UPDATED METHODS FOR ASSESSING HARVEST RULES FOR FRASER RIVER SOCKEYE SALMON

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acknowledgements

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Note: This report carries over text from two previous reports (Cass et al. 2004, Pestal et al. 2008)

Abstract

The Fraser River Sockeye Spawning Initiative (FRSSI) has been an 8-year process to develop guidelines for setting annual escapement and exploitation targets for Fraser sockeye stocks. The initiative began in early 2002, and has since evolved through a series of workshops and on-going feedback from stakeholders. A quantitative modeling tool has been used to support the planning process, and was reviewed by PSARC in 2003. The model has evolved substantially since then, and this Working Paper provides an update on model expansions and revisions. Changes include assumptions about spawner-recruit relationships (e.g. delayed density effects), the range of strategies that can be explored (e.g. allowable mortality rules), mixed-stock simulations (i.e. 19 stocks in 4 management groups), and additional biological mechanisms (e.g. environmental management adjustments, pre-spawn mortality, future patterns in productivity).

Résumé

1 INTRODUCTION

1.1 Purpose of this Working Paper

The Fraser River Sockeye Spawning Initiative (FRSSI) has been a multi-year collaborative planning process to develop a long-term escapement strategy for Fraser River sockeye salmon.

- A simulation model to evaluate alternative control rules for Fraser sockeye was reviewed by PSARC in June 2003. The resulting CSAS Research Document provided the background for a series of multi-interest stakeholder workshops (Cass et al. 2004)
- The simulation model evolved considerably as the initiative progressed over 4 years of collaborative development and implementation. The FRSSI process and its application to annual escapement planning are documented in Pestal et al. (2008).
- Given the substantial amount of accumulated revisions to the model and its underlying assumptions since 2004, a review of the methods is once again necessary.

The objective of this Working Paper is to:

- Review methods to evaluate the performance of alternative escapement strategies (i.e. harvest control rules) for Fraser River sockeye populations.
- Explore the sensitivity of different escapement strategies to key sources of uncertainty (e.g. alternative population dynamics, patterns of productivity)

Methods documented in this Working Paper support the evaluation of alternative escapement strategies. Target levels of allowable mortality shape pre-season fishing plans, guide in-season management decisions, and provide a reference point for post-season review.

1.2 Population structure and life history of Fraser River sockeye salmon

Sockeye spawn in over 150 natal areas throughout the Fraser River watershed, from areas near the estuary to as far as 1,300 km upstream. More than 270 groups of spawning sockeye have been identified throughout the Fraser River watershed, each with a specific combination of spawning location and migration time (Holtby and Ciruna 2007). Sockeye are not persistently present at all of these sites, but were observed at least once in the available assessment data

The Fraser watershed is vast at over 220,000 km^2, and the spawning migration is protracted from June to October, so that these spawning groups are aggregated into production units, called *stocks*, for the purpose of monitoring status (e.g. Cass et al. 2000) , developing forecasts (e.g. Grant et al. 2010), and analyzing population dynamics (e.g. Ricker 1997). Stocks are identified based on the geographic location of spawning streams and rearing lakes, as well as the timing of adult migration. Most of the system's production is accounted for by a few large stocks or stock groups: Birkenhead, Weaver, Chilko, Quesnel, Stellako, Stuart (Early and Late), Adams and Shuswap (Table 1). The model documented in this Working Paper incorporates 19 distinct stocks that capture most spawning populations and most of the annual sockeye production. However, in some recent years, *miscellaneous* stocks that are not covered in the model have contributed 30-40% of the Early Summer run size (Table 3).

Stocks are further aggregated into management groups based on similar migratory timing during their return from the ocean. These management groups overlap to a varying degree each year, and discrete harvest of individual stocks or stock aggregates downstream of terminal areas is not possible for three of four timing groups (p. 16).

The management groups are, in order of adult migration:

- *Early Stuart:* about 7 individual spawning sites in the Takla-Trembleur lake system, arriving in the lower Fraser River from late June to late July. Early Stuart is modelled as a single stock.
- *Early Summer:* about 75 individual spawning sites throughout the Fraser system, arriving in the lower Fraser River from mid-July to mid-August; Early Summer is modelled as 8 stocks (Bowron, Raft, Seymour, Fennel Creek, Scotch Creek, Gates, Nadina, Upper Pitt River). In annual implementation, escapement strategies for Early Summer are scaled up to account for the expected abundance of miscellaneous other stocks.
- *Summer:* about 12 individual spawning sites, mostly in the Chilko, Quesnel, Stellako and Stuart systems, arriving in the lower Fraser River from mid-July to early September.
- *Late:* about 160 individual spawning sites in the lower Fraser, Harrison-Lillooet, Thompson and Seton-Anderson systems, arriving in the river from late August to mid-October. The Late group is modelled as 6 stocks (Late Shuswap, Birkenhead, Cultus, Portage, Weaver, Harrison).

Finer distinctions have been used in recent years. For example, some components of the Late run (i.e.. Birkenhead-type lates) were managed differently from the other components which were thought to experience a higher rate of en-route mortality (i.e. true lates). Following a decision by the Fraser Panel in 2010, the Birkenhead-type lates will be re-integrated into the Late run management regime, including the escapement planning model discussed in this paper.

As implementation of the *Wild Salmon Policy* (DFO 2005) unfolds, the focus of salmon management is shifting to functionally distinct conservation units (CU). A methodology for delineating CUs has been established (Holtby and Ciruna 2007), but the resulting list of CUs is still undergoing scientific and public review[1].For Fraser sockeye, these CUs are generally based on rearing lakes and timing, currently with 251 individual groupings in 31 CUs. In addition, approximately 20 individual groupings are river-type sockeye which do not rear in lakes (e.g. spawners from the Harrison River/Widgeon Creek system), and these are grouped into 6 CUs. River-type sockeye start their migration to the ocean a year earlier than populations that rear in lakes, and can face very different environmental conditions as juveniles.

The life history of Fraser River sockeye is complex, and has been intensively studied (e.g. Groot and Margolis 1991, Roos 1991, Ricker 1997). A brief summary follows: Fraser sockeye spawn in small streams, large rivers, or lakes. Juveniles generally rear in large lakes for one year as fry before migrating seaward as smolts, entering the Strait of Georgia and moving north along the continental shelf into the Gulf of Alaska. The majority of Fraser River sockeye rear in the Gulf of Alaska for two winters before returning to the Fraser River as 4-year old adults. The technical notation for this life

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[1] Updated CU lists are available at http://www.pac.dfo-mpo.gc.ca/consultation/wsp-pss/strat1/index-eng.htm

cycle is 4_2, designating a total life span of four years, with the first 2 winters spent in the freshwater environment. A variable proportion of adults return as 5-year olds, and some males also return as smaller 3-year olds called jacks. Returning adults typically approach the North Coast of BC, and then migrate south to the Fraser River estuary.

Assumptions about the life history of Fraser sockeye are the single biggest factor in the simulated performance of alternative escapement strategies, with vigorous on-going debate about the following:

- Estimates of inherent productivity (i.e. recruits / spawner at low abundance)
- Estimates of productive capacity (i.e. abundance of spawners that maximizes recruitment)
- Effect of large spawner abundance in the brood year (i.e. potential for over-escapement?)
- Effect of large spawner abundance in some previous year (i.e. cyclic dominance / delayed density effects)

Section 2.2.4 covers each of these topics.

1.3 Developing escapement strategies for Fraser River sockeye salmon

Pestal et al. (2008) summarize escapement planning for Fraser River sockeye since the mid-1980s. A brief overview follows below. Implementation details are documented in the annual reports of the Fraser River Panel (e.g. PSC 2006).

Following the signing of the Pacific Salmon Treaty in 1985, a "*Rebuilding Plan*" was designed to increase annual escapements incrementally from historical levels (Collie et al. 1990, FRAP-FMG 1995). The DFO task force identified *Interim Escapement Goals* between escapements observed at the time and estimated optimal escapements. A basic premise of the rebuilding plan was to increase escapements each year beyond brood year levels to maintain an increasing rebuilding trajectory towards interim escapement targets. In periods of high or increasing survival, these escapement targets can be met with little short-term economic losses. To meet rebuilding targets during years of low survival, a higher fraction of the run is allocated to escapement rather than catch.

An implementation plan was developed which identified:

- Lower bounds for annual target escapement designed to maintain escapements above brood year levels for Early Summer, Summer and Late Run aggregates.
- Lower bound for annual target escapement on the Early Stuart aggregate fixed at 66,000 spawners and then revised to 75,000 spawners through consultations.
- Upper bounds on annual target escapement for all aggregates based on a 65% exploitation rate ceiling.

This implementation plan guided escapement management from 1987 to 2002, but stocks and harvests didn't respond as hoped (Figure 1, Figure 2). Productivity fluctuated considerably (Figure 3), and has shown a marked decrease in recent years (Figure 4). In addition, harvest opportunities on abundant and productive stocks were constrained by less productive or less abundant stocks intercepted in the same fisheries (e.g. Interior Fraser coho, steelhead). Due to a combination of these factors, the management balance has shifted from catch to spawner abundance (Figure 4). Larger total abundances could likely have been achieved from the increased escapements of the 1990s and early 2000s if productivity had remained stable at the levels observed in the 1970s and 1980s. However, spawner levels and resulting returns would have been much lower for many of the Fraser River sockeye stocks if pre-1987 exploitation patterns had been maintained in the face of reduced productivity.

Support for the rebuilding plan, as conceived in the 1980s, had diminished by the early 2000s due to a decline in catch, difficulty of accommodating multiple objectives, and the constraints of a strict rebuilding schedule (Cass et al. 2000, Pestal et al. 2008).

DFO initiated a review of the rebuilding plan in 2003 to address the growing concerns expressed by stakeholders and recommendations from the 2002 Ministerial review of Fraser River sockeye fisheries (DFO 2003). The mandate of the review process was to incorporate new information, integrate emerging policies such as the *Wild Salmon Policy* (DFO 2005), and establish a formal framework for setting annual escapement targets. Over the next 8 years DFO led a collaborative process, called the *Fraser River Sockeye Spawning Initiative* (FRSSI), and regularly brought together participants from First Nations, the commercial fishing industry, recreational fishing, environmental non-government organizations, and the provincial and federal governments.

The technical groundwork was laid through the development of a simulation model (Cass et al. 2004) which was refined over three years and six workshops, leading up to an intensive two-year planning exercise that merged FRSSI into a pilot implementation of the integrated management processes envisioned under the Wild Salmon Policy.

Since 2006, the simulation model has been fully integrated into the annual management cycle for Fraser River sockeye, which is bracketed by two phases of public consultation, the *post-season review* in the fall and *pre-season planning* in the spring. Both of these consultations unfold as a combination of formal advisory processes (e.g. *Integrated Harvest Planning Committee),* bilateral meetings with First Nations, and townhall-style meetings with the general public (e.g. in coastal communities). Each year, the FRSSI model is used to examine a range of alternative escapement strategies for each management group. A shortlist of 3 to 5 options for each management group is selected based on pre-season expectations for each alternative and a summary of simulation results. These options are then presented for broad public review during the annual pre-season consultations (e.g. draft Integrated Fisheries Management Plan, annual technical memo). Occasionally, additional options are added to the options list based on feedback generated during the review process. One option is then included in the final management plan.

The modelling framework developed for the *Spawning Initiative* is consistent with the biological principles outlined in the WSP. For example, the stocks included in the simulation model closely match up with lake-based conservation units (Table 2) and escapement strategies are evaluated based on the performance of individual stocks, not management groups. Unfortunately, there are only 19 stocks with sufficient escapement and return data to allow incorporation into the simulation model. This presents an ongoing challenge for the operational aspects of the *Wild Salmon Policy*, and a coast-wide approach is under development for incorporating CUs with insufficient data into the planning and implementation of fisheries (Mark Saunders, pers. comm.). In addition, there is a paper in progress that is scheduled to be reviewed in the fall of 2010 on Fraser Sockeye benchmarks. Once these are available, we will re-assess the performance of the stocks against the formal WSP benchmarks.

2 METHODS

2.1 Model overview

The FRSSI model is intended as a formalized, quantitative tool for exploring the expected long-term performance of escapement strategies for Fraser sockeye under a wide range of alternative assumptions (e.g. population dynamics, future changes in productivity). The model is simply a thinking aid, a consistent way of linking and tracking some of the many considerations that are debated during the annual planning process. Alternative options and assumptions can be easily explored through a series of "what if?" scenarios. This works best in a collaborative setting, but the inevitable complexities create substantial communication challenges in multi-stakeholder workshops.

The FRSSI model currently simulates 19 stocks of Fraser sockeye forward for 48 years and applies different long-term escapement strategies chosen by the user. It tracks the performance of management groups as well as individual stocks, and is set up to explore the following options and assumptions:

- Alternative escapement strategies applied on an annual basis (i.e. fixed escapement, fixed exploitation rate, modified hockey stick: allowable mortality changes with run size)
- Alternative spawner-recruit models
- Changing patterns of productivity
- Alternative assumptions about management adjustments (i.e. en-route mortality)
- Effect of overlap in return timing
- All stocks within a management group are exposed to the same exploitation rate and environmental mortality, and catches are not taken in specific areas or fisheries

However, the current model is not set up to address the following:

- in-season management strategies (e.g. dealing with uncertain and changing forecasts)
- alternative fishing plans (i.e. timing and location of harvests)
- catch sharing across sectors or areas
- annual adjustments to escapement strategy

The FRSSI model is designed as a big-picture model to address long-term management questions (e.g. Which types of strategies tend to be robust to uncertainty in population dynamics?) rather than a detailed model to address operational questions (e.g. What is the optimal fishing plan for next week, given the latest estimates of abundance, timing, and management adjustments?). As an illustration, the FRSSI model can be thought of as a regional planning tool (e.g. helps to choose among alternative transit plans for a region), and not like an engineering tool (e.g. simulates earthquake safety of alternative bridge designs).

Given this intent, the FRSSI model does not attempt to explicitly incorporate all of the biological mechanisms that are being investigated for Fraser sockeye. There are other processes, with their own models, that deal with them in more detail. For example:

- Annual forecasting models for each stock to shape pre-season expectations (Grant et al. 2010 *in press*)
- In-season fisheries planning model and Management Adjustment (MA) model that support in-season deliberations of the Fraser River Panel (Cave and Gazey 1995, Patterson and Hague 2007, Macdonald et al. 2010)
- Population viability model for Cultus sockeye that supports the deliberations of the Cultus Recovery Team (Korman and Grout 2008)
- Conservation Unit (CU) viability model that supports the development of benchmarks under the Wild Salmon Policy (Holt et al. 2009).
- The conceptual structure for a more detailed in-season management model is currently being developed, and that more detailed model is expected to simulate how individual stocks, each with their own timing, move through a sequence of fishing areas

2.2 Biological Sub-Model

2.2.1 Definitions

The primary data that describe the population dynamics are the estimates of annual spawning escapement and the number of adult progeny that are caught in fisheries, perish during upriver migration, or survive to spawn. Escapement is estimated directly using systematic surveys of the spawning population. Estimates of the catch removed from each stock, estimates of migration mortality and estimates of escapement are combined to estimate the total abundance of returning sockeye in a given year.

