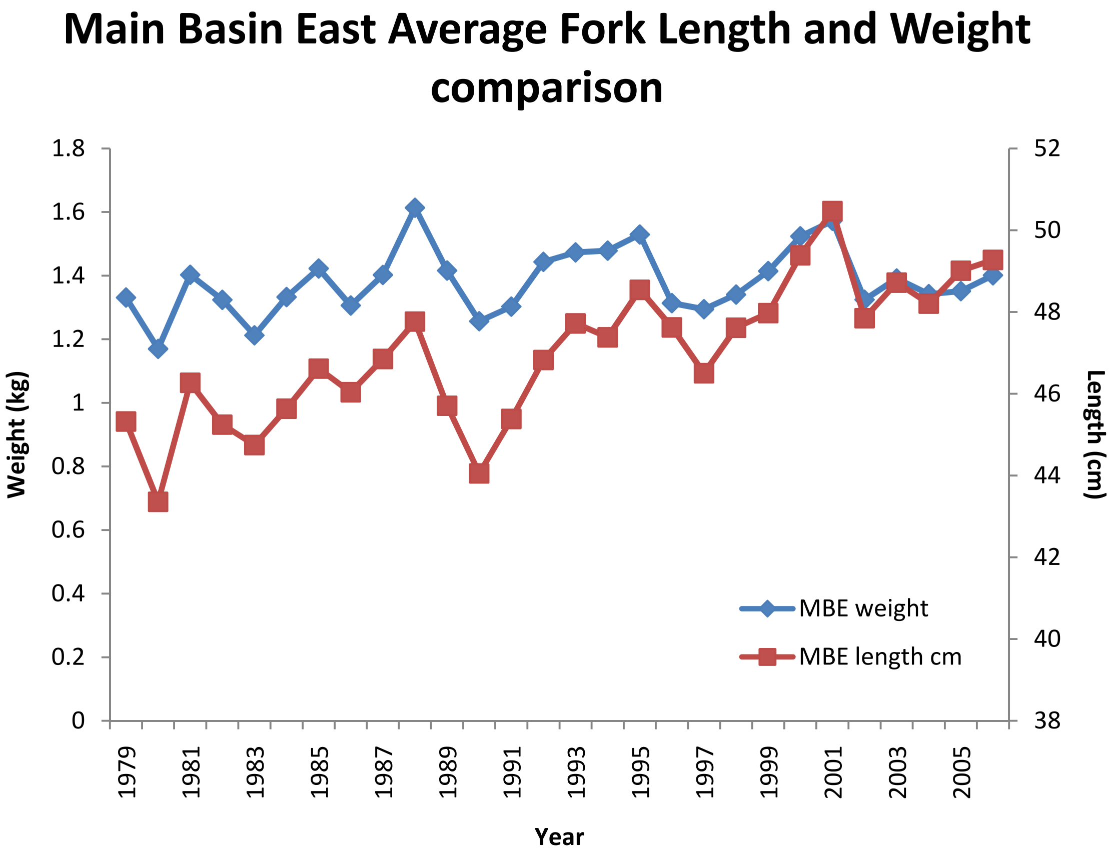


Figure A2.1 - Comparison of Average Fork Length and Average Weight for Main Basin East of Lake Huron. From 1979 to 1995 increases and decreases in average fork length and average weight are proportional to one another. From 1996 to 2006 increases and decreases in average fork length and weight are less proportional to one another, with increases and decreases for average weight being more dramatic than those of average length. Overall, the relation between length and weight for Lake Whitefish caught in Main Basin East has been relatively constant.

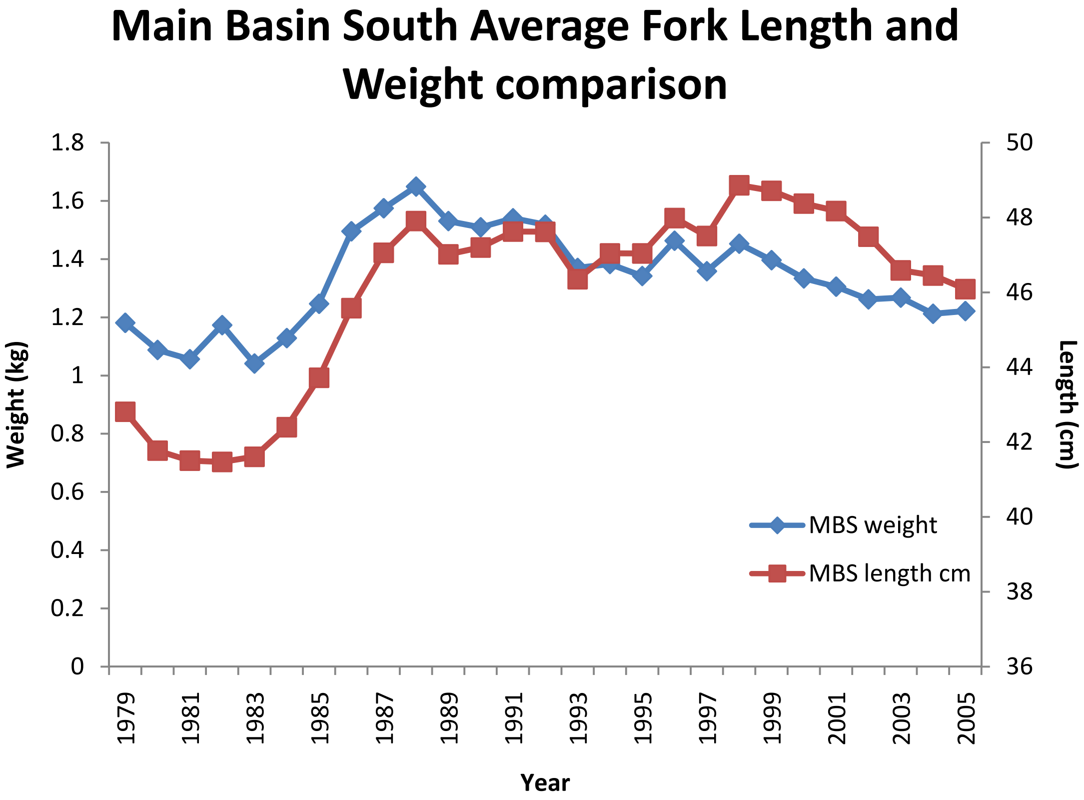


Figure A2.2 - Comparison of Average Fork Length and Average Weight for Lake Whitefish caught in Main Basin South of Lake Huron. In general increases and decreases in length and weight of Lake Whitefish across the entire twenty-seven year time series sampled change proportionally in tandem to one another. In the first part of the time series examined from 1979 – 1989 the average weight of Lake Whitefish increases more dramatically than increases in average length over the same time series. From 1989 -1997 average length and average weight increase in direct proportion to one another. From 1999 – 2006 average weight decreases more rapidly in proportion to average length, possibly lending credence to relatively recent anecdotal observations of Saugeen-Ojibway fisherpersons that more of the catches are comprised of longer and skinnier individuals.