- Run = adults returning in a brood year (e.g. 2004)
- Catch = total estimated harvest in commercial, recreational, and aboriginal fisheries
- Total spawners = abundance of adults on the spawning grounds in a brood year (e.g. 2004)
- Difference between estimates (DBE) = difference between abundance estimated in the lower river at the Mission hydroacoustics site and abundance on the spawning grounds. Negative DBEs are assumed to be losses due to en-route mortality for the purposes of modelling.
- Effective female spawners = Number of females that successfully contributed to spawning
- Recruits = total adults produced from a brood year (e.g. 2004) and returning 3-5 years later (e.g. 2007 to 2009).
- Productivity = recruits per adult spawner (or per effective female spawner)

The next five sections summarize the current approach to estimating each of these quantities. Figure 5 illustrates how the simulation model links them together.

The simulation model currently includes 19 stocks (Table 1). For 12 of these stocks, escapement and catch by brood year have been routinely measured since 1948. Early in the FRSSI process, another 7 stocks, with shorter time series of available data, were added to better reflect the mixed-stock challenges of management (e.g. differing productivity, more uncertainty in spawner-recruit models). Appendix 3 lists available data for each of the 19 stocks, which account for 98% of the long term average annual run size and escapement, but has ranged from a high of 100% to a low of 89% of the total run and 87% of the escapement in 2004 (Table 3).

The spawner-recruit data used in this analysis are maintained by the Pacific Salmon Commission. For the most up-to-date version of the data, contact Mike Lapointe (lapointe@psc.org). Data for Cultus Lake sockeye are currently being reviewed by the Cultus Sockeye Conservation Team. Note that updated spawner-recruit data include additional years as well as revised estimates for earlier years. Appendix 5 shows the resulting changes in parameter estimates.

2.2.2 Estimates of spawning escapement

Since the late 1930s, escapements have been estimated annually for most of the individual spawning populations in the Fraser River watershed. Over 150 individual populations have been identified. The catch and spawning escapement data for these populations has historically been grouped into 19 stocks for management purposes (Section 1.2).

Between 1937 and 1985, the International Pacific Salmon Fisheries Commission (IPSFC) was responsible for estimating spawner abundance at spawning sites in the Fraser watershed. Experimental work developed during the early years of the IPSFC led to a two-tiered approach for estimating escapement (Atkinson, 1944; Howard, 1948; Schaefer, 1951). Methods used by the IPSFC are described by Woodey (1984). For small populations (<75,000 fish), visual techniques were applied. For larger populations the estimates were based on mark-recapture experiments and to a lesser extent fence counts. With the signing of the Pacific Salmon Treaty in 1985, DFO assumed the responsibility and has generally followed the approach developed by the IPSFC (Schubert, 1998). Pestal and Cass (2009) summarize sampling sites and recent survey coverage.

Visual surveys are either ground or aerial-based and are the least accurate of methods used to estimate salmon spawning escapement. Typically, visual surveys underestimate the known abundance based on fence counts by 2-12 times (Symons and Waldichuk, 1984). Expansion factors for Fraser sockeye have been developed by comparing visual estimates to known fence counts in an attempt to account for the bias in visual estimates (Woodey, 1984; Schubert, 1998). Schubert (1998) reports a factor of 1.8 has been used for Fraser sockeye to expand visual count data. Estimates of total escapement were calculated for river and lake spawning stocks as the product of the maximum daily count of live spawners, the cumulative recovery of carcasses to the day of peak live count and the expansion factor. In glacial systems or lake populations where live fish cannot be observed directly, escapement estimates were the product of the total carcasses recovered and an expansion factor that assumed that each person-day of survey effort recovered 5% of the population. For most populations, however, the reliability of visual survey estimates has not been verified and the uncertainty in accuracy and precision of the estimate is unknown but assumed to be large. Fence counts are considered the most reliable, but are used at relatively few locations for logistical and budgetary reasons (Schubert, 1998). Errors in fence counts result from counting/measurement errors, for example, if the fence is breached or damaged from obstructions or high river discharge.

Mark-recapture estimates are potentially positively biased as a result of tag shedding, tagging induced mortality and abnormal behavioural effects of tagged fish. In comparative studies on the Stellako River, mark-recapture estimate had estimation errors ranging from –1% to 18% compared to the fence counts (Schubert, 2000). This error is less than the error reported in other studies where errors of 2-3 times were typical (Simpson, 1984).

Alternative escapement estimation methods using DIDSON sonar technology have been assessed against traditional methods in recent years.

Sampling at the spawning sites provides estimates of the number of precocious males (jacks) and non-jack males and females. Female carcasses are sub-sampled to estimate the proportion of female spawners that contributed to spawning based on estimates of eggs retained in the sampled carcasses. The latter are categorized as "effective females". In some stocks, anomalously low spawning success has occurred in some years as a result of high pre-spawning mortality. For example, estimated effective females for Chilko sockeye in 1963 only constituted 38% of the total female population. High pre-spawning mortality of Chilko sockeye in 1963 was associated with high water temperatures and anomalous early river entry (Anon., 1964).

The FRSSI model includes spawner-recruit relationships based on total spawners or effective females (Section 2.2.4)

2.2.3 Estimates of catch, en-route mortality, and recruitment

Historic catch estimates from commercial fisheries are based on landing records on fish tickets from U.S. fisheries and dock tallies and fish sales from Canadian fisheries. The Pacific Salmon Commission (PSC) and formerly the IPSFC were responsible for estimating the catch by age and stock (Woodey, 1987; Gable and Cox-Rogers, 1993). Historically, the contribution of individual stocks has been estimated mainly by comparing freshwater growth patterns on scales from catch samples with the pattern from stocks of known origin, based on samples from spawning sites (Henry, 1961; Gable and Cox-Rogers, 1993).

Catch estimation errors of individual stocks in the historical database are the result of insufficient discrimination in scale patterns among stocks, unrepresentative sampling of the catch or spawning sites, or incorrect assumptions about the stock mixture used in the assessment models (Cass and Wood, 1994; Gable and Cox-Rogers, 1993). Biased estimates result from misallocation of the catch of one or more stocks in a mixture to other stocks in the mixture. The bias is larger for small stocks because proportional errors in large stocks within a mixture result in larger absolute errors in catch of small stocks. Catch allocation bias overestimates the abundance and productivity of small populations in years when catch allocation is based on scale growth patterns. Small stock bias still occurs when using DNA for stock identification, but the magnitude of the bias is smaller than when using scale analysis for stock identification (Steve Latham, pers comm.).

Other information used in stock discrimination include differences in age and size composition and historical data on run timing and spawning ground arrival data (Gable and Cox-Rogers, 1993). The accuracy and precision in estimates of catch by stock depends on the number and size of stocks in the catch mixture and the uniqueness of scale patterns. The latter vary depending on variable annual juvenile growth conditions such as juvenile density (Goodlad et al., 1974).

Scale pattern analysis has been supplemented in recent years using parasite and genetic differences among stocks (Bailey and Margolis, 1987; Beacham et al., 1987). DNA-based methods for identifying individual stocks in mixed stock fisheries have improved stock identification accuracy and precision, and are now being used routinely (personal communication Mike Lapointe, Pacific Salmon Commission, Vancouver B.C.)

Section 2.2.6 describes data on the difference between estimates (DBE) of sockeye in the lower Fraser River measured at the hydro-acoustic site at Mission, B.C. and estimates of the population at the spawning sites plus in-river catch above Mission. If they differences are considered to be real, they are incorporated into estimates of total recruitment.

Recruits associated with a particular year of spawning can potentially return as adults 3 to 6 years from the year of spawning. Typically, after hatching, their progeny rear in a lake for one year and spend two summers in the north Pacific before returning to the Fraser River to spawn in the fall. The age of fish that spawn after one year in freshwater and two summers in the ocean is reported by convention as age 4_2 sockeye (Roos, 1991), but hereafter referred to as age-4. We simulate population dynamics based on two predominant age classes for each stock, with age-4 adults accounting for most of the recruitment in 17 of the 19 stocks (Figure 6). Exceptions are Upper Pitt, which return in higher proportions than other stocks as age-5 adults, and Harrison, which are immediate migrants and have a substantial component of mature 3_1 adults (i.e. spent 2 years in the ocean, similar to age 4_2 sockeye). Jacks contribute little to sockeye fisheries and their reproductive potential is unclear. Jacks are not used in the analysis as spawners, but they are included in the estimates of total recruits.

2.2.4 Spawner-Recruit models

Statistical methods have been developed to model the relationship between spawners and recruits, later referred to as SR models (Hilborn and Walters 1992, Quinn and Deriso 1999). For sockeye, these models typically calculate the expected number of 4yr old and 5yr old recruits produced by the spawners in each brood year, and combine these age classes into a projection of run size. SR models typically have 2 estimated parameters: productivity and capacity. Where additional data is available, more complex models can be developed to incorporate additional life stages (e.g. smolt abundance) or environmental factors (e.g. sea surface temperatures when young salmon first enter the ocean).

Models differ depending on the assumptions they make about:

- Inherent productivity (i.e. recruits / spawner at low abundance)
- Productivity at very low escapement (e.g. is there a point at which production levels fail to provide sufficient recruits to recover due to density-dependent predation, called the predator pit?) (Section 2.2.8)
- Productivity at large escapement (e.g. is there a pronounced decrease in productivity if escapement exceeds capacity, due to mechanisms such as competition for spawning locations?)
- Interaction between cycle lines (e.g. does a large escapement last year affect survival of this year's brood, due to mechanisms such as reduced food availability and increased predator abundance? Or does periodic large escapement increase long-term production due to increased marine nutrients released into the watershed by the carcasses?)

Of the 19 sockeye stocks in the watershed that are enumerated consistently, 8 exhibit persistent cycles with a consistent peak in abundance every four years. If this pattern is very pronounced it is referred to as *cyclic dominance*. In these cases the *dominant* cycle line is the sequence of years with run size persistently larger than the other cycle lines. The *sub-dominant* line has moderate abundance, and *off-year* lines tend to have extremely low abundance relative to the dominant and sub-dominant lines. The dominant cycle lines for different stocks do not necessarily coincide.

Despite 50 years of study, there is still no scientific consensus on the cause of cyclic patterns in the abundance of Fraser sockeye, but recent research points to a combination of biological mechanisms and past harvest patterns (Ward & Larkin 1964, Walters & Staley 1987 , Cass & Wood 1994, Ricker 1997, DFO 2006b). Various ecological hypotheses have been proposed, including interactions with predators, diseases, or parasites. Marine influences have been discounted because it is unlikely they could generate cycles where some stocks are dominant one year, and some stocks are dominant the next. Reduced food availability imposed by dominant cycle lines on off-cycle years is also unlikely since growth rates of highly cyclic Fraser sockeye are highest in off-cycle lines. Human impacts can perpetuate or increase the cyclic pattern in abundance: off-cycles have been consistently fished at higher relative rates than dominant and subdominant cycle lines. Some researchers have suggested that genetic factors, such as strongly inheritable age-at-maturity and age-dependent mortality, could maintain population cycles or at least slow the recovery of off-cycle lines, *in combination with high fishing mortality*.

In 2006, DFO hosted a technical workshop to assess alternative models for explaining the observed cyclic dynamics of some stocks (DFO 2006b). This workshop was a direct result of concerns raised by participants in the FRSSI process The two main recommendations from the technical workshop were to change the escapement strategy to a fixed exploitation rate for run sizes above a certain threshold, and to use a more flexible model to calculate recruitment for all stocks based on the observed degree of interaction between cycle lines. Both of these recommendations have since been implemented in the simulation model.

Another on-going debate concerns potentially detrimental influences of large escapements (e.g. Walters et al. 2004, Clark et al 2007). The concern is that overall survival and growth of the offspring could be greatly reduced due to biological mechanisms such as competition (e.g. for spawning sites, prey, oxygen in the lake), disease outbreak, or increased predation. However, a broad review for Fraser sockeye found declines in productivity at higher escapement levels, but no evidence of collapse, concluding that productive stocks should not suffer drastic reductions in recruitment as a result of management actions to protect weak stocks in mixed-stock fisheries (Walters et al. 2004). These conclusions were supported by observations in 2005 and 2006, when offspring from the 2001 and 2002 spawners returned in reduced, but substantial numbers despite an on-going decline in productivity However, individual stocks may have suffered pronounced delayed-density effects. For example, sockeye smolts migrating out of Quesnel Lake in 2004 were the smallest on record, resulting in severely reduced marine survival. These were the offspring of spawners in 2002, facing high densities at early life stages, but the observation may be confounded by low food availability in the lake at the same period. Several broad-scale reviews of Fraser sockeye are on-going, and they will undoubtedly include a thorough re-evaluation of this issue.

The productive capacity of Fraser River sockeye stocks is limited in the freshwater environment, either by available spawning habitat or by available lake rearing habitat. Several approaches have been used to estimate productive capacity for individual sockeye stocks, including available spawning area, lake productivity, and numerical estimates of the capacity parameter from population models (FRAP-FMG 1995, Shortreed et al. 2000, Bodtker et al 2007). This information can be used to shape prior assumptions about density-dependent parameters in the spawner-recruit model (Section 2.2.5)

Uncertainty around the effects of large escapements is closely linked to yearly variability in environmental, marine and freshwater conditions, as well as the large uncertainty in estimates of productive capacity for Fraser sockeye stocks The current management approach is based on the assumption that occasional large escapements likely reduce the efficiency of sockeye production in that year (i.e. smaller number of recruits per spawner), but do not cause stock collapses. Potential benefits of escapement spikes to individual systems include increased genetic diversity and transport of marine nutrients into distant watersheds (e.g. Naiman et al 2002).

We currently include two alternative SR models to capture the on-going debate around cycle-line interactions. The remainder of this section documents the mathematical details. Figure 7 summarizes the differences between these two SR models.

The most widely applied model to quantify the population dynamics of Pacific salmon is the Ricker model (Ricker, 1954). The classical form of the Ricker model is:

$$\log(R_{BY} / S_{BY}) = \alpha - \beta\ S_{BY} \quad \text{.......... Eq. 1}$$

where recruits (R_{BY}) per spawner (S_{BY}) produced from a brood year are determined based on two parameters. The α parameter is the productivity at low run size (i.e. intrinsic growth rate of the stock) and β is a density-dependent parameter that describes the rate at which productivity decreases as spawner abundance (S_{BY}) increases. An intuitive way to think about the density effect is:

$$\beta = 1 / S^{*} \quad \text{.......... Eq. 2}$$

where S^{*} reflects the capacity of the stock (i.e. spawning abundance associated with maximum sustainable yield). Stocks with larger capacity have smaller β, and less of a density-dependent drop in productivity. The Ricker model is dome-shaped with declining recruitment at higher stock sizes. Mechanisms that can lead to a Ricker-shaped stock-recruitment curve are cannibalism of juveniles by adults, disease transmission, over-crowding on the spawning sites and density-dependent growth coupled with size-dependent mortality (Hilborn and Walters 1992).

The formulation of the Ricker model in Eq.1 was extended by Larkin (1971) to include cross-cycle interactions, as follows:

$$\log(R_{BY} / S_{BY}) = \alpha - \beta_0\ S_{BY} - \beta_1\ S_{BY-1} - \beta_2\ S_{BY-2} - \beta_3\ S_{BY-3} \quad \text{.......... Eq. 3}$$

In Eq. 3 the recruits per spawner (R_{BY} / S_{BY}) produced from a brood year are still the result of spawning stock in the brood year (S_{BY}), but also depend on spawning abundance 1 to 3 years earlier. The lag terms (β_1, β_2, β_3) are surrogates for the effects of predators assuming that the abundance of predators is related to the abundance of prey in the brood year (BY) and the preceding years *BY-1*, *BY-2* and *BY-3*. The classical Ricker model is a subset of the Larkin model wherein the additional lag terms are zero. The Larkin model has no unique solution for S^{*} because of its dependence on S_{BY}, S_{BY-1}, S_{BY-2} and S_{BY-3}, but for consistency we maintain this notation.