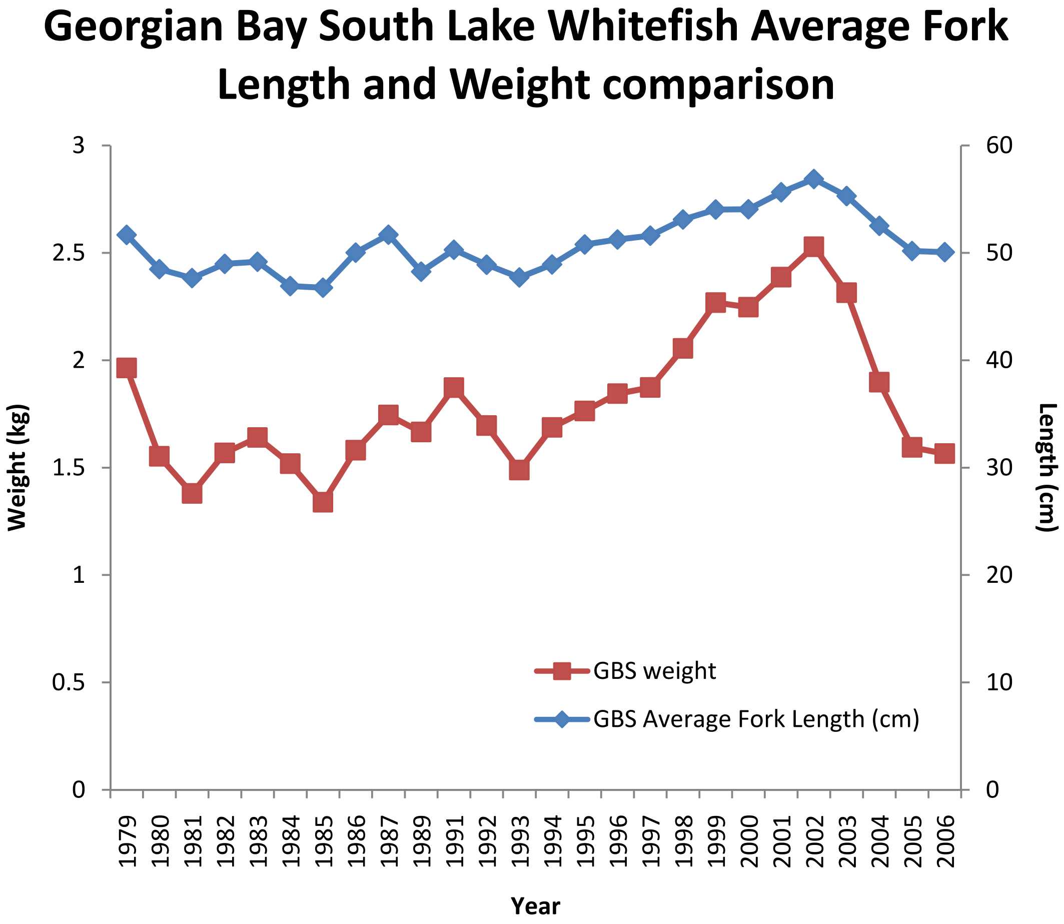


Figure A2.3. Comparison of Average Fork Length and Average Weight for Lake Whitefish caught in Georgian Bay South. When comparing changes in Average Fork Length and Average Weight of Lake Whitefish caught in Georgian Bay South over twenty-seven years the general trend of length and weight increasing in tandem is seen. From 1993 to 2002 the increases in length and weight are not as proportional as in previous years, with weight increasing more dramatically than length during this time period. Additionally from 2002 to 2006 weight decreases more dramatically than length.

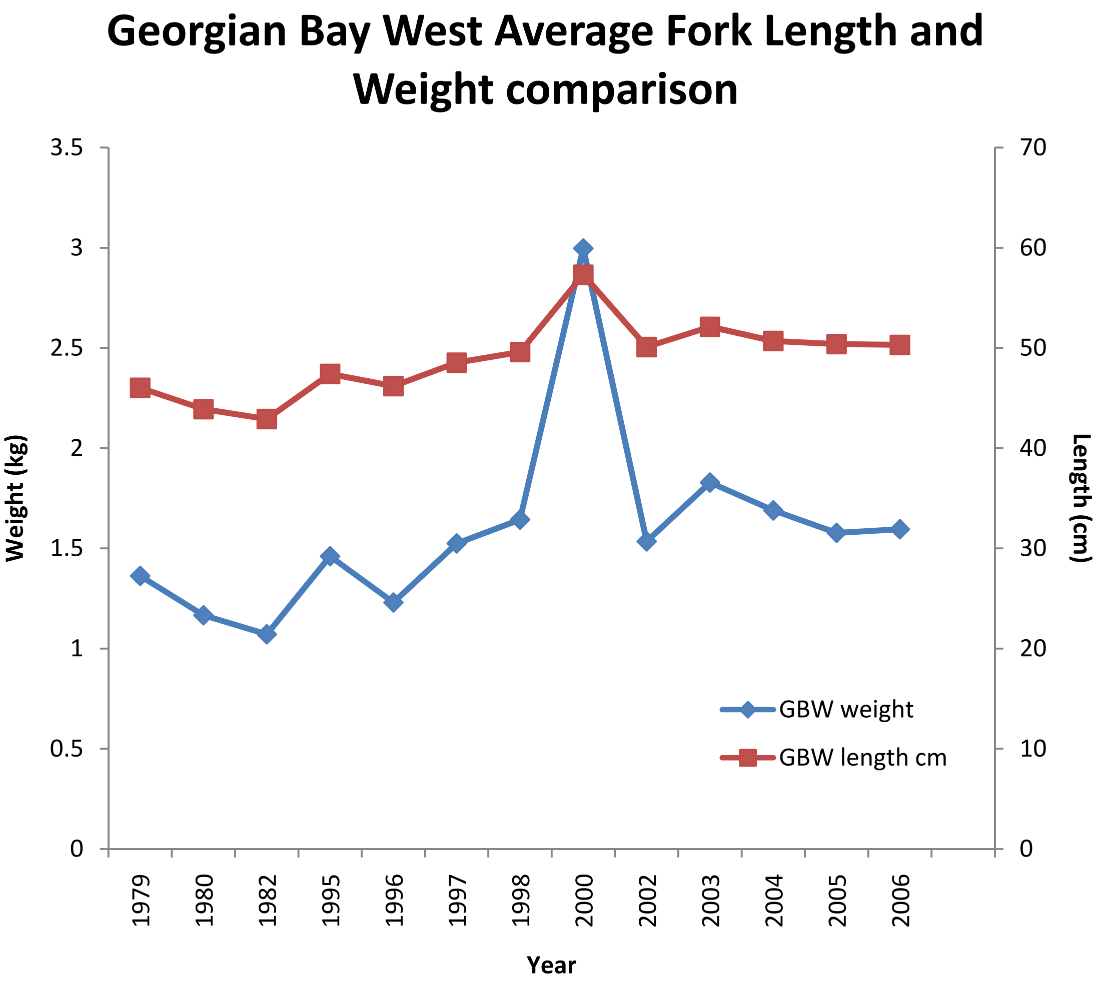


Figure A2.4. Comparison of Average Fork Length and Average Weight in Georgian Bay West. With the exception of the year 2000, length and weight increase proportionally in tandem and then decrease proportionally from 2002 to 2006.