Theoretically, substituting effective female spawners for total spawners in the stock-recruitment relationship reduces both uncertainty in parameter estimates and bias due to underestimating spawner potential for years with a low proportion of effective females. The problem with using effective female escapement instead of total spawners is that recruitment and spawners are in different units. As shown by Collie and Walters (1987), the spawner-recruitment parameters estimated using effective female spawners can be re-scaled to represent total sockeye in Eq. 1 and 3. However, we included the option to directly use parameters estimated for effective females by adding an extra step that accounts for sex ratio and spawning success. We model the proportion of effective female spawners by sampling from a fitted distribution.. Figure 8 shows observed and fitted distributions for the 19 stocks, based on maximum-likelihood fit to a beta distribution (using “fitdistr()”, Venables and Ripley 2002)

2.2.5 Bayesian parameter estimates

We applied the Bayes inference Markov Chain Monte Carlo methodology described in Cass et al. (2004) with the following changes:

- the software language changed from S-PLUS to R
- analysis of SR relationships concentrated on different forms of the Larkin model, including the zero lag term form (i.e. Ricker model)
- the prior for the capacity parameter b0 was changed from one based on a uniform distribution to one based on a lognormal distribution
- the lag beta terms were evaluated to determine the best fit model
- in keeping with the forecast methods described in Grant et al. (2010) for forecasting, we used the effective female spawners as the spawner numbers to evaluate the best fit models.

Bayesian methods characterize the uncertainty in the parameters, and as such, are highly useful for evaluating management decisions (Gelman et al. 1995).

Prior Assumptions about the capacity parameter

The β_0 prior is based around the relationship of b=1/Smax (Ricker 1997). In Cass et al. 2004, Smax was described as a uniform distribution between zero and the highest Spawners number (S_hi) in the dataset. This convention precludes the possibility of the capacity being greater than what has been observed to date. In this analysis, we describe Smax as a lognormal distribution with the mean as S_hi, a precision of 1, and an upper constraint of three times S_hi. The upper constraint was necessary for two reasons: first, the practical reason that the unconstrained lognormal was too uninformative and WinBUGS had difficulty searching over the space; second, while we accept the possibility of the capacity of a stock not being fully reached in the past, especially given the recent performance of the Harrison population, it does not seem realistic to assume that the capacity would be greater than three times what we have seen to date. For most stocks, the β_0 posterior estimate was well within these assumptions. The exceptions to this are Early Stuart and Cultus.

A lognormal prior for the lag terms was also evaluated, but rejected, as the posterior distribution that resulted from lognormal priors were irregularly shaped.

See Appendix 1 for revised Larkin code used in this paper.

Methods for determining best fit models

To determine the best fit model for each stock, we quantitatively used the Deviance Information Criterion (DIC) method in WinBUGS as described by Spiegelhalter et al. (2002) and implemented by Michielsens and McAllister (2004). As well, we qualitatively used the stepwise analysis of the linear model using Akaike's Information Criterion (AIC) in R and the probability of a lag term being significantly different from zero using the step() function in WinBUGS (methodology from C. Michielsens, pers. comm.).

First, we assessed the probability of having to include a lag beta term. In WinBUGS, we estimated the parameters for the full Larkin model (3 lag betas) using wide, normal priors (mean=0, precision =

0.00001) for the lag terms to determine which direction (positive or negative) the parameter estimates would be and calculated the probability of the parameter being significant by using the step function. The step function assigns a value of 1 when the lag term in a single MCMC draw is ≥ 0 and a value of 0 when it is < 0. Thus, the mean of the step function term is the probability that a given lag term is positive and will be referred to as the Bayes parameter probability. The closer the mean is to 1, the more likely that the lag term is significant and positive. A mean near 0.5 indicates the lag term is likely insignificant, and a mean near zero indicates that a lag term is likely significant and negative. Lag beta terms with probabilities higher than 75% were taken to be “significant” for this first step. For the purposes of this paper, as with Cass et al. 2004, we are assuming that all lag beta terms are positive. The few populations with lag terms which were strongly negative (i.e. probabilities less than 25%) will be examined at a later date. For now, we are treating these lag terms as if they were not significant.

Secondly, we solved for the deterministic “best fit” model. The step(AIC) function in R was used to determine which model form(s) were the deterministic best fit model for each population. We used the guidelines suggested by Burnham and Anderson (2002) that models with differences in AIC values of less than 2 are not significantly different.

Thirdly, we estimated the “best fit” model with uncertainty. In WinBUGS, we calculated a measure of model fit known as the Deviance Information Criterion (DIC) (Spiegelhalter et al. 2002) for the full Larkin, the Ricker, and the alternative model structures suggested by the assessment of probabilities described in the preceding steps. In keeping with the methodology used by Cass et al. (2004), the priors for the lag terms were uniform distributions constrained to be between zero and 100. However, the $\beta 0$ prior was changed from a uniform to a lognormal. When examining the posterior distribution of the parameters, a few stocks appeared to run up against either the upper or the lower constraint for the lag beta terms. However, we feel that more work needs to be done before increasing the upper constraint or allowing negative beta terms. To compare between model forms, we used the method in the DIC documentation which suggests that differences in DIC values of less than 5 are not substantial. While Spiegelhalter et al (2002) suggest using Burnham and Anderson’s (2002) “within 2 AIC values” rule of thumb could also work for DIC values, they also noted that Monte Carlo error could have an effect on DIC values.

Finally, we combined the information from the first three steps to decide on a “best fit” model for each population. In general, if the DIC results agreed with the AIC and Bayes parameter probability results, that model was chosen as the best fit model. If the results from the DIC were equivocal, we generally chose the simpler model, unless there was reason to choose otherwise from the AIC or Bayes parameter probability results.

The information from all three sources of analysis are summarized in Table 4 and were used to determine the best fit model.

2.2.6 En-route Mortality

Since the early 1990s there have been, with increasing frequency, large differences between estimates (DBE) of sockeye in the lower Fraser River measured at the hydro-acoustic site at Mission, B.C. and estimates of the population at the spawning sites plus in-river catch above Mission (Banneheka et al., 1995). The discrepancies potentially arise from a number of different sources, including: estimation error, unreported catch, and en-route mortality from adverse environmental conditions (MacDonald 2000, MacDonald et al. 2000, Patterson and Hague 2007, Macdonald et al 2010). Discrepancies are evaluated post-season, and if they are concluded to be real, the DBE will be incorporated into the recruitment data used in the spawner-recruit dataset (Section 2.2.3).

We use observed DBE data provided by Maxine Reichardt (PSC) to approximate en-route mortality in the forward simulations. Positive DBEs, where upstream estimates are large than lower-river estimates are set to 0, assuming negligible en-route mortality that year (Table 3). Figure 9 shows observed patterns in DBE.

We include four alternative options for DBE in forward simulations (Figure 10). The base case samples from the observed distribution of % DBE, with the alternative option to only sample from the worse half of the observations to account for the potential effects of climate change (Merran Hague, pers. Comm.). To reflect the possibility that harvest patterns influence the future distribution of % DBE, two additional options are included based on the linear and log-linear simple regressions of actual vs. potential escapement.

Two of the three types of escapement strategy included in the model adjust the annual target exploitation rate based on % DBE (Section 2.3).

2.2.7 Productivity scenarios

A recurring concern raised by participants in the FRSSI workshops relates to assumptions about future productivity of Fraser sockeye stocks. Any forward simulation using parameters estimated from observed data implies that the range of future outcomes (e.g. recruits per spawner at a given abundance of spawners) resembles the range observed in the past.

We include two options for exploring assumptions about future productivity. An abrupt and persistent loss of productivity across all stocks can be included by specifying a scaling parameter z_R for the recruits calculated based on Eq. 1 or Eq. 3, such that:

$$R_{BY} = z_R \; S_{BY} \; (R_{BY} \,/\, S_{BY}) \quad \text{.......... Eq. 4}$$

with $0 \leq z_R \leq 1$ and R_{BY}/S_{BY} is calculated from Eq. 1 or Eq. 3.

Proposed patterns in productivity over time and across stocks can be specified as a grid of scalars for each year and stock (Figure 11).

On-going work (Sue Grant, pers. comm.) is exploring the use of a Kalman filter (Dorner et al. 2008) to identify past patterns in productivity (i.e. estimating changes over time in the α parameter of Eq. 1 and Eq. 3). Once these analyses are complete, the identified patterns can be fed directly into the FRSSI model by converting the each year's scalar on the α parameter into a scalar z_R for use in Eq. 4:

$$z_R = \frac{\exp(\alpha \; z_\alpha)}{\exp(\alpha)} \quad \text{.......... Eq. 5}$$

2.2.8 Depensatory mortality

A number of factors could result in depensatory mortality. For example, inbreeding may occur and result in increased mortality, spawner densities may be so low that fish cannot easily find mates, and predation may result in higher proportions of fish killed when densities are low. Depensatory mortality will accelerate population declines and increase their probability of extinction (McElhany et al 2000).

Several approaches have been used to incorporate possible depensatory effects in the analysis of stock recruit data. Hilborn and Walters (1992) recommended including a power term in the Beverton-Holt model to represent the effects of predators. Liermann and Hilborn (1997) used a Bayesian hierarchical model to estimate the distribution describing the variability of depensation within various taxa. Routledge and Irvine (1999) introduced a cut-off value to allow for the effects of possible depensation at low abundance. Frank and Brickman (2000) were the first to introduce a S-R model that incorporated Allee effects by permitting a non-zero intercept representing recruitment failure. Chen et al. (2002) extended the standard Ricker function by incorporating an additional parameter and estimating the value of non-zero intercepts using S-R data. They found evidence for significant depensatory mortality in a northern BC coho population but not for Chilko sockeye.

Our purpose here is not to estimate depensatory mortality, but to include the option of simulating potential implications on the performance of alternative escapement strategies. If S falls below a critically low value S_c, users can specify an associated proportional reduction in recruitment. We chose an arbitrary value for S_c recognizing the difficulty in estimating it reliably from the S-R data. We set S_c to the lowest S value observed in the S-R data set, because stocks were able to recover from S_c to much greater levels of abundance, at least given survival conditions at the time. Table 1 lists lowest observed spawning abundances for the 19 stocks,

2.3 Harvest Sub-Model

2.3.1 Escapement strategies

The purpose of this model is to explore the expected long-term performance of different escapement strategies for Fraser sockeye under a wide range of alternative assumptions (e.g. population dynamics, future changes in productivity). During the annual management cycle, escapement strategies guide the annual balance sought between catch and abundance of spawners as run sizes vary from on year to the next and among stocks. In the model, these strategies are specified as quantitative control rules that prescribe a target level of exploitation rate for each management group.

Three types of escapement strategies are currently available in the model:

- Fixed escapement
- Fixed exploitation rate
- Target rate of allowable mortality that changes with run size.

Figure 12 shows the sequence of choices necessary to define a specific escapement strategy for each of these types.

TAM rules are designed around three fundamental considerations (Figure 13):

- Cap on total allowable mortality rate at larger run sizes to ensure robustness against uncertainty in population dynamics (e.g. capacity estimate), changing in-season information, and differing productivity among component stocks.
- Fixed escapement at low run sizes to protect the stocks and reduce process-related challenges at this critical stage (e.g. uncertain run size).
- ER floor at very low run size (e.g. for test fishing).

These TAM rules are consistent with the minimal requirements for harvest strategies to be compliant with the Precautionary Approach (DFO 2006). Specifically, the target mortality is reduced as abundance drops from a healthy to a cautious zone, and target mortality is minimal if abundance is critically low.

2.3.2 Constraints imposed by run timing

Timing overlap is simulated based on long-term average migration timing through Area 20 (i.e. in a mixed-stock fishing area). Two alternative approaches for approximating the constraints imposed by timing overlap are included in the model:

- *Window*: Mixed-stock exploitation rate for each day is constrained by the smallest exploitation rate among those timing group that are present that day based on a time-window that captures s user-specified portion of each run centered around the peak. Realizable catch in mixed-stock fisheries is calculated based on these revised exploitation rates

- *Abundance*: Mixed-stock exploitation rate for each day is constrained by the smallest exploitation rate among those timing groups that contribute more than a user-specified percentage of the abundance (e.g. 10%), and realizable catch in mixed-stock fisheries is calculated based on these revised exploitation rates.

Figure 14 illustrates the difference between these two approaches. In both cases the intent is to reflect the implementation challenges introduced by escapement strategies that tend to result in widely differing target exploitation rates for the four management groups. If the same fixed exploitation rate were chosen for all management groups, there is no overlap constraint.

2.4 Forward Simulations

We evaluate the expected performance of alternative escapement strategies over 48 years, seeding the simulations with the most recent spawner abundances. All 19 stocks are projected forward concurrently, with some mechanisms applied to individual stocks (SR model, % effective females) and others applied to management groups (% DBE, TAM rule). Forward simulations avoid potential artefacts in the observed data, which may introduce biases, and add flexibility for exploring effects of potential future patterns in productivity (Section 2.2.7), en-route mortality (Section 2.2.6) or pre-spawn mortality (Section 2.2.4)

The Bayesian approach for capturing parameter uncertainty and posterior sampling techniques, such as the MCMC approach of Gelman et al. (1995) used here, offer the advantage that complex parameter distributions can be naturally incorporated into policy analysis. To explicitly incorporate parameter uncertainty, a subsample of 500 stock-recruitment parameter sets for each stock was systematically subsampled from the original 20,000 MCMC samples. For each parameter set sampled from the Bayes posterior distribution, the effect of applying an escapement strategy is simulated by generating trajectories of run size, catch and spawner abundance in annual time steps.

If escapement strategies are specified for management groups rather than individual stocks, the model reflects the complex interactions between individual stock dynamics and mixed-stock fisheries.

In single-stock fisheries there is a direct feedback between the exploitation rate, future recruitment and ultimately conservation and socio-economic performance measures. Recruitment and performance in response to exploitation is only conditional on the underlying population dynamics of the stock.

A common exploitation rate applied to a stock mixture potentially affects future recruitment and performance of the individual stocks differently for a number of reasons. Productivity varies among stocks to the extent that a common harvest rule is not optimal for some or any of the stock components

(Figure 3). This, of course, is the weak-stock problem of mixed-stock fisheries. Differences in productivity among stock are captured in the model using Bayesian inference. Temporal differences in productivity among stocks in mixtures, however, also affect performance, even though the long-term mean productivity may not vary among the stocks. The effect of temporal variation in survival patterns among stocks in mixed-stock fishery models therefore must be assessed.

Mixed-stock fisheries models are more complex than single-stock models and the complexity increases with the number of stocks in the mixture given variations in timing among and within management groups, and the recruitment survival patterns among stocks. For example, Mueter et al. (2002) showed that the survival patterns among Fraser sockeye stocks are weak, but significantly positive.For simplicity, we assume that:

- Exploitation rates for each stock the equal exploitation rate applied to a management group
- Temporal survival patterns between stocks are uncorrelated (i.e. stochastic residuals are sampled independently for each stock).

2.5 Performance evaluation

The overarching goal of the FRSSI process is to seek a balance between the fundamental objectives of (1) ensuring spawner abundance and production for individual stocks and (2) accessing the catch-related benefits from the timing aggregates. However, there are many nuances to be considered when interpreting the simulation results. Early on in the process, we moved away from optimizing a value function with user-supplied weightings to a more interactive exploration of alternative scenarios. Over the course of more than a dozen workshops the list of potentially interesting variations of performance measures grew steadily to over 300.