Appendix 3. Sensitivity Analysis

Georgian Bay South

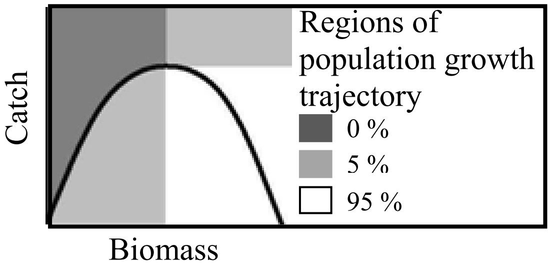
Sensitivity to changes in r and K

Table A3.1 Posterior distributions for alternative priors for *r* and *K*

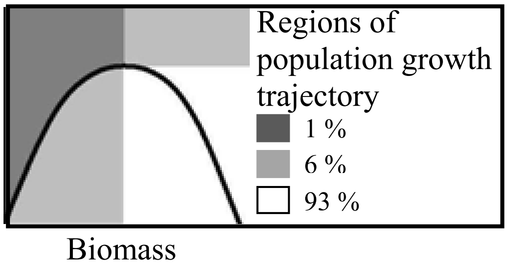
Priors (all others *base-case*)		**Posterior Distributions**					
		r		*K*		*q*	
r	*K*	Mean	SD	Mean	SD	Mean	SD
Base-case	*Base-case*	0.36	0.14	3210	1700	0.08	0.04
Base-case	*100% Increase*	0.34	0.14	10000	2145	0.02	0.006
Base-case	*50% Decrease*	0.42	0.15	2604	1190	0.09	0.04
100% Increase	*Base-case*	0.76	0.13	2888	1662	0.09	0.04
50% Decrease	*Base-case*	0.24	0.17	4173	1909	0.06	0.03

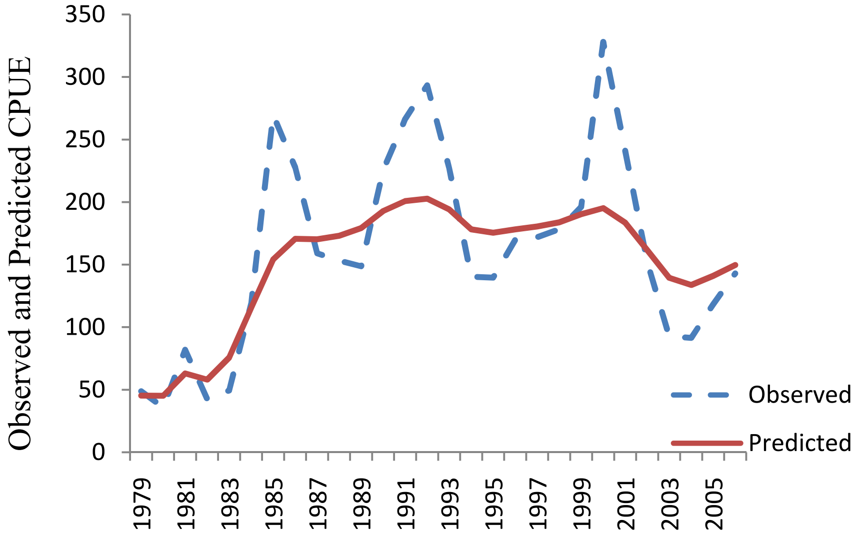
1. r=base case, K=100% increase K ~ dlnorm(9.2,21.1)I(5500,17000)

TAC 180 000 rkg 10-year



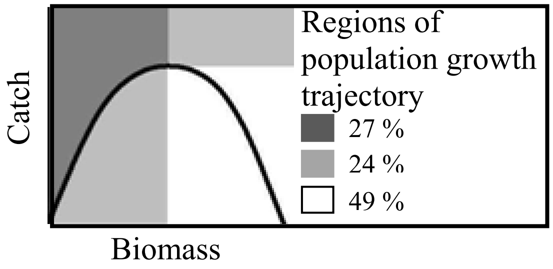
TAC 240 000 rkg 10-year



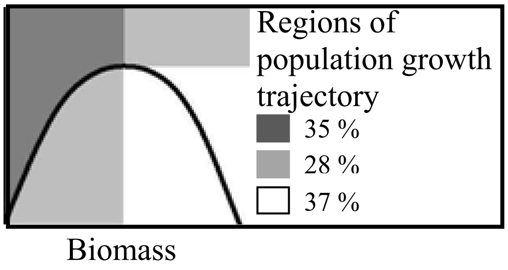


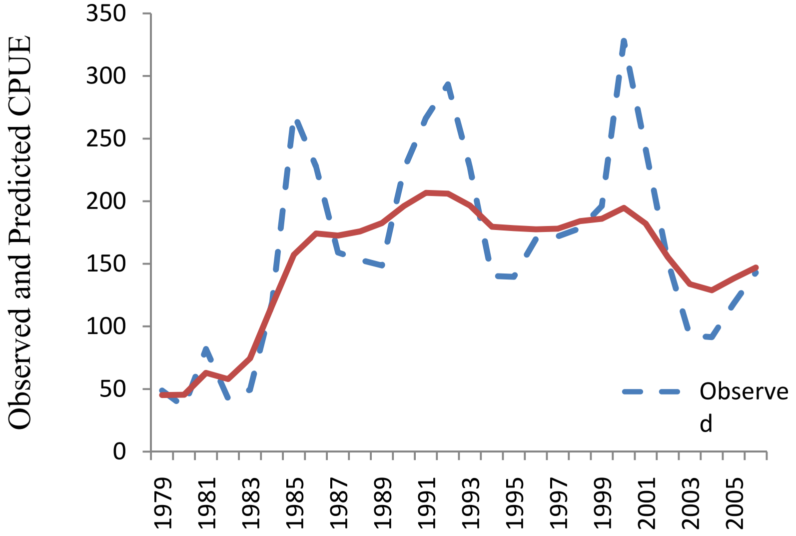
2. r=base case, K=50% decrease K~dlnorm(6.6,1)I(50,7000)