We use the following subset for this Working Paper:

- Proportion of simulated years where the 4yr running average of spawner abundance falls below a stock-specific benchmark.
- Proportion of simulated years where catch for an aggregate falls below a benchmark.

The notions of low escapement and low catch can be quantified in many different ways, and even the Wild Salmon Policy offers a range of potential benchmark definitions that should be explored on a case-by-case basis (pages 17 and 18 of DFO 2005). Methods for determining WSP benchmarks for conservation units have been finalized (Holt et al 2009, Holt 2009), but the resulting benchmarks for the 19 stocks of Fraser sockeye are still under development.

Pending the completion of this work, we continue to use interim benchmarks developed during the 2006 planning process. Workshop participants reviewed alternative approaches for setting biological benchmarks and settled on a robust combination using the smallest and largest value resulting from 5 different definitions of low escapement (Table 1). These benchmarks are based on a combination of population dynamics (e.g. 20% of the escapement that maximizes run size) and past observations (e.g. smallest observed 4yr average escapement). Benchmarks for identifying low catch for each management group are based directly on feedback received from workshop participants: Early Stuart – 15,000; Early Summer – 100,000; Summer – 600,000 ; Late – 300,000.

3 SAMPLE RESULTS

3.1 Notes on interpretation

The results presented in this chapter are intended to illustrate the range of questions to be explored with this model and to elicit feedback on the way results are being presented. This feedback will then shape preparations for the next round of planning workshops. The intent here is not to choose a particular spawner-recruit model, future scenario, suite of assumptions, or recommended management strategy. That will take place through the planning process.

3.2 Alternative SR models and Bayesian parameter estimates

3.2.1 WinBUGS

WinBUGS is a freeware program that is meant to test models using Baysian analysis, specifically, Markov Chain Monte Carlo methods. The program and documentation is available on the web at: www.mrc-bsu.cam.ac.uk/bugs/.

For the purposes of this paper, in addition to the MCMC sampling methods to estimate parameter values, we used the Deviance Information Critieria (DIC) as described by Spiegelhalter et al. (2002) and implemented by Michielsens and McAllister (2004) and the step() function to determine the best fit models. The DIC is essentially the Bayesian form of Akaike's Information Criterion (AIC) which assesses model fits and takes the number of parameters being estimated into account. The step() function was used to determine the "Bayesian parameter probability estimates" in Table 4. It assigns a value of 1 when the lag term in a single MCMC draw is ≥ 0 and a value of 0 when it is < 0. Thus, the mean of the output is the probability that the lag term is positive, and the closer the value is to 1, the more likely that the lag term is significant (methodology from C. Michielsens, pers. comm.).

See Appendix 1 for the Larkin model structure used to estimate the parameter estimates.

3.2.2 Ricker vs. Larkin model

Assumptions about delayed-density effects (i.e. cycle interactions) have potentially important implications for shaping escapement strategies. Figure 15 to Figure 17 illustrate the difference for Quesnel sockeye, using a simplified scenario with 30% fixed exploitation rate, without en-route mortality, and without random variation. The Larkin model with 3 lag terms creates strong and persistent cyclic patterns in escapement (Figure 15), while the Ricker model stabilizes abundance quickly as "off-cycle" lines rebuild (Figure 16). Figure 17 summarizes across the trajectories in Figure 15 and Figure 16. However, increased mortality on stock with Ricker-type dynamics can create strong cyclic patterns as well (e.g. 60% fixed ER plus median en-route mortality, Figure 18, also without random variation)

This illustration emphasises the importance of improving estimates of lag-terms are for each stock (Section 2.2.5) and highlights the difficulty in trying to determine where a stock falls at any given point in time: Larkin-type or Ricker-type with harvest rates perpetuating cycles?

3.2.3 Model selection

The best fit analysis presented in this paper is using the effective female dataset only. This is in keeping with the dataset used to forecast Fraser River Sockeye run sizes (Grant et al., 2010 *in press).* It was assumed for the purposes of this paper that the best fit model form for total spawners is the same as for effective females. This assumption will be explored in more detail at a later time.

Table 4 summarizes the information we used to determine the best-fit model by stock. Appendix 2 lists the detailed results. In general, the following criteria were used to determine the "best fit" model for this paper:

1. If there was a DIC "best fit", and the AIC and Bayes parameter probability results agreed with it, this was the "best fit" model.
2. If there is no obvious DIC "best fit", the simplest model was chosen unless there was disagreement from the AIC and Bayes parameter probability results.

Examples of "simpler" models would be choosing:

- Ricker (no lag terms) over Larkin (three lag terms)
- model with continuous lag terms (e.g. lag 1 or lag 1 & 2) over a model with discontinuous lag terms (e.g. lag 2 or lag 1 & 3)

Table 5 identifies the best fit model for each stock. A brief summary of selection rationale follows below:

- Early Stuart – Larkin (full). The Larkin model was the DIC "best fit" model. The AIC & Bayes parameter probability results agreed.
- Late Stuart – Larkin with 2 lag terms. There was no difference in the DIC values of the model structures tested. The AIC and Bayes parameter probability results indicate that some lag terms are significant. The Bayes parameter probability's continuous lag terms was chosen.
- Stellako – Larkin (full). There was no difference in DIC values of the full Larkin model and the Larkin with lag 1 & 3. The AIC and Bayes parameter probability results indicated that all lag terms are likely significant. The continuous lag term form was chosen.
- Bowron – Ricker. The Ricker model was the DIC "best fit" model. The AIC & Bayes parameter probability results indicate that the lag 3 term is likely significant but negative in value.
- Raft – Ricker. The Ricker model was the DIC "best fit" model. There are no continuous, significant, positive model lag terms.
- Quesnel – Larkin (full). There was no difference in DIC values of the Larkin or the Ricker. The AIC & Bayes parameter probability results indicate that all three lag terms were significant.
- Chilko – Larkin with 1 lag term. There was no difference in DIC values of the full Larkin model and the Larkin with lag 1. The simpler model with one lag term is consistent with the AIC & Bayes parameter probability results.
- Seymour – Larkin (full). There was no difference in DIC values of the Larkin or the Ricker. The AIC & Bayes parameter probability results indicate that all three lag terms were significant.
- Late Shuswap – Larkin (full). There was no difference in DIC values of the full Larkin model and the Larkin with lag 1 & 2. The AIC & Bayes parameter probability results indicate that all three lag terms were significant.
- Birkenhead – Larkin with 1 lag term. There was no difference in the DIC values of the model structures tested. The AIC & Bayes parameter probability indicate that the first lag term is likely significant and positive, while the second term is likely negative.

- Cultus – Ricker. The Ricker model was the DIC “best fit” model. There are no continuous, significant, positive model lag terms.
- Portage – Ricker. The Ricker model was the DIC “best fit” model. The AIC and Bayes parameter probability results indicate the possibility of significant lag terms. However, the Ricker is clearly outperforming the other model forms in the DIC results.
- Weaver – Ricker. There was no difference in DIC values of the Ricker or the alternate model forms. The AIC and Bayes parameter probability results indicate the possibility of significant lag terms. However, the second lag term is likely negative and the strongest positive lag term is lag 3.
- Fennel – Ricker. The Ricker model was the DIC “best fit” model. The AIC and Bayes parameter probability results indicate the possibility of significant lag terms. However, the Ricker is clearly outperforming the other model forms in the DIC results. This is due to the Bayesian DIC methodology taking uncertainty in the parameter estimates into account and is likely due to the shorter time series for this dataset.
- Scotch – Larkin (full). There was no difference in DIC values of the Larkin or the Ricker. The AIC & Bayes parameter probability results indicate that all three lag terms were significant.
- Gates – Ricker. The Ricker model was the DIC “best fit” model. The AIC and Bayes parameter probability results indicate the possibility of significant lag terms. However, the Ricker is clearly outperforming the other model forms in the DIC results. This is due to the Bayesian DIC methodology taking uncertainty in the parameter estimates into account and is likely due to the shorter time series for this dataset.
- Nadina – Ricker. The Ricker model was the DIC “best fit” model. The AIC and Bayes parameter probability results indicate the possibility of significant lag terms. However, the Ricker is clearly outperforming the other model forms in the DIC results. This is due to the Bayesian DIC methodology taking uncertainty in the parameter estimates into account and is likely due to the shorter time series for this dataset.
- Upper Pitt – Ricker. There was no difference in DIC values of the Ricker or Larkin with lag 2. The AIC & Bayes parameter probability results are inconclusive except for the lag 2 term, which would not be a continuous lag model form.
- Harrison – Ricker. The Ricker model was the DIC “best fit” model. The AIC and Bayes parameter probability results indicate that the possibility of significant, negative lag terms.

3.2.4 Spawner-recruit parameter estimates

Bayesian estimates confront a prior assumption about a variable with data to arrive at a revised assumption. Prior assumptions can be informative (i.e. constrain or strongly influence the estimate) or uninformative. Less informative priors shift more weight onto the observed data.

Figure 20 to Figure 22 illustrate the sequence from spawner recruit data to the resulting Bayesian parameter estimates for Early Stuart. In this case, the best fit model is full Larkin model with 3 lag terms (Table 5).

Figure 20 shows the timer series of total spawners, recruits, and recruits per spawner. The largest abundance of spawners and the largest recruitment were observed in the 1993 brood year, but productivity (i.e. recruits/spawner) was low that year, and even lower the year after (1994 brood year).

Figure 21 shows the resulting parameter estimates. The lag terms (β_1 to β_3) are of similar magnitude as the capacity constraint for the brood year (β_0), indicating strong cycle line interactions (i.e. strong reduction in recruits/spawner for larger spawner abundances in previous years). The middle panel shows that the fitted model predicts the dominant years (i.e. which years have a spike in total number of recruits), but also shows the large uncertainty associated with trying to predict just how large the recruitment is.

Figure 22 shows the implications of including lag-terms in the spawner-recruit model. The top row shows the recruitment curves for each year (i.e. modeled recruitment at different levels of spawner abundance). Recruitment curves shift depending on spawner abundance in the three previous years. The large spawner abundance in 1993, combined with the strong 1-year lag term (β_1), result in a recruitment curve the predicts very poor recruits/spawner for any level of spawner abundance in the 1994 brood year. Appendix 4 includes the same series of figures for the other 18 stocks.

Figure 23 to Figure 26 compare estimated spawner-recruit parameters across the 19 stocks, for the full Larkin model with 3 lag terms and the best-fit model with 0 to 3 lag terms.

Figure 23 and Figure 25 highlight the challenge of mixed-stock management by identifying stocks with lower intrinsic productivity within a management group (top panel), with larger uncertainty in parameter estimates (middle panel), or larger capacity constraint (i.e. lower optimal spawner abundance in brood year).

Figure 24 and Figure 26 highlight stocks with strong lag-terms (relative to β_0).

Table 6 and Table 7 summarize median parameter estimates based on either total spawners or effective female spawners. Each table contains three sets of parameter estimates: full Larkin with 4 β parameters (i.e. 3 lag terms) , the best-fit model with a variable number of lag terms, and the full Larkin with an alternative prior assumptions about β_0 . Lag-terms that are similar in magnitude to β_0 (bold font in panel A) tend to be retained as significant in the best-fit model (panel B). In cases where lag terms are dropped, estimates of α and β_0 tend to change by more than 10% (orange fields in panel B). Using a uniform prior tends to shift estimates of β_0 by more than 10% (orange fields in panel C), but also tends to identify the same lag-terms (bold font in panel C). Figure 19 illustrates the difference in distributions for Early Stuart sockeye. Appendix 5 includes the same series of figures for the other 18 stocks.

Table 8 lists deterministic parameter estimates using simple linear regressions on Eq. 3. Values that differ by more than 20% from panel A in Table 7 are highlighted. Overall, α estimates are well determined and match closely across multiple estimation methods (Panels A and B in Table 7, Table 8). Further analysis is needed to investigate the sensitivity of the capacity constraint β_0 and the lag-terms (β_1 , β_2 , β_3) to alternative estimation methods and prior assumptions. For example, some β estimates that are negative in the deterministic linear regression drop out as insignificant in the DIC and AIC analysis, but some appear to be both significant and negative.

The capacity parameter β_0 turned out to be the most sensitive to prior assumptions. Specifically:

- We constrained β_0 to ≥ 0 because it is a capacity constraint. This was only ever an issue for Scotch, using the deterministic Ricker estimates.
- In the case of Scotch, where the deterministic linear regression would estimate a negative β_0, we believe it is more a case of a short dataset (1980 – present) that doesn't provide as much information as the other stocks, rather than a "real" negative β_0 value.
- The choice of priors on β_0 tend not to have much affect on alpha or lag beta terms.

- A lognormal prior allows for the capacity estimate to be greater than that calculated from the maximum number of spawners to the grounds in the historical data.
- In general, when using a lognormal prior, β_0 decreases from when using a uniform prior, as would be expected when 1/S_hi is used as the mean as opposed to the maximum of the distribution. An upper constraint on the prior of a maximum of three times the highest spawner numbers ever seen was imposed to exclude unrealistically optimistic results. Applying upper constraint to the lognormal prior had the largest effect on Early Stuart and Cultus estimates.
- In most cases the lognormal prior increases the uncertainty of β_0 without affecting the median estimate of β_0 to a large degree, but in 2 cases it decreases the value of β_0 (i.e. increases the estimate of capacity): Early Stuart and Cultus. We interpret these results to mean that capacity estimates for Early Stuart and Cultus are more uncertain than for other stocks, and not that the actual capacity of the population would result in a number of spawners at maximum recruitment (Smax) of greater than three times the maximum number of spawners ever recorded to the grounds.

3.3 Exploring alternative types of escapement strategies

3.3.1 Base-case Scenario

The following assumptions are used throughout all of the results shown, except for the explicitly-stated variation explored in a particular section:

- Use best-fit SR models and parameter estimates based on effective female spawners (Section 2.2.5).
- En-route mortality sampled from past observations (Section 2.2.6).
- No patterns in productivity (Section 2.2.7).
- No depensation (Section 2.2.8).
- No overlap constraint applied due to run-timing (Section 2.3.2).
- Random variation in recruitment, en-route mortality, and % effective females.

3.3.2 Changing fixed exploitation rates

Figure 27 shows the expected effect of applying fixed exploitation rates ranging from 5% to 90%.

Stock-specific differences in productivity (α) are reflected in the exploitation rate at which each stock approaches a high probability of low spawner abundances. Relative patterns can be directly compared across stocks (i.e. at which point does if hit a rapid change in performance), but comparisons of absolute values are confounded by cyclic patterns (i.e. off-cycle effect on performance measure) and choice of benchmark. Careful review on a case-by-case basis is necessary, but beyond the scope of this paper.

Broadly, Figure 27 shows that:

- Summer run stocks respond similarly to increasing exploitation rates, as is expected given their similarity in estimated productivity (Figure 23). Component stocks in the Early Summer and Late management groups exhibit a wider range of productivities, resulting in different levels of resilience to exploitation rate.

- Probabilities of low escapement tend to sharply increase at exploitation rates ranging from 40% to 60% (top 4 panels), which is also the range that stabilizes catch (i.e. minimizes the probability of low catch) for each of the management groups (bottom left panel). This result supports a cap on allowable mortality around 60%, which has been applied in recent years.
- Higher exploitation rates around 80% maximize long-term median catch for all 4 management groups, but median catch is highly sensitive to hitting the peak exactly (i.e. steep degradation in median catch if optimal exploitation rate is slightly exceeded.