TAC 180 000 rkg 10-year



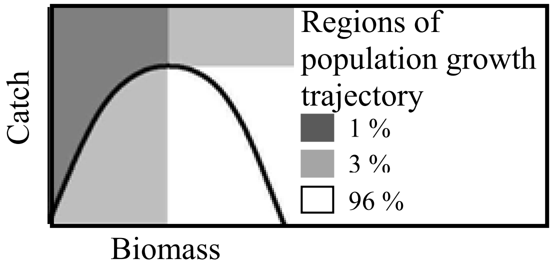
TAC 240 000 rkg 10-year



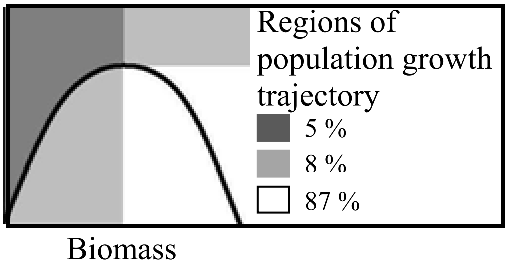


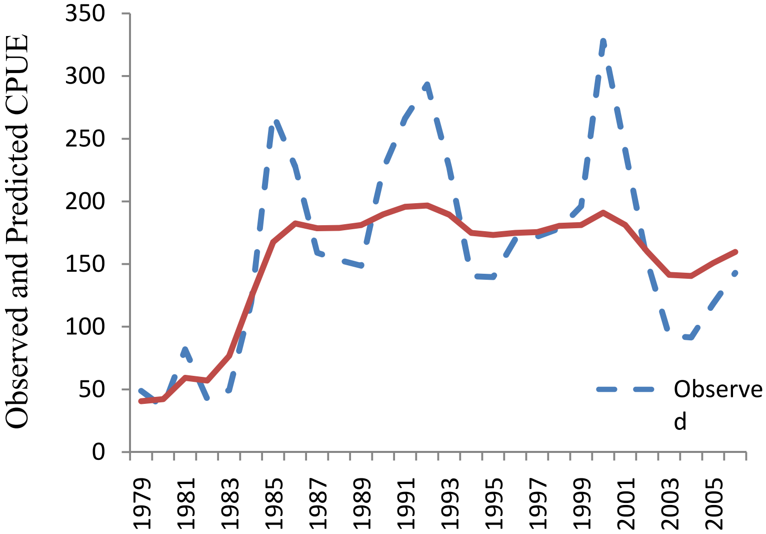
3. r=100% increase r~dlnorm(-0.105,24)I(0.01,2), K=base case

TAC 180 000 rkg 10-year



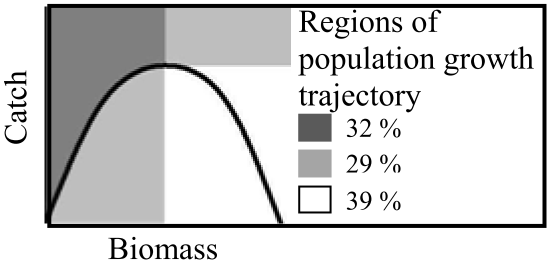
TAC 240 000 rkg 10-year



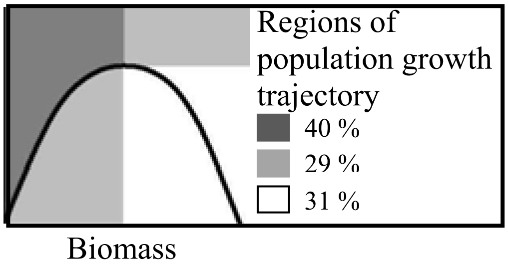


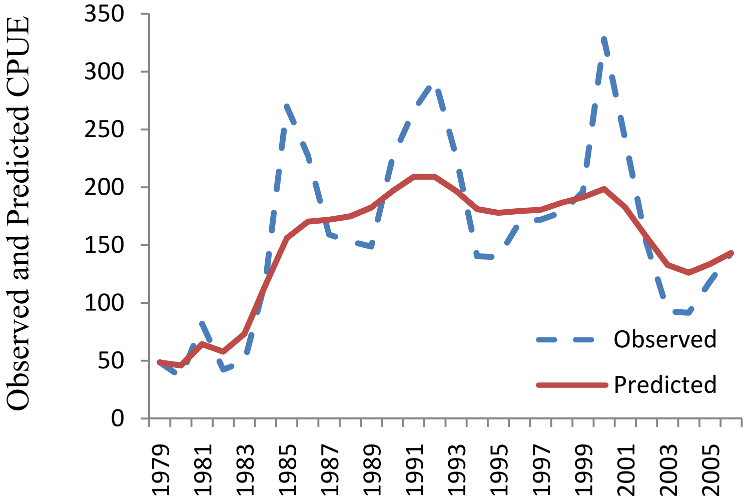
4. r=50% decrease r~dlnorm(-2.6,1)I(0.001,2), K=base case

TAC 180 000 rkg 10-year



TAC 240 000 rkg 10-year





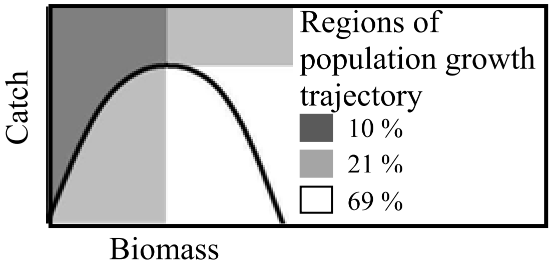
Sensitivity to changes in σ^2 and τ^2

Table A3.2. Posterior distributions for alternative priors for σ^2 and τ^2

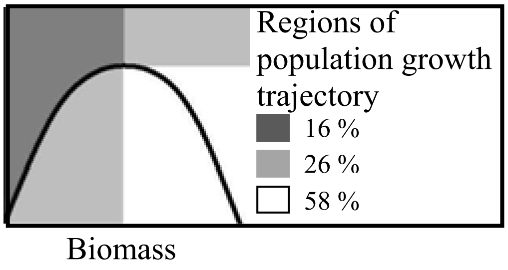
Priors (all others *base-case*)	**Posterior Distributions**	
	Mean	SD
σ^2 Base Case	0.01	0.004
σ^2 Increased Variance	0.03	0.005
τ^2 Base Case (log τ^2)	0.10	0.03
τ^2 Increased Variance (log τ^2)	0.28	0.06

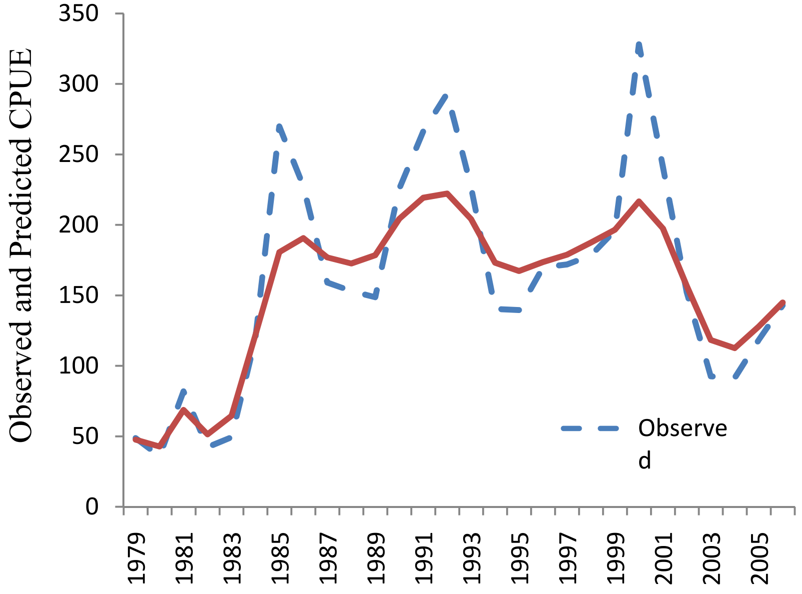
1. σ^2 Increased Variance sigma~dlnorm(31.5,0.04)I(15,45)