3.3.3 Changing fixed escapement targets

Figure 28 and Figure 29 summarize the performance of alternative fixed escapement targets for each stock, expressed as multiples of Benchmark 2 (Table 1). Performance depends on the relative productivity of component stocks as well as the management approach: If each stock is managed to its own target, risk comes only from how closely the management target is set to the benchmark. Performance in terms of escapement stabilizes at roughly 3 times BM 2. If, however, aggregates are managed based on the strongest component (i.e. max ER based on surplus over escapement target), then stock-specific differences in productivity are picked up strongly, because productive stocks tend to have large surplus, resulting in higher exploitation rate.

If stocks are managed individually, catches tend to be largest for escapement targets set to about double BM2, but increasingly stable as targets are reduced.

3.3.4 Changing cut-back point on TAM rule – Summer

Figure 30 shows the effect of changing the cut-back point of the TAM Rule for the Summer management group (see Figure 12 for definition of TAM rules).

For this scenario, timing overlap does not impose a constraint, so the performance of the other 3 management groups is not influenced by changes in the Summer TAM rule (horizontal lines for all performance measures.

Probability of low escapement (middle-left panel) is highly robust to changes in cut-back point, with only small changes in performance for large changes in cut-back point (e.g. 1 Million vs. 3 Million). Some of the results appear counter-intuitive at first, with one of the stocks worsening slightly as the cut-back point is pushed higher. As the cut-back point increases, aggregate abundances increases, raising aggregate exploitation rates, which in turn affects the least productive stock in the mix.

Cut-back points between about 1 and 1.5 Million are expected to stabilize catch, while median catch is highly robust to different cut-back points up to about 3 Million. Compare this to the highly sensitive response of median catch to changes in fixed exploitation rate (Figure 27).

3.3.5 Changing cap on TAM rule – All 4 Management Groups

Figure 31 shows the effect of changing the cap on TAM rules. Performance is more sensitive to changing the cap than to changing the cut-back points. The response pattern for each stock is similar to the effect of increasing fixed exploitation rates (Figure 27), but buffered by the consideration of en-route mortality.

3.3.6 Changing exploitation rate floor on TAM rule – All 4 Management Groups

Figure 32 shows the effect changing the exploitation rate floor. Performance with respect to stock-specific escapement is quite robust, but shows a gradual worsening (i.e. higher probability of low escapement) as the floor is pushed up. This is consistent with the results for the lower end of fixed exploitation rates explored above (Figure 27).

3.4 Sensitivity to alternative biological assumptions

3.4.1 Productivity scenarios

Figure 33 to Figure 37 illustrate the effect of reduced productivity assumptions on various performance evaluations. All scenarios use the "immediate and permanent" option for including reduced productivity. More complex patterns will be explored as part of the planning workshops.

Figure 33 shows how the expected performance of the 2009 TAM rule degrades as productivity decreases. Most stocks are resilient to some loss of productivity (i.e. up to bout half).

Figure 34 illustrates another way of taking productivity scenarios into account. The scenario is the same as in Figure 27, except with productivity set to half. The general patterns from the base case are retained, but shifted towards lower exploitation rates. For example, the fixed exploitation rate that maximizes median catch shifts from about 80% to about 60%.

Figure 35 applies the same approach to exploring the effect of changing the cap on TAM rules. The scenario is the same as in Figure 31, except with productivity set to half. The general patterns from the base case are maintained, but more pronounced.

3.4.2 Alternative SR models

Figure 36 and Figure 37 show the expected performance of 2009 TAM rules under half productivity, using 2 different spawner-recruit models. Both can be compared to the corresponding base case (Figure 33). More work is on-going regarding the choice of "best model".

3.4.3 Alternative SR parameter estimates

Figure 38 and Figure 39 show a more detailed set of simulation results for Chilko, with long-term distributions for 6 key performance measures.

Figure 40 shows how a background variable (i.e. "productivity like past") can shape the evaluation of alternative strategies.

3.4.4 Assumptions about en-route mortality

Figure 41 shows the effect of en-route mortality assumptions on sensitivity to changing ER.

3.4.5 Assumptions about depensatory mortality

Figure 42 shows the effect of depensatory mortality assumptions on sensitivity to changing ER.

4 DISCUSSION

4.1 Use of the FRSSI model

The model presented in the Working Paper, as well as the planning process it supports, focus on long-term strategies, and don't attempt to capture all of the operational complexities of in-season management. The model assumes that one strategy is going to be adopted and applied for 48 years, which is not likely in practice. However, previous versions of this model have proven sufficient to explore and illustrate the long-term differences between major categories of escapement strategies for aggregates. For example, during previous planning processes the model showed clear advantages of a strategy that responds to run size compared to fixed escapement strategies or fixed exploitation rate strategies (Figure 12). Discussions around annual model revisions helped with highlighting alternative hypotheses and brought practical considerations into the analytical work. For example, the TAM rule was adapted to specify a fixed escapement in the middle range (bottom panel of Figure 13), rather than a linear reduction in allowable mortality rate (top panel of Figure 13).

Fundamental changes from the previous management approach include:

- Escapement strategies for a given year are based on a target mortality rate, not on a fixed escapement target. Estimates of spawning capacity are highly uncertain for some stocks, and harvest strategies based on target mortality rates should be more robust to this uncertainty.
- Escapement strategies respond to run size, but do not change for different cycle years. Under the 1987 Rebuilding Plan, a different interim escapement goal was identified for each cycle line. Under the Spawning Initiative, off-cycle years in cyclic stocks are simply treated as an instance of low abundance, with the target mortality rate based on the shape of the escapement strategy.
- Escapement strategies specify total mortality rates, which when put into practice, need to take into account en-route mortality. The proportion of each run available for harvest, the target exploitation rate, is determined by deducting projected en-route mortalities from the allowable total mortality.
- The requirement to stay above brood year escapement was removed to account for the fluctuating productivity of many stocks; and
- Escapement strategies are explicitly based on simulated long-term performance relative to explicitly stated management objectives (e.g. keep 4 yr average above benchmark)

Over the course of 8 years, the model has gone through 4 incarnations in 3 different programming languages, and has been adapted to support discussions during the pre-season planning process. For example, the approach of optimizing a value function, and eliciting weightings from workshop participants shifted towards a collaborative exploration of alternative scenarios.

Updates for this latest version of the model have focused on:

- In-depth review of spawner-recruit dynamics
- Flexibility to incorporate a wide range of future patterns in productivity
- Including pre-spawn mortality and modelling population dynamics based on % effective females
- communication of input information and results
- computing efficiency (faster simulations, streamlined output)

4.2 Implications for management

Spawner-recruit dynamics for Fraser sockeye have been intensively studied, but as yet there is no agreement on whether populations are intrinsically cyclic or not, and whether harvesting could initiate cycles or is the perpetuating mechanism (Larkin & Hourston 1964, Walters & Staley 1987 , Cass & Wood 1994 , DFO 2006, Meyers et al 1998, Ward & Larkin 1964, Martell et al. (2008)

In addition to uncertainty in the form of the underlying dynamics, there is also substantial uncertainty in the parameter estimates for each model form. We account for this uncertainty by sampling from Bayes posterior distribution rather than using a best estimate (Section 2.2.5).

The following considerations are particularly relevant to the annual planning process:

- Productivity (α) differs widely across stocks, creating challenges for mixed-stock management (Figure 23). However, estimates of α for a particular stock are fairly robust, and could provide a solid basis for determining lower benchmarks. Additional work is under way to isolate time trends in productivity.
- Shorter time series of spawner-recruit data result in larger uncertainty (Weaver, Fennel, Scotch, Gates, Nadina). This is showing up as best fit models being different when choosing between Larkin & Ricker models in the short time series stocks – when using the deterministic AIC fits, it tends to choose model forms with more lag terms than the Bayesian DIC results, which tends to choose the Ricker. The DIC takes uncertainty in the parameter estimates into account when assessing the model fits, whereas the AIC results do not.
- Uncertain response at/above largest observed escapements (1982 Weaver, 1990 Seymour, 2000 Raft & Nadina, 2005 Harrison).
- Also incorporated into this version of the model is the ability to directly simulate the effect of overlap in migration timing of stocks. This is important when estimating total catch and spawners to the grounds in the simulation. Previous model versions assumed an ability to harvest the full amount available in each timing group without taking into account constraints from co-migrating stocks. This led to catches that were larger than realistically achievable and escapement that was smaller than would have occurred.
- The ability to explicitly examine the consequences of future productivity patterns has been added to this model. Previous model versions allowed for total and sudden changes in productivity, but this model will allow us to apply patterns of productivity into the future.

4.3 Next steps

We identify six priority areas for on-going work in preparation for the next round of stakeholder workshops, which are planned for the end of 2010 and early 2011 :

- Review the freshwater ecology of each stock to identify plausible hypotheses for the structure of best fit models (i.e. why are some lag-terms significant?)
- Explore risk management approach to uncertainty in SR models and assess the risk of being wrong in assumptions about delayed-density effects (e.g. what if we manage a Ricker-type stock based on Larkin model assumptions).
- Explore implications of alternative SR models (i.e. number of lag terms) for setting benchmarks under the *Wild Salmon Policy.*
- Investigate differences between this model and the previous version.

- Explore alternative approaches for random variation in forward simulations. For example, should there be a constraint on the multiplicative error, or on calculated recruitment? A constraint on simulated recruits could be based on observed recruitment (e.g. 2 or 3 times largest observed) , or some multiple of what's been modelled in the previous two cycles in the simulation.
- Enhance the communication of model scenarios and implications (e.g. Larkin fits), and facilitate real-time use during workshop deliberations (e.g. speed, graphical user interface)
- Finalizing the dataset(s) for Fraser Sockeye. There are several on-going processes dealing with this, including: a) Cultus dataset from the Cultus Conservation Team, b) data checking for the non-Cultus populations by the Pacific Salmon Commission staff, and c) checking historic escapement estimates for proper use of zeroes versus NAs by Fraser Stock Assessment staff. Figure 19 and Appendix 5 show the effect of recent data revisions on parameter estimates (bottom panel vs top panel on the left.

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Tables and Figures

Table 1: Observed range of spawner abundance and low escapement benchmarks

	Observed Range of Total Spawners								Low Escapement BM (Compare to 4yr Avg)	
Stock	Min	Lower 10th	Lower Quarter	**Median**	Upper Quarter	Upper 10th	Max	Min 4yr Avg	BM1	BM2
E. Stuart	1,522	4,657	21,044	**38,807**	117,445	234,219	688,013	10,218	10,200	50,300
Bowron	836	1,501	2,560	**6,395**	12,780	25,205	35,000	1,514	1,500	4,900
Fennell	9	220	1,681	**5,709**	9,901	15,195	32,279	483	500	2,200
Gates	70	777	2,582	**7,181**	14,838	28,899	99,470	2,401	1,100	3,500
Nadina	1,625	2,179	3,665	**9,547**	22,952	55,253	194,381	9,094	2,000	9,100
Pitt	3,560	9,290	13,412	**18,673**	37,747	55,380	131,481	11,229	3,400	11,200
Raft	464	1,279	2,714	**6,244**	9,988	18,369	66,292	2,572	2,500	5,200
Scotch	107	605	2,156	**4,609**	14,772	75,222	144,199	2,186	900	4,000
Seymour	1,323	2,802	5,709	**11,971**	44,588	78,371	272,041	9,087	9,100	19,000
Chilko	17,308	55,675	120,104	**305,853**	544,364	825,837	1,037,737	164,485	66,400	164,500
Late Stuart	35	1,620	6,315	**25,562**	157,197	372,859	1,363,826	29,499	29,500	78,300
Quesnel	49	111	308	**10,222**	278,961	1,349,263	3,510,789	7,803	7,800	154,500
Stellako	15,763	36,700	42,099	**86,688**	138,794	185,641	371,604	37,018	22,700	45,400
Birkenhead	11,905	18,213	30,656	**48,916**	83,787	189,445	335,630	23,175	19,700	39,300
Cultus	52	418	1,227	**9,055**	16,919	25,922	47,779	1,053	1,000	7,300
Harrison	313	2,202	4,239	**8,259**	19,717	33,044	388,605	3,555	2,000	4,100
Portage	9	89	1,118	**3,724**	9,071	17,321	31,343	1,301	100	1,300
Weaver	2,756	11,621	25,442	**42,002**	59,165	74,903	294,083	19,488	8,600	19,800
L. Shuswap	164	1,395	3,606	**21,113**	1,144,115	2,026,693	5,532,263	320,500	111,100	320,500

Table 2: Fraser River sockeye stocks and conservation units.
From Table 1 of Pestal and Cass (2009), which was based on Holtby and Ciruna 2007 and subsequent updates (pers.comm. Holtby, Whitehouse, Benner - DFO)

Mgmt Group	CU label	CU type	# of Lakes	# of Sites	Esc Obs*	Freshwater Adaptive Zone	CU Rationale	Stock**
Early Stuart	Stuart-EStu	lake	1	2	13	Middle Fraser	lake	Early Stuart
	Takla/Trembleur-E	lake	2	42	70	Middle Fraser	lake complex	Early Stuart
Early Summer	Anderson-ES	lake	1	2	59	Middle Fraser	lake	Gates
	Bowron-ES	lake	1	2-3	70	Upper Fraser	lake	Bowron
	Chilko-ES	lake	1	1	19	Middle Fraser	lake	Chilko
	Chilliwack-ES	lake	1	2	36	Lower Fraser	lake	Early Summer Miscellaneous
	Francois-ES	lake	1	3-4	67	Middle Fraser	lake	Nadina
	Fraser-ES	lake	1	2	43	Middle Fraser	lake	Early Summer Miscellaneous
	Indian/Kruger-ES	lake	3	1	3	Upper Fraser	lake	
	Kamloops-ES	lake	2	9	70	North Thompson	lake	Raft, Fennel, ES Miscellaneous
	Nadina-ES	lake	1	1	2	Middle Fraser	lake	Nadina
	Nahatlatch-ES	lake	1	2	33	Fraser Canyon	lake	Early Summer Miscellaneous
	Pitt-ES	lake	1	2	69	Lower Fraser	lake	Pitt
	Shuswap Complex-	lake	8	21-27	66	South Thompson	lake complex	Scotch,Seymour, ES Misc.
	Taseko-ES	lake	1	1-2	43	Middle Fraser	lake	Early Summer Miscellaneous
Summer	Chilko-S	lake	1	3	70	Middle Fraser	lake	Chilko
	Francois-S	lake	1	3	9	Middle Fraser	lake	Stellako
	Fraser-S	lake	1	1	70	Middle Fraser	lake	Stellako
	Mckinley-S	lake	1	1	19	Middle Fraser	lake	Quesnel
	Quesnel-S	lake	4	51-66	67	Middle Fraser	lake	Quesnel
	Stuart-S	lake	1	5	64	Middle Fraser	lake	Late Stuart
	Takla/Trembleur-S	lake	2	4-5	67	Middle Fraser	lake complex	Late Stuart
Late	Cultus-L	lake	1	1	70	Lower Fraser	lake	Cultus
	Harrison (D/S)-L	lake	1	6-8	68	Lower Fraser	lake	Misc. non-Shuswap
	Harrison (U/S)-L	lake	1	4	70	Lower Fraser	lake	Weaver
	Kamloops-L	lake	1	1	48	South Thompson	lake	Misc. Shuswap
	Kawkawa-L	lake	1	1-2	8	Fraser Canyon	lake	
	Lillooet-L	lake	1	8	70	Lillooet	lake	Birkenhead
	Seton-L	lake	1	1	60	Middle Fraser	lake	Portage
	Shuswap Complex-	lake	1	44-58	70	South Thompson	lake complex	Late Shuswap, Misc. Shuswap
River	Fraser Canyon	river	-	6	10	Fraser Canyon	ecotypic	
	Lower Fraser	river	-	5	70	Lower Fraser	genetics	Harrison
	Middle Fraser	river	-	8-10	36	Middle Fraser	timing + gen.	Stellako, Quesnel
	Thompson	river	-	2	4	N&S Thompson	ecotypic, gen. similar to MFR, diff. timing	
	Upper Fraser	river	-	1	1	Upper Fraser	ecotypic, status uncertain	
	Widgeon	river	-	1	65	Lower Fraser	genetics	Misc. non-Shuswap
			Total Sites:	271-275				

Table 3: DBE and contribution of non-model stocks for 4 management groups.

	% Difference between estimates				% Contribution of non-model stocks	
Year	Early Stuart	Early Summer	Summer	Late	% of run	% of esc
1977	-	33%	0%	-	0%	0%
1978	41%	0%	14%	0%	1%	1%
1979	37%	28%	2%	-	0%	0%
1980	-	31%	7%	-	1%	1%
1981	31%	5%	12%	-	0%	0%
1982	-	17%	0%	1%	5%	5%
1983	54%	53%	0%	-	1%	1%
1984	-	0%	19%	-	1%	2%
1985	0%	0%	0%	-	0%	0%
1986	-	0%	23%	23%	1%	1%
1987	4%	43%	0%	-	1%	1%
1988	0%	59%	0%	-	3%	4%
1989	0%	52%	0%	-	0%	0%
1990	16%	24%	16%	0%	2%	3%
1991	27%	45%	0%	-	1%	1%
1992	63%	36%	27%	-	2%	2%
1993	0%	-	0%	-	0%	0%
1994	82%	37%	29%	0%	4%	4%
1995	26%	0%	7%	-	1%	1%
1996	31%	15%	0%	63%	2%	3%
1997	70%	51%	2%	41%	0%	0%
1998	81%	64%	40%	43%	2%	1%
1999	83%	74%	14%	60%	1%	1%
2000	41%	0%	0%	90%	4%	6%
2001	17%	18%	0%	80%	1%	1%
2002	56%	18%	-	8%	2%	1%
2003	55%	40%	22%	17%	3%	3%
2004	91%	82%	70%	67%	11%	13%
2005	50%	61%	37%	3%	4%	3%
2006	22%	64%	29%	36%	3%	2%
2007	58%	22%	11%	41%	4%	4%
2008	14%	44%	6%	84%	7%	10%
2009	40%	64%	17%	0%		

Table 4: Model selection criteria

Stock	Based on WinBUGS DIC values: Larkin	Ricker	Alt model	Based on Akaike's Information Criterion: β_1	β_2	β_3	Based on Bayesian parameter probability estimate: β_1	β_2	β_3
E. Stuart	X			X	X		X	X	0.81
Bowron		X							0.22
Fennell		X			X				
Gates		X			X	X	0.86	X	X
Nadina		X				X		0.86	X
Pitt		X			X		0.74	X	0.78
Raft		X				X	0.35	X	
Scotch	X			X	X	X	X	X	X
Seymour	X			X	X	X	X	X	X
Chilko			X	X			X		
Late Stuart			X	X			X	X	
Quesnel	X			X	X	X	X	X	X
Stellako			X	X		X	X	0.75	X
Birkenhead			X	X			X	0.35	
Cultus		X					0.24		0.09
Harrison		X					0.36		0.30
Portage		X		X			X		0.33
Weaver		X				X	0.73	0.18	X
L. Shuswap			X	X	X		X	X	0.72

(shaded) indicates the model form(s) defined as "best fit" by DIC results (i.e. within a value of 5 of the model with the lowest DIC value)

X indicates the model form that had the very lowest DIC value

(shaded) indicates the model form(s) defined as "best fit" by AIC results (i.e. within a value of 2 of the model with the lowest AIC value)

X indicates the model form that had the very lowest AIC value

(shaded) indicates probability higher than 75% that β is something other than zero

X indicates probability higher than 90 % that β is something other than zero (otherise the number is shown)

123 underscored values in red indicate potentially significant negative beta terms

Table 5: Best-Fit SR models
Selection based on info in Table 4

Stock	β_1	β_2	β_3	**Model**
E. Stuart	X	X	X	Larkin - Full
Bowron				Ricker
Fennell				Ricker
Gates				Ricker
Nadina				Ricker
Pitt				Ricker
Raft				Ricker
Scotch	X	X	X	Larkin - Full
Seymour	X	X	X	Larkin - Full
Chilko	X			Larkin - Partial
Late Stuart	X	X		Larkin - Partial
Quesnel	X	X	X	Larkin - Full
Stellako	X	X	X	Larkin - Full
Birkenhead	X			Larkin - Partial
Cultus				Ricker
Harrison				Ricker
Portage				Ricker
Weaver				Ricker
L. Shuswap	X	X	X	Larkin - Full

Table 6: Median SR parameter estimates – Using total spawners

A) Larkin 4 - Log-Normal Prior on β_0

Stock	α	β_0	β_1	β_2	β_3	σ
E. Stuart	1.935	1.479	**2.95**	**1.86**	0.98	0.755
Bowron	2.041	34.330	8.34	12.39	5.69	0.825
Fennell	2.737	76.095	34.63	23.29	21.38	0.792
Gates	2.554	18.415	11.88	**15.56**	**17.12**	0.783
Nadina	1.785	6.316	3.40	**5.79**	**6.07**	0.885
Pitt	1.877	11.075	5.28	**11.08**	4.39	0.709
Raft	1.767	14.710	5.51	11.43	7.22	0.748
Scotch	2.683	9.119	**28.43**	**17.88**	**30.31**	0.653
Seymour	2.051	3.870	**7.39**	**3.34**	**5.38**	0.803
Chilko	2.445	1.424	0.77	0.26	0.21	0.680
Late Stuart	2.313	1.349	**1.53**	**1.33**	0.54	1.229
Quesnel	2.124	0.366	**0.33**	**0.38**	**0.38**	0.780
Stellako	2.479	3.121	1.98	0.65	**3.57**	0.575
Birkenhead	2.547	6.599	3.33	0.84	0.98	0.942
Cultus	1.462	14.225	6.46	7.94	5.14	1.300
Harrison	2.573	66.720	6.44	6.34	7.41	1.099
Portage	3.079	70.170	**58.17**	10.86	11.93	1.037
Weaver	2.755	5.322	2.98	1.59	4.19	0.924
L. Shuswap	2.241	0.403	**0.40**	**0.39**	0.12	0.895

B) Best fit - Log-Normal Prior on β_0

Stock	α	β_0	β_1	β_2	β_3	σ
E. Stuart	1.935	1.479	2.950	1.860	0.984	0.755
Bowron	1.683	28.940	0.000	0.000	0.000	0.781
Fennell	2.358	101.450	0.000	0.000	0.000	0.820
Gates	1.832	13.935	0.000	0.000	0.000	0.890
Nadina	1.450	5.483	0.000	0.000	0.000	0.865
Pitt	1.592	21.310	0.000	0.000	0.000	0.730
Raft	1.563	17.125	0.000	0.000	0.000	0.731
Scotch	2.683	9.119	28.425	17.875	30.310	0.653
Seymour	2.051	3.870	7.391	3.341	5.376	0.803
Chilko	2.330	1.520	0.899	0.000	0.000	0.670
Late Stuart	2.207	1.288	1.482	1.165	0.000	1.207
Quesnel	2.124	0.366	0.332	0.379	0.380	0.780
Stellako	2.479	3.121	1.977	0.650	3.575	0.575
Birkenhead	2.434	6.581	3.720	0.000	0.000	0.924
Cultus	1.162	14.210	0.000	0.000	0.000	1.230
Harrison	2.259	65.935	0.000	0.000	0.000	1.040
Portage	2.560	72.560	0.000	0.000	0.000	1.100
Weaver	2.236	5.324	0.000	0.000	0.000	0.916
L. Shuswap	2.241	0.403	0.404	0.391	0.120	0.895

C) Larkin 4 - Uniform prior on all parameters

Stock	α	β_0	β_1	β_2	β_3	σ
E. Stuart	1.986	1.948	2.971	1.752	1.032	0.752
Bowron	2.083	37.980	9.107	11.600	6.180	0.823
Fennell	2.745	75.130	34.005	24.875	19.280	0.790
Gates	2.581	19.035	11.725	16.410	17.100	0.779
Nadina	1.816	7.717	3.561	5.148	6.137	0.883
Pitt	1.907	11.820	5.302	11.205	4.142	0.700
Raft	1.806	19.710	4.793	10.960	8.267	0.743
Scotch	2.808	12.495	29.040	19.040	31.580	0.668
Seymour	2.093	5.067	7.205	3.524	5.238	0.812
Chilko	2.459	1.445	0.817	0.221	0.204	0.675
Late Stuart	2.319	1.376	1.503	1.321	0.487	1.221
Quesnel	2.131	0.422	0.314	0.391	0.366	0.780
Stellako	2.498	3.407	1.976	0.637	3.425	0.570
Birkenhead	2.549	6.535	3.314	0.737	0.999	0.959
Cultus	1.547	25.055	5.860	8.513	4.682	1.298
Harrison	2.575	66.395	6.450	6.891	7.886	1.101
Portage	3.090	70.005	59.770	11.635	13.210	1.039
Weaver	2.758	5.852	2.792	1.406	4.171	0.892
L. Shuswap	2.247	0.402	0.399	0.388	0.111	0.883

123 = lag terms > 80% of β_0

123 (shaded) = more than 10% different from Table A

Table 7: Median SR parameter estimates – Using effective female spawners

	A) Larkin 4 - Log-Normal Prior on β_0						B) Best fit - Log-Normal Prior on β_0						C) Larkin 4 - Uniform prior on all parameters					
Stock	α	β_0	β_1	β_2	β_3	σ	α	β_0	β_1	β_2	β_3	σ	α	β_0	β_1	β_2	β_3	σ
E. Stuart	2.502	2.034	**4.54**	**3.31**	**1.77**	0.722	2.502	2.034	4.544	3.305	1.771	0.722	2.557	3.197	**4.83**	**3.06**	1.79	0.724
Bowron	2.769	74.220	16.58	23.66	13.06	0.830	2.431	62.000	0.000	0.000	0.000	0.797	2.833	82.780	18.60	24.70	13.09	0.836
Fennell	3.417	155.250	58.09	52.28	42.77	0.789	3.101	208.800	0.000	0.000	0.000	0.858	3.427	156.800	57.49	50.89	41.68	0.788
Gates	3.606	58.685	34.68	**67.16**	**75.97**	0.795	2.795	52.665	0.000	0.000	0.000	0.927	3.654	72.540	35.98	**69.89**	**71.59**	0.793
Nadina	2.617	16.190	8.09	**16.63**	**19.36**	0.846	2.175	12.295	0.000	0.000	0.000	0.821	2.700	21.045	7.76	**17.65**	**21.11**	0.851
Pitt	2.576	22.025	9.32	**23.02**	10.30	0.708	2.293	42.235	0.000	0.000	0.000	0.738	2.585	23.435	8.31	**21.82**	9.31	0.705
Raft	2.561	31.820	12.16	**29.56**	18.01	0.772	2.350	37.895	0.000	0.000	0.000	0.775	2.595	45.460	9.96	29.93	16.87	0.775
Scotch	3.273	15.275	**60.59**	**37.17**	**67.24**	0.739	3.273	15.275	60.590	37.165	67.235	0.739	3.402	24.240	**62.48**	41.49	**68.53**	0.753
Seymour	2.840	9.196	**17.84**	**10.54**	**10.29**	0.807	2.840	9.196	17.835	10.535	10.285	0.807	2.861	12.260	**16.52**	**11.13**	9.02	0.815
Chilko	3.026	2.123	**1.95**	0.36	0.34	0.639	2.955	2.285	2.251	0.000	0.000	0.624	3.046	2.289	**1.89**	0.35	0.33	0.638
Late Stuart	3.000	2.427	**3.38**	**2.45**	1.16	1.265	2.916	2.402	3.076	2.295	0.000	1.251	3.061	2.511	**3.31**	**2.52**	1.07	1.254
Quesnel	3.018	0.772	**0.80**	**0.97**	**0.95**	0.835	3.018	0.772	0.800	0.970	0.953	0.835	3.015	0.841	**0.76**	**1.00**	**0.89**	0.825
Stellako	3.112	6.180	2.59	1.75	**7.14**	0.566	3.112	6.180	2.591	1.753	7.144	0.566	3.135	6.703	2.57	1.61	**6.92**	0.568
Birkenhead	3.202	11.040	6.86	1.66	1.84	0.951	3.058	10.875	7.573	0.000	0.000	0.928	3.185	11.085	6.77	1.65	1.77	0.947
Cultus	2.067	23.670	11.16	14.34	9.61	1.230	1.803	24.660	0.000	0.000	0.000	1.149	2.191	41.480	10.82	13.31	8.70	1.238
Harrison	3.110	113.350	13.00	13.19	12.27	1.113	2.811	112.100	0.000	0.000	0.000	1.052	3.087	111.300	10.65	15.99	11.92	1.121
Portage	3.563	134.850	76.36	27.60	18.63	1.057	3.206	146.950	0.000	0.000	0.000	1.088	3.572	135.950	74.61	27.07	22.05	1.037
Weaver	3.532	10.485	7.56	3.41	**11.39**	0.871	2.964	11.895	0.000	0.000	0.000	0.885	3.583	13.175	6.62	3.09	**10.97**	0.870
L. Shuswap	2.910	0.787	**0.82**	**0.85**	0.32	0.872	2.910	0.787	0.819	0.848	0.324	0.872	2.903	0.768	**0.81**	**0.86**	0.30	0.877

123 = lag terms > 80% of β_0
123 (shaded) = more than 10% different from Table A

Table 8: SR parameter estimates – Using linear regression fits and effective female spawners.