TAC 180 000 rkg 10-year



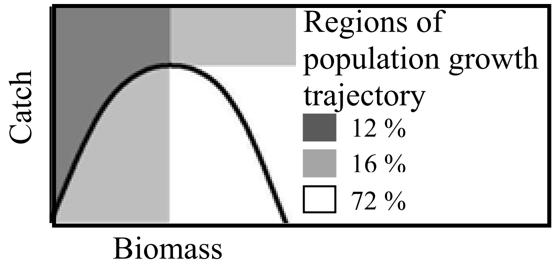
TAC 240 000 rkg 10-year



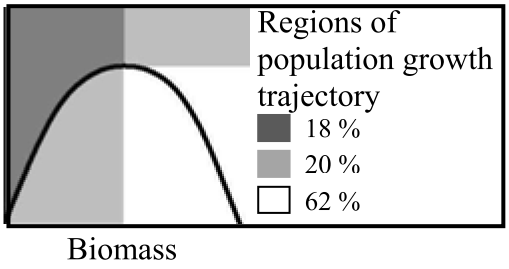


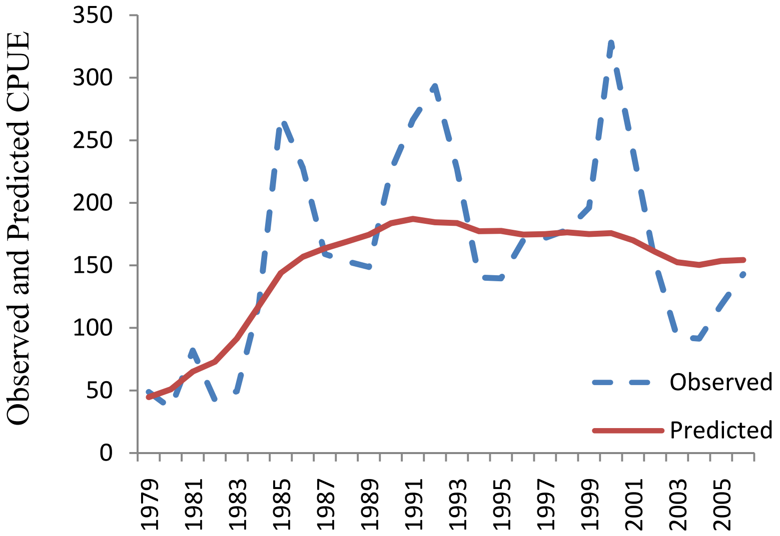
2. τ^2 Increased Variance tau ~dnorm(2.3,1.2)I(0.1,7)

TAC 180 000 rkg 10-year



TAC 240 000 rkg 10-year





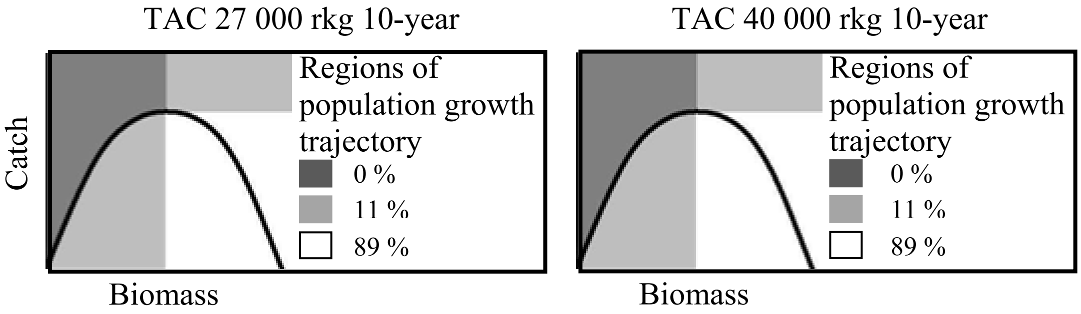
Georgian Bay West

Sensitivity to changes to r and K

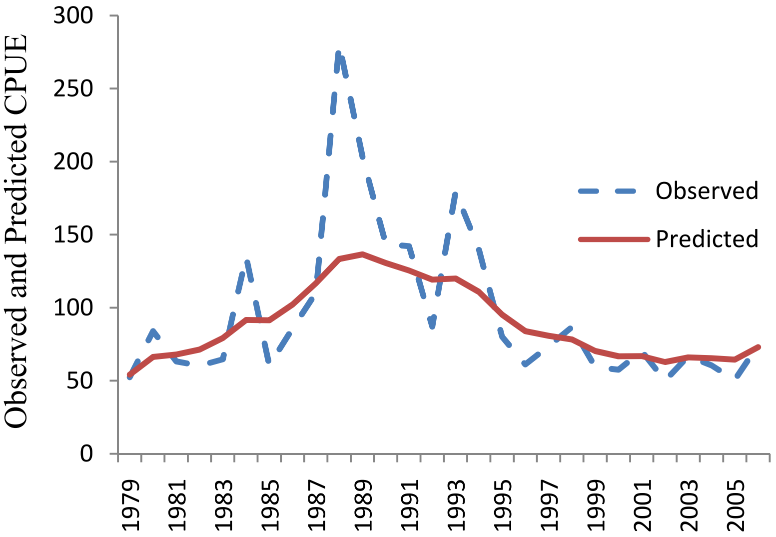
Table A3.3 Posterior distributions for alternative priors for *r* and *K*

Priors (all others *base-case*)		**Posterior Distributions**					
		r		*K*		*q*	
r	*K*	Mean	SD	Mean	SD	Mean	SD
Base-case	*Base-case*	0.31	0.13	799	644	0.23	0.12
Base-case	*100% Increase*	0.21	0.09	4460	1126	0.03	0.01
Base-case	*50% Decrease*	0.33	0.13	635	427	0.26	0.17
100% Increase	*Base-case*	0.35	0.07	689	507	0.23	0.10
50% Decrease	*Base-case*	0.16	0.12	1308	1062	0.16	0.10

1. r=base case, K=100% increase K ~ dlnorm(8.4,16)I(50,10000)