Stock	α	β_0	β_1	β_2	β_3
E. Stuart	2.48	2.3119	4.738	3.163	1.341
Bowron	2.38	73.504	-5.133	6.206	-18.73
Fennell	3.47	174.84	55.96	58.6	28.36
Gates	3.71	71.791	32.82	75.77	80.91
Nadina	2.45	18.245	-2.515	13.96	16.77
Upper Pitt	2.56	30.228	4.744	23.87	5.955
Raft	2.46	42.536	-9.556	34.59	9.526
Scotch	3.24	13.695	60.37	36.28	66.33
Seymour	2.82	10.542	17.6	10.02	9.327
Chilko	2.96	2.5883	2.213	-0.109	-0.161
L. Stuart	2.93	11.947	-4.77	0.559	1.009
Quesnel	3.02	0.9247	0.743	1.007	0.893
Stellako	3.1	7.0348	2.421	1.061	7.098
Birkenhead	3.07	12.529	7.458	-1.243	-0.037
Cultus	1.49	31.404	-18.42	5.303	-35.92
Harrison	2.24	31.047	12.72	11.15	-34.82
Portage	3.45	152.53	102	-3.572	-24.89
Weaver	3.34	17.549	4.67	-7.729	12.59
L. Shuswap	2.92	0.8698	0.803	0.869	0.259

123 = more than 20% different from Table A in Figure 7

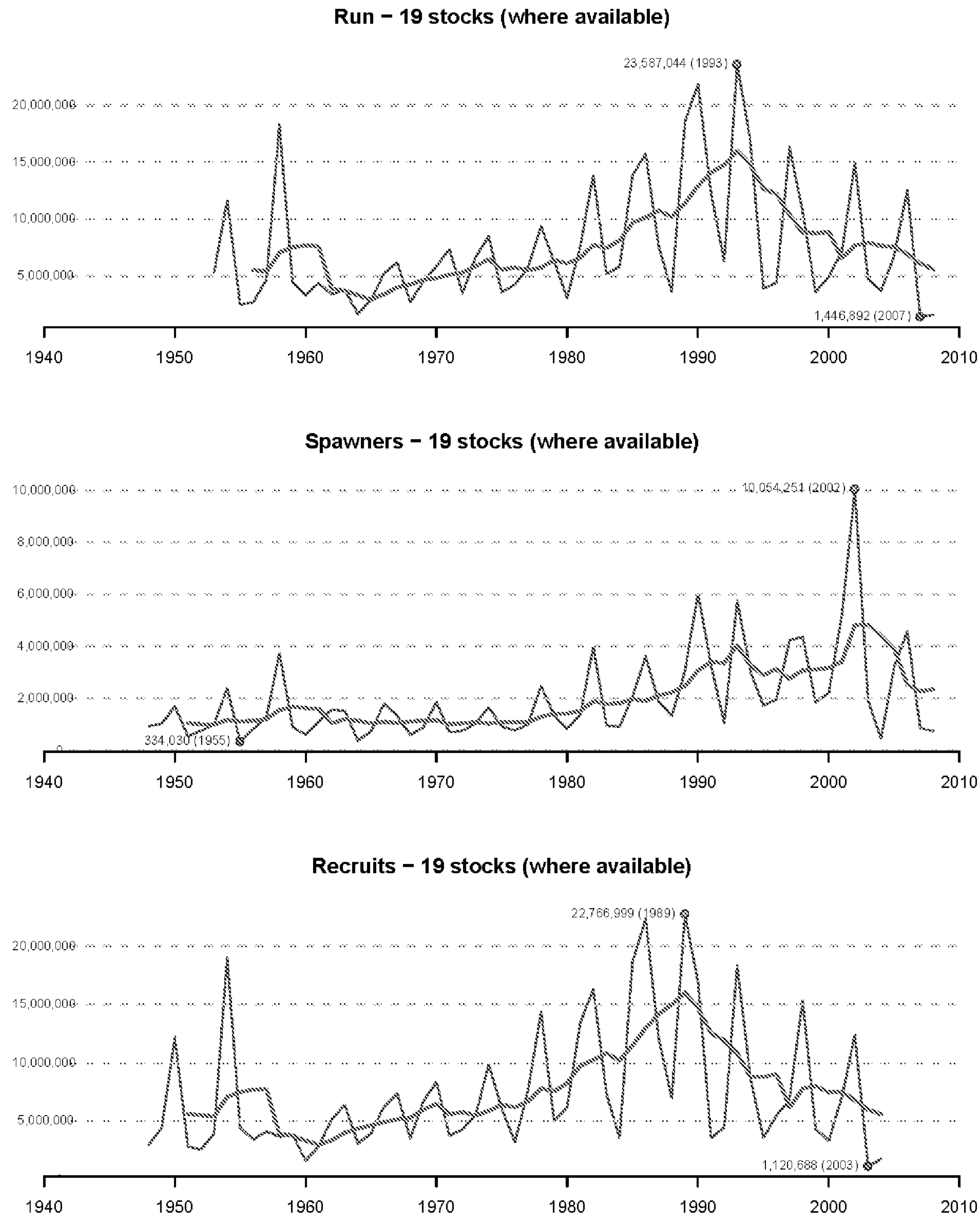


Figure 1: Total run, spawners, and recruitment for 19 stock of Fraser River sockeye.
Note that run, spawners, and recruits are all for the same year (i.e. run returning that year, spawner abundance that year, and recruits produced by those spawners. Totals include all data available for a year, with more stocks included in the later part of the time series. Figure 2 extracts only those 12 stocks with long time series. Trend lines (in red) show 4yr running averages. Table 1 lists the component stocks, and 3 list the available data for each stock.

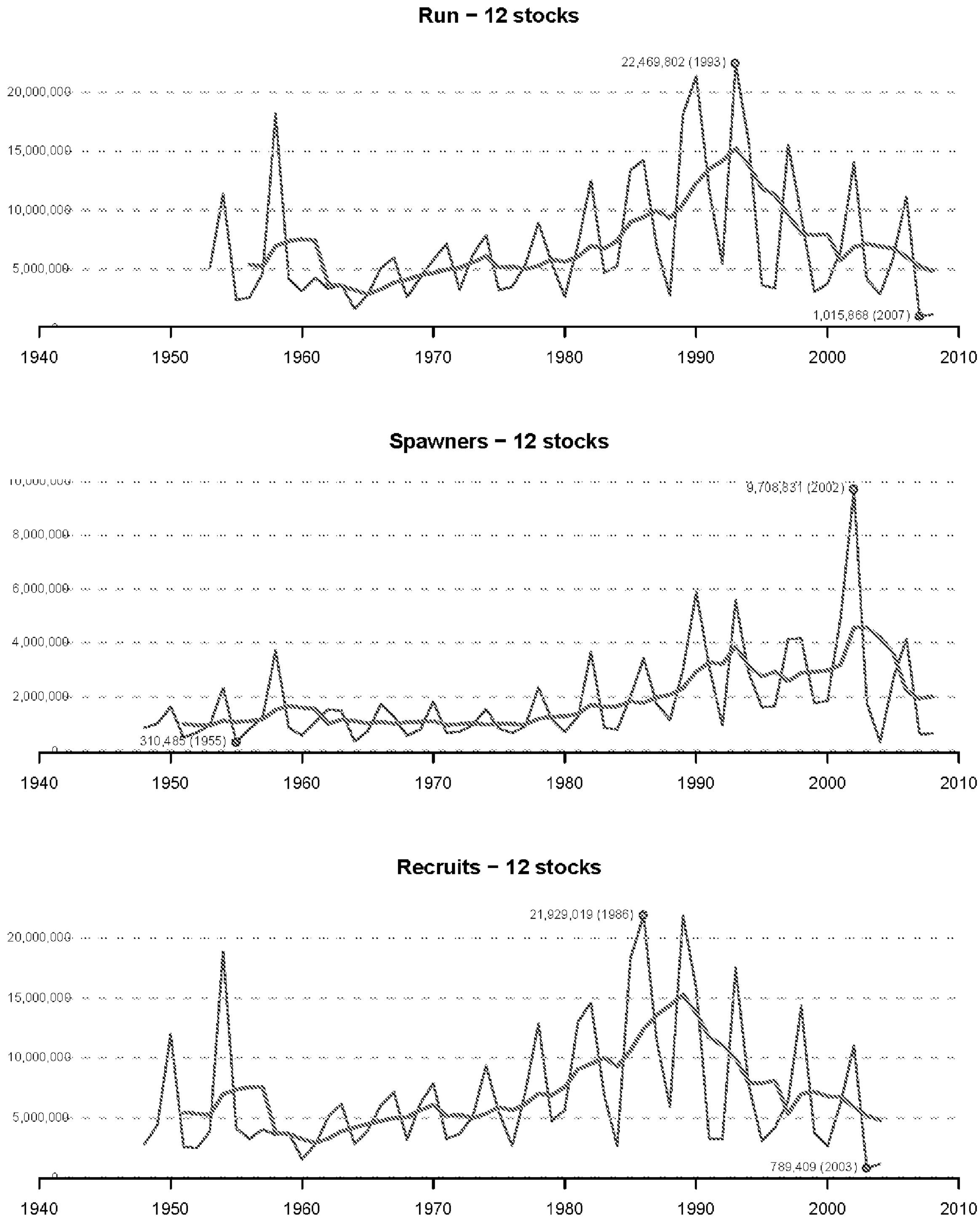


Figure 2: Total run, spawners, and recruitment for 12 stocks with long time series
Note that run, spawners, and recruits are all for the same year (i.e. run returning that year, spawner abundance that year, and recruits produced by those spawners. Totals include all data available for a year, with more stocks included in the later part of the time series. Trend lines (in red) show 4yr running averages. Table 1 lists the component stocks, and 3 list the available data for each stock.

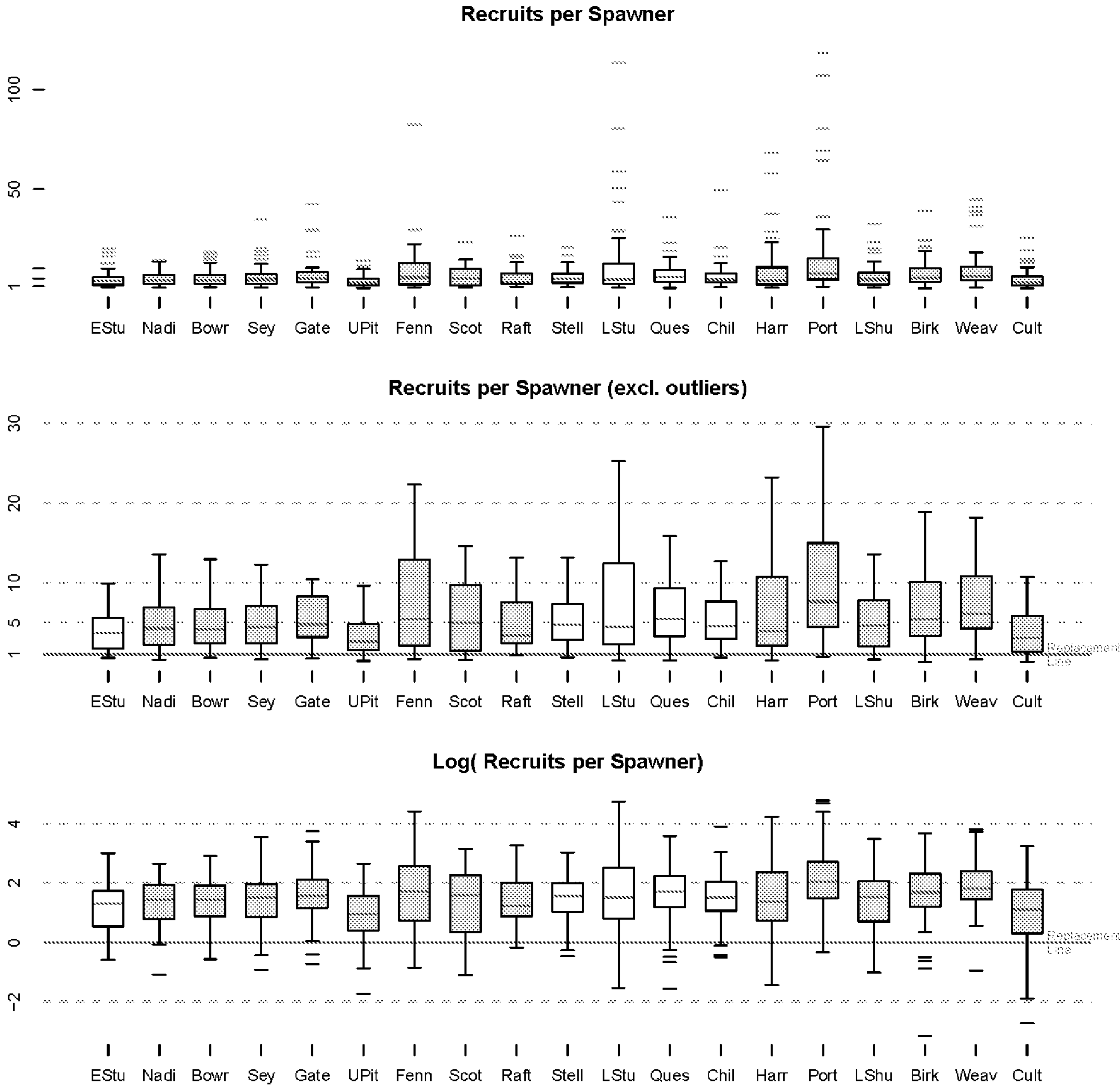


Figure 3: Distribution of observed productivity for 19 stocks of Fraser sockeye.
Boxes show the median and capture half of the observations. Whiskers mark the most extreme point within 1.5 box-lengths of the box. Stocks are sorted roughly in order of return timing. Management groups are marked by colour: Early Stuart (white), Early Summer (grey), Summer (white), Late (grey).

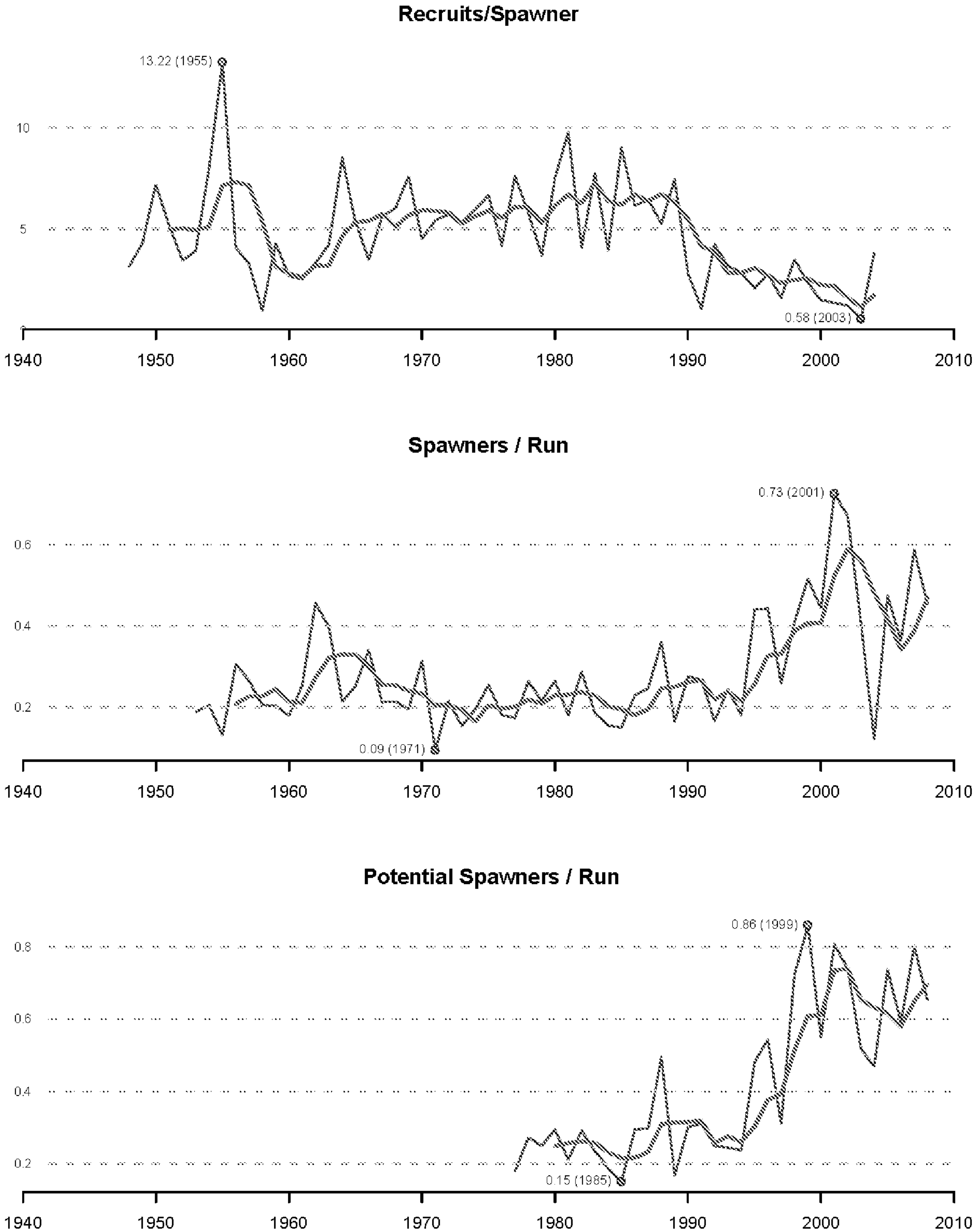


Figure 4: Patterns in productivity and management response for 19 stocks of Fraser sockeye. Totals include all data available for a year, with more stocks included in the later part of the time series. Trend lines show 4yr running averages. Potential spawning escapement is reconstructed, based on estimated in-river mortality (Section 2.2.6).