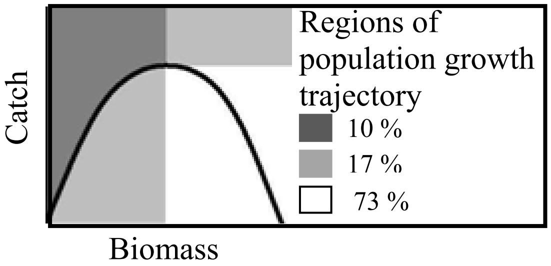

TAC 27 000 rkg 10-year

TAC 40 000 rkg 10-year

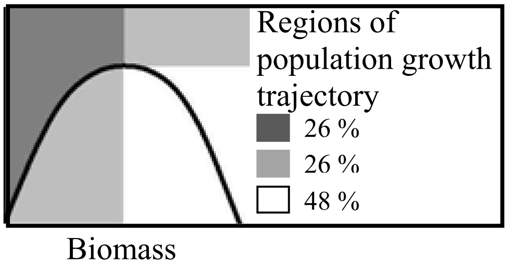


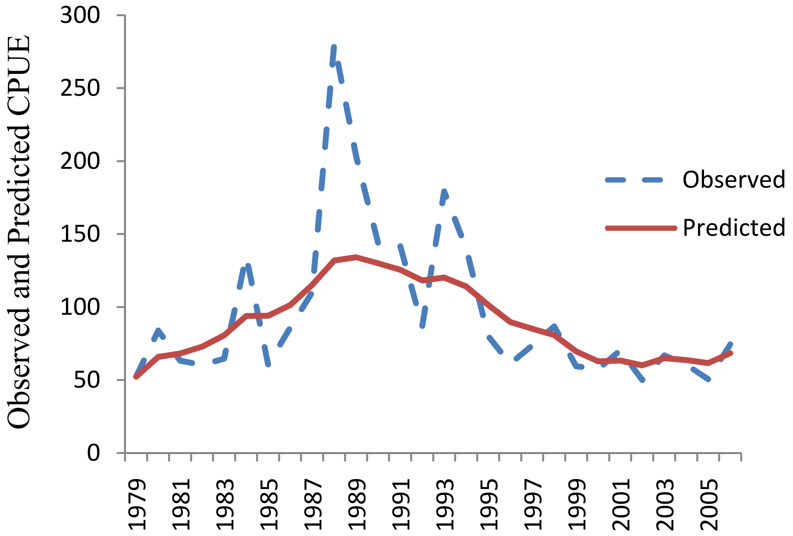
2. r=base case, K=50% decrease K ~ dlnorm(6.2,1.6)I(50,10000)

TAC 27 000 rkg 10-year



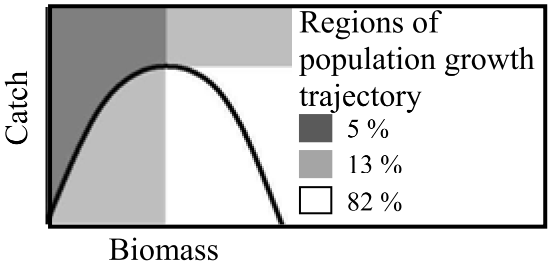
TAC 40 000 rkg 10-year



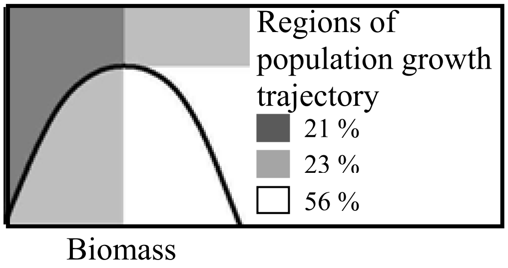


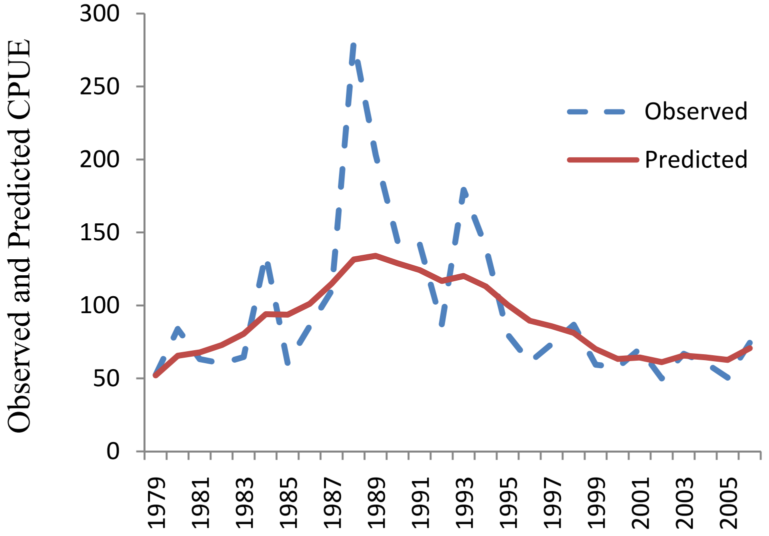
3. r=100% increase r~dlnorm(-0.105,24)I(0.01,2), K=base case

TAC 27 000 rkg 10-year



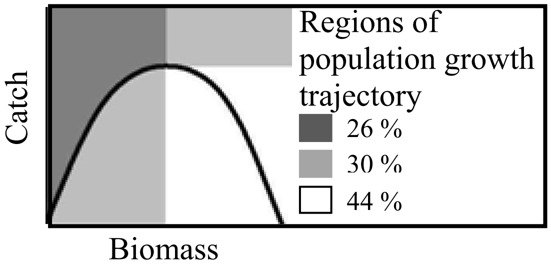
TAC 40 000 rkg 10-year



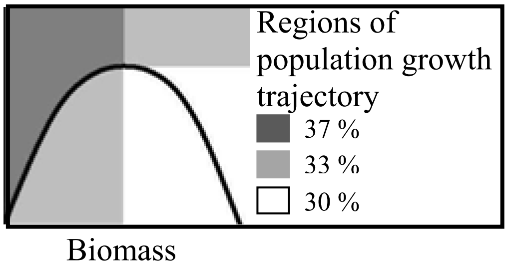


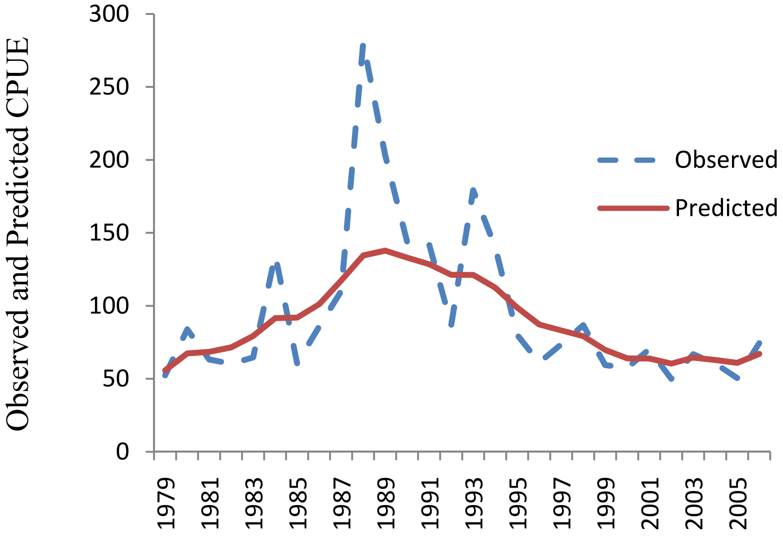
4. r=50% decrease r~dlnorm(-2.6,1)I(0.001,2), K=base case

TAC 27 000 rkg 10-year



TAC 40 000 rkg 10-year



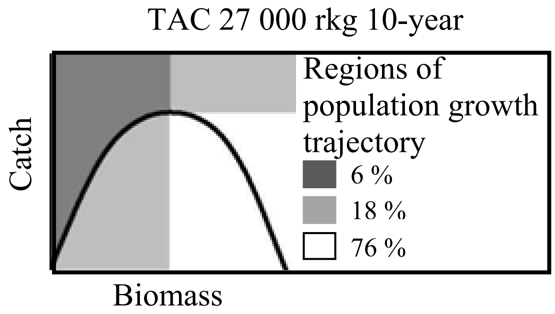


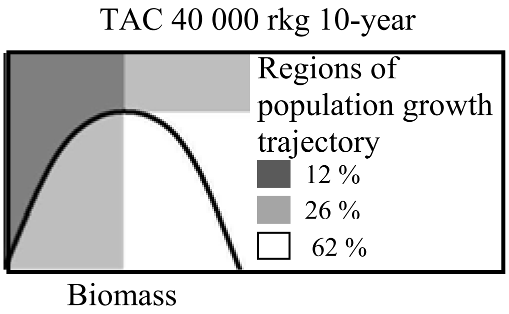
Sensitivity to changes in σ^2 and τ^2

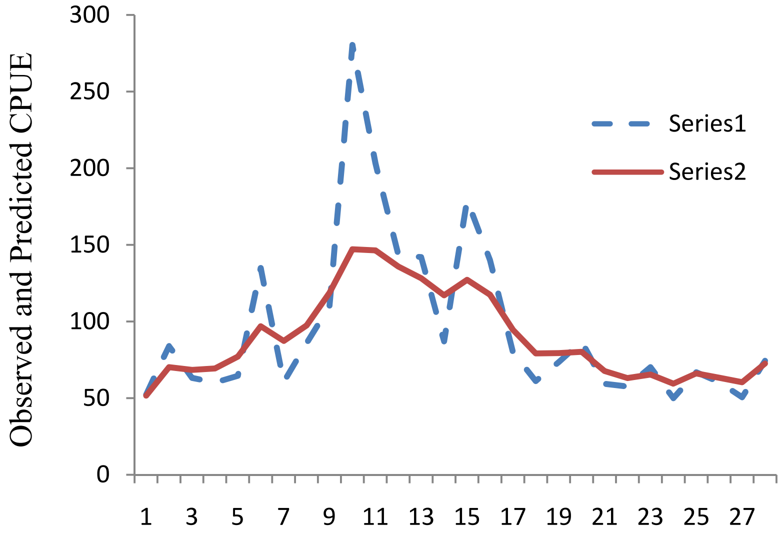
Table A3.4. Posterior distributions for alternative priors for σ^2 and τ^2

Priors (all others *base-case*)	**Posterior Distributions**	
	Mean	SD
σ^2 Base Case	0.01	0.003
σ^2 Increased Variance	0.03	0.005
τ^2 Base Case(log τ^2)	0.09	0.028
τ^2 Increased Variance (log τ^2)	0.23	0.046

1. σ^2 Increased variance sigma~dlnorm(31,0.04)I(15,45)

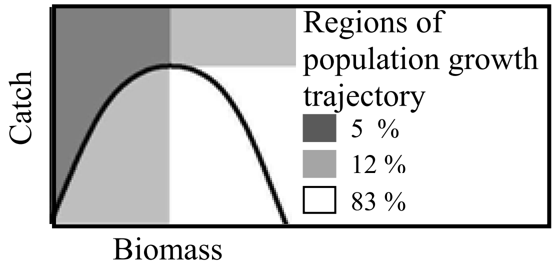

TAC 27 000 rkg 10-year


TAC 40 000 rkg 10-year

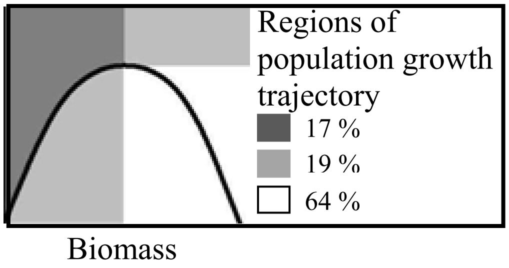


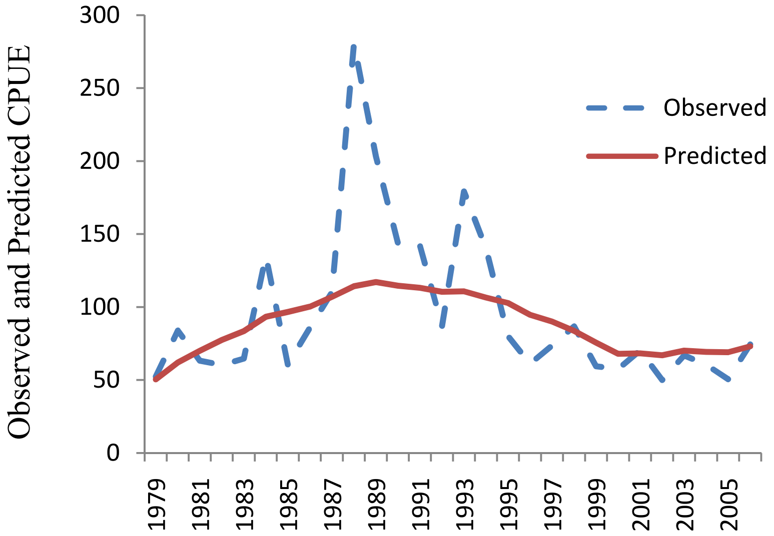
2. τ^2 Increased variance tau ~ dnorm(2.8,0.8)I(0.01,6)

TAC 27 000 rkg 10-year



TAC 40 000 rkg 10-year





Appendix 4. Data Exchange and Data Management

<u>Formatting OMNR commercial harvest and effort data</u>

The OMNR databases, received from LHMU on May 1, that are used in this report:
LHMU_CF_07MAR06.mdb
LHMU_CH_07MAR06.mdb

CH Database

1. Creation of a unique identifier for effort information in table LHMU_New_131
    - A make table query created a new *COMB_CODE* using *[YEAR] + [-OMNR-] +[PRJ_CD] + [CHSAM]* from table LHMU_New_131.
    - The formatted table is named LHMU_New_131_coded.

2. Creation of a unique identifier for effort information in table LHMU_New_132
    - A make table query created a new *COMB_CODE* using *[YEAR] + [-OMNR-] +[PRJ_CD] + [CHSAM]*, and created a new *COMB_EFF_CODE* for each commercial harvest using *[YEAR] + [-OMNR-] + [PRJ_CD] + [CHSAM] + [EFF]* from table LHMU_New_132.
    - Six criteria were used in the creation of the formatted table:

Field	Criteria
SPCTRG	“091”
GRID	>””
GRTP	“GL”
MESH5	>0
EFFDST (converted to km)	>0
EFFDUR (converted to days)	>0

    - The formatted table is named LHMU_New_132_coded_091_GL.
    - A find duplicates query identified no records with duplicate *COMB_EFF_CODE.*

3. Creation of a unique identifier for effort information in table LHMU_New_133
    - A make table query created a new *COMB_EFF_CODE* for each commercial harvest using *[YEAR] + [-OMNR-] + [PRJ_CD] + [CHSAM] + [EFF]* from table LHMU_New_133.
    - One criteria was used in the creation of the formatted table:

Field	Criteria
SPC	“091”

    - The formatted table is named LHMU_New_133_coded_91.

4. Creation of a targeted lake whitefish harvest table
    - A find unmatched query identified unmatched harvest records between LHMU_New_132_coded_091_GL and LHMU_New_133_coded_91 using the field *COMB_EFF_CODE*. 324 unmatched records were removed.
    - A make table query was used to combine targeted gillnet effort for lake whitefish (LHMU_New_131_coded and LHMU_New_132_coded_091_GL) with harvest of lake whitefish (LHMU_New_133_coded_91).

- A field named *SumOfHVSWT* was created to sum *HVSWT* (round kg) across dublicate *COMB_EFF_CODE* records. *SumOfHVSWT* provides the total weight of lake whitefish for each unique harvest event (*COMB_EFF_CODE*).
- The formatted table is named LHMU_overall_091_GL_091.mdb

5. Creation of a targeted lake whitefish CPUE table
   - A make table query was used to add two additional fields to the LHMU_overall_091_GL_091.mdb table, these are:

Field	Description
CPUE_RKGKM	Round kg / km gillnet
CPUE_RKGKMDAYS	Round kg / km gillnet / days set

   - The formatted table is named LHMU_overall_091_GL_091_CPUE.

CF Database

The Effort information in the OMNR CF database (Biological Samples) does not link to the Effort information in the CH database (Commercial Harvest). Both are given *COMB_CODE* fields; however, at no time in the data formatting or analysis process are these tables linked.

1. Creation of a unique identified for effort information in table cf_121
   - A make table query created *COMB_CODE* using *[YEAR] + [-OMNR-] +[PRJ_CD] + [SAM]* from cf_121.
   - Three criteria were used in the creation of the formatted table:

Field	Criteria
SPCTRG	"091"
MESH5	>0
GRTP	"GL"

   - The formatted table is named cf_121_coded_091_GL

2. Creation of a unique identified for biological sample information in cf_125
   - A make table query created *COMB_CODE* using *[YEAR] + [-OMNR-] +[PRJ_CD] + [SAM]*, and *INDIV_CODE* using *IIf([EFF] Is Null,[YEAR]+'-OMNR-'+[PRJ_CD]+'-'+[SAM]+'-'+[FISH],[YEAR]+'-OMNR-'+[PRJ_CD]+'-'+[SAM]+'-'+[EFF]+'-'+[FISH])* from table cf_125.
   - Six criteria were used in the creation of the formatted table:

Field	Criteria
SPC	"091"
FLEN	>0
RTW (converted to kg)	>0

   - Formatted table is named cf_125_coded_091

3. Creation of a targeted lake whitefish biological samples database
   - A make table query was used to combine targeted gillnet effort for lake whitefish (cf_121_coded_091_GL) with individual biological sample data (cf_125_coded_091).

- The formatted table is named cf_overall_GL_091 (Several records contain ages with missing AGEM or contain unknown AGEM codes; these were removed before using this database for age analyses).
- A find duplicates query was used to identify and remove 1 record (both entries removed as they contained different values) with duplicate *INDIV_CODE*

<u>Formatting Saugeen Ojibway commercial harvest and effort data</u>

Databases used in this report:
2006_07_26 SO Master.mdb

Modify Saugeen Ojibway Nations Master database to mirror "CH" and "CF" format

1. Creation of targeted lake whitefish harvest (CPUE) table
   - A make table query was used to combine targeted gillnet effort for lake whitefish (Effort) with harvest of lake whitefish (Harvest)
     Three criteria were used in the creation of the formatted table:

Field	Criteria
SPCTRG	"091"
GRTP	"GL"
SPC	"091"

   - A field named *SumOfHVSWT* was created to covert harvest weights to round kg, based on fields *HVSWT9*, *WUT* and *WFT*.
   - Two additional fields were added, these are:

Field	Description
CPUE_RKGKM	Round kg / km gillnet
CPUE_RKGKMDAYS	Round kg / km gillnet / days set

   - The formatted table is named SO_overall_GL_091_CPUE.mdb

2. Creation of targeted lake whitefish individuals table in "CF" format
   - A make table query was used to combine targeted gillnet effort for lake whitefish (Effort) with individual biological sample data for lake whitefish (Individuals)
     Five criteria were used in the creation of the formatted table:

Field	Criteria
SPCTRG	"091"
GRTP	"GL"
SPC	"091"
FLEN	>0
RWT (converted to kg)	>0

   - Formatted table is named SO_overall_coded_GL_091_scale (only scale ages were included for consistency with cf_overall_GL_091)

<u>Lake Huron lake whitefish Master Database</u>

Database name: 2006_07_26 Lake Huron Master_091

1. Merging OMNR and Saugeen Ojibway targeted lake whitefish harvest databases

- Append table query was used to append table SO_oveall_GL_091_CPUE to LHMU_overall_091_GL_091_CPUE.
- The formatted table is named Harvest_Lake Huron Mater_091.

2. Merging OMNR and Saugeen Ojibway targeted lake whitefish individual biological sample databases
   - Append table query was used to append table SO_overall_GL_091_scale to cf_oveall_GL_091.
   - Formatted table is named Individuals_Lake Huron Master_091.

3. Creation of a merged Individuals database containing only individuals with scale ages
   - A make table query was used to create a subset of records from Individuals_Lake Huron Master_091 that contain scale ages.
     The following criteria were used in the creation of the formatted table:

Field	Criteria
AGE	>0

   - Seven records were deleted that contained non-scale or unknown ageing structures (field generated from XAGEM). Null entries were retained under the assumption that these fish were aged using scales.
   - Formatted table is named Individuals with ages_Lake Huron Master