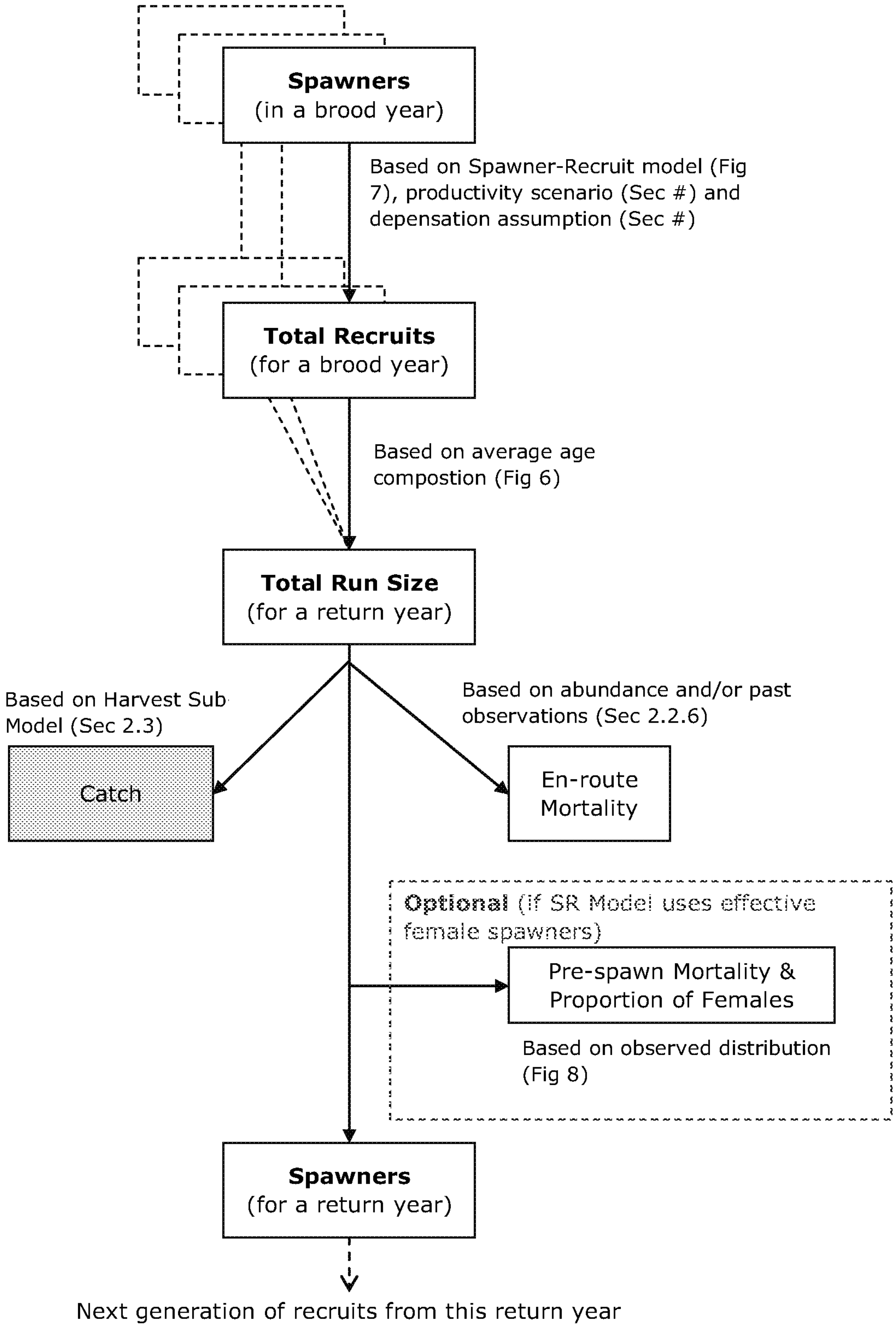


Figure 5: Overview of processes included in the model.

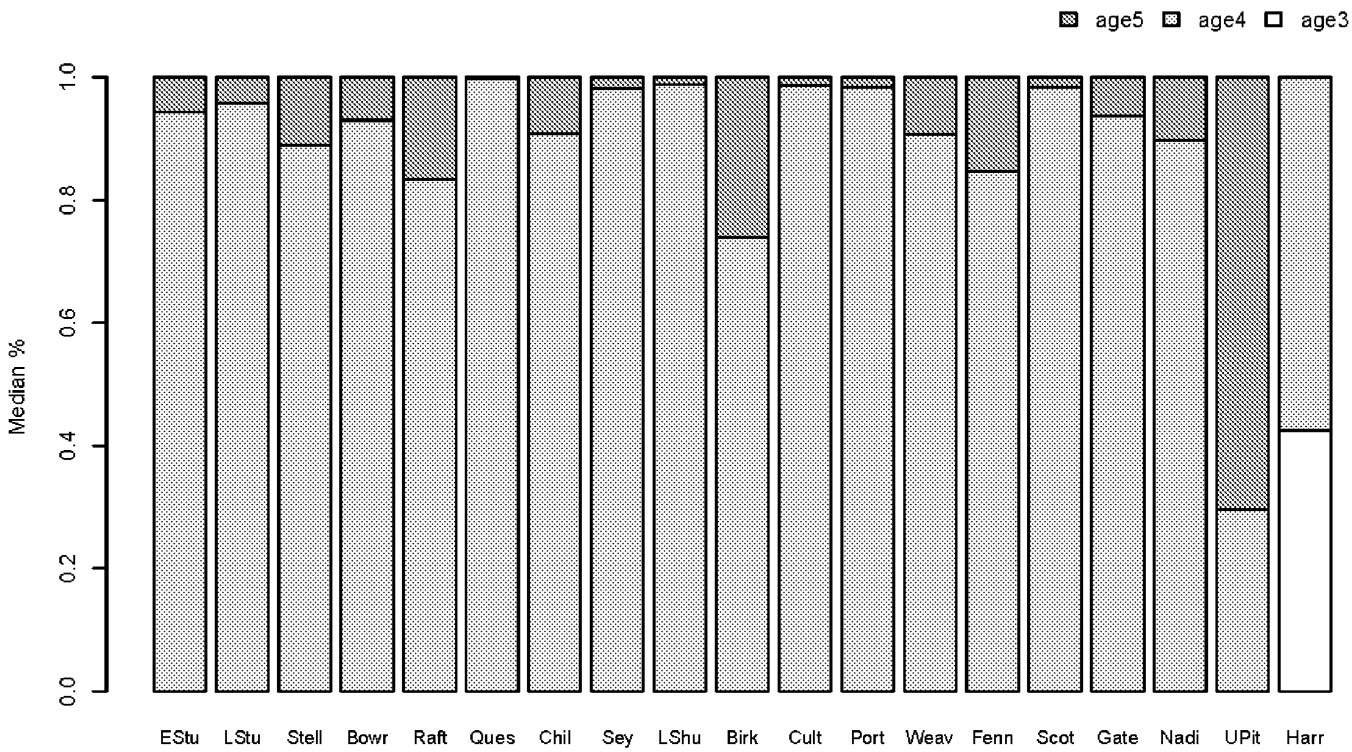


Figure 6: Age composition of recruitment for 19 stocks of Fraser River sockeye
Only the two predominant age classes are shown. Stocks are sorted roughly in order of return timing.

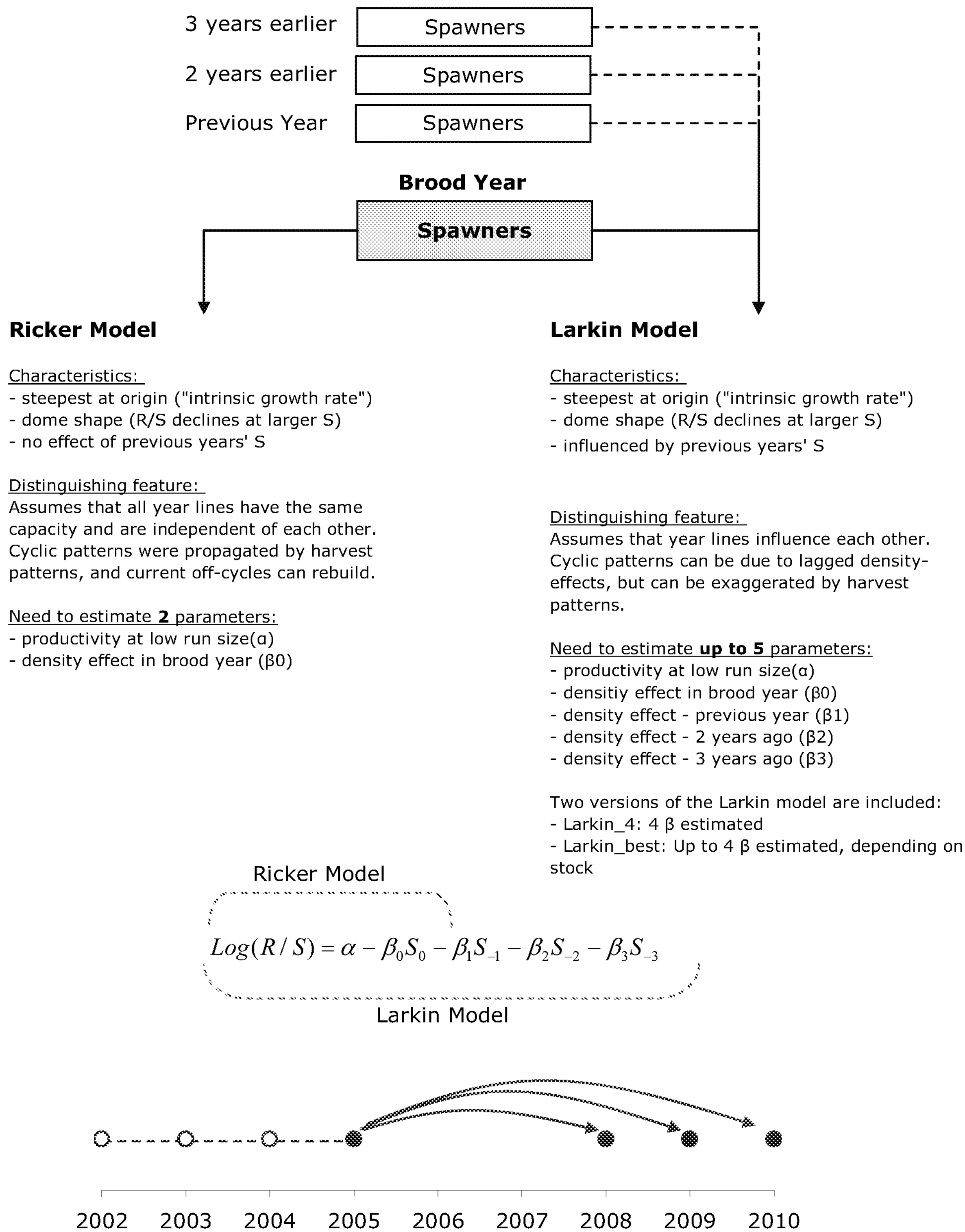


Figure 7: Comparison of spawner-recruit models currently available in the model.

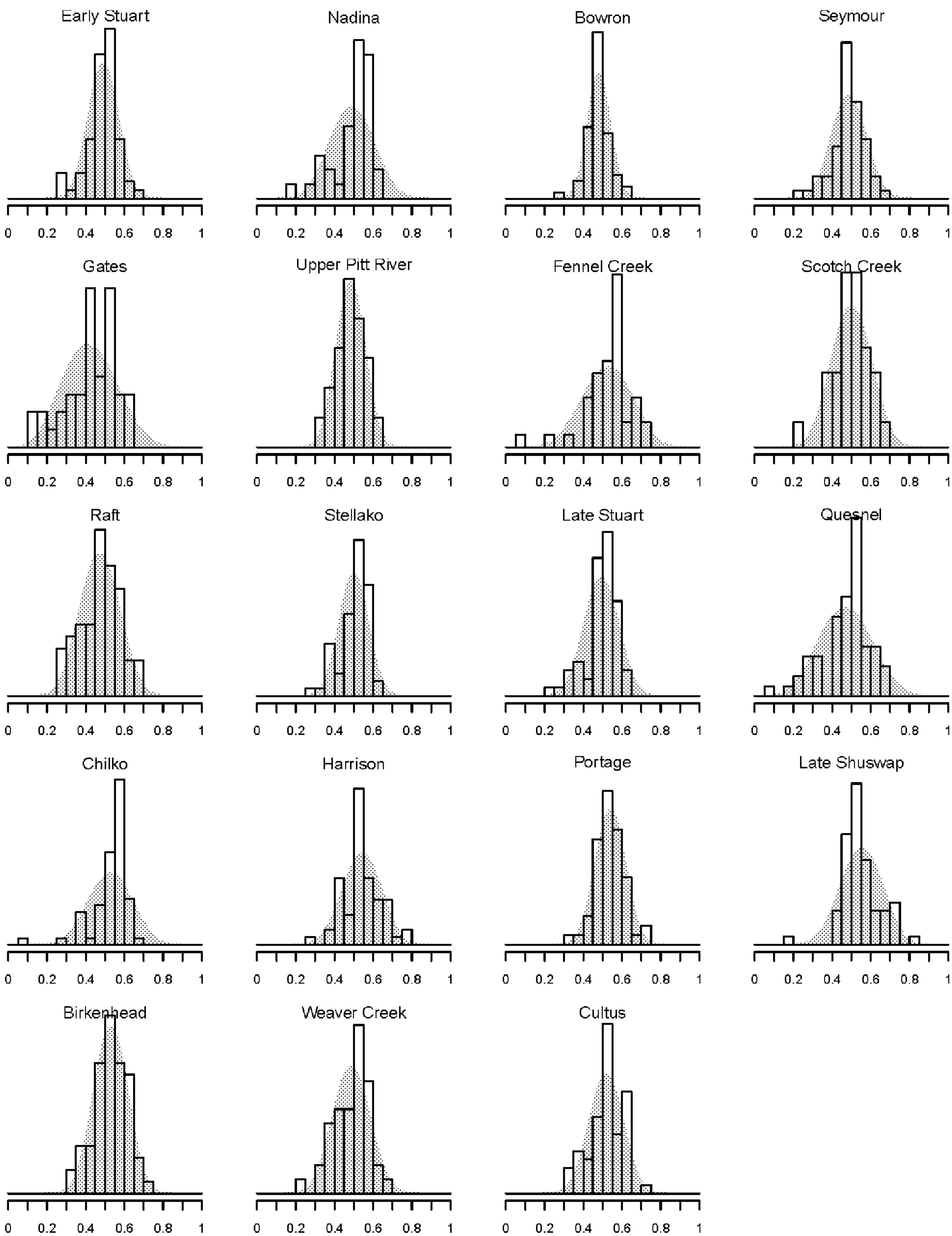


Figure 8: Observed and estimated distributions of the proportion of effective female spawners. Simulations use maximum-likelihood fit to beta distribution (Section 2.2.4)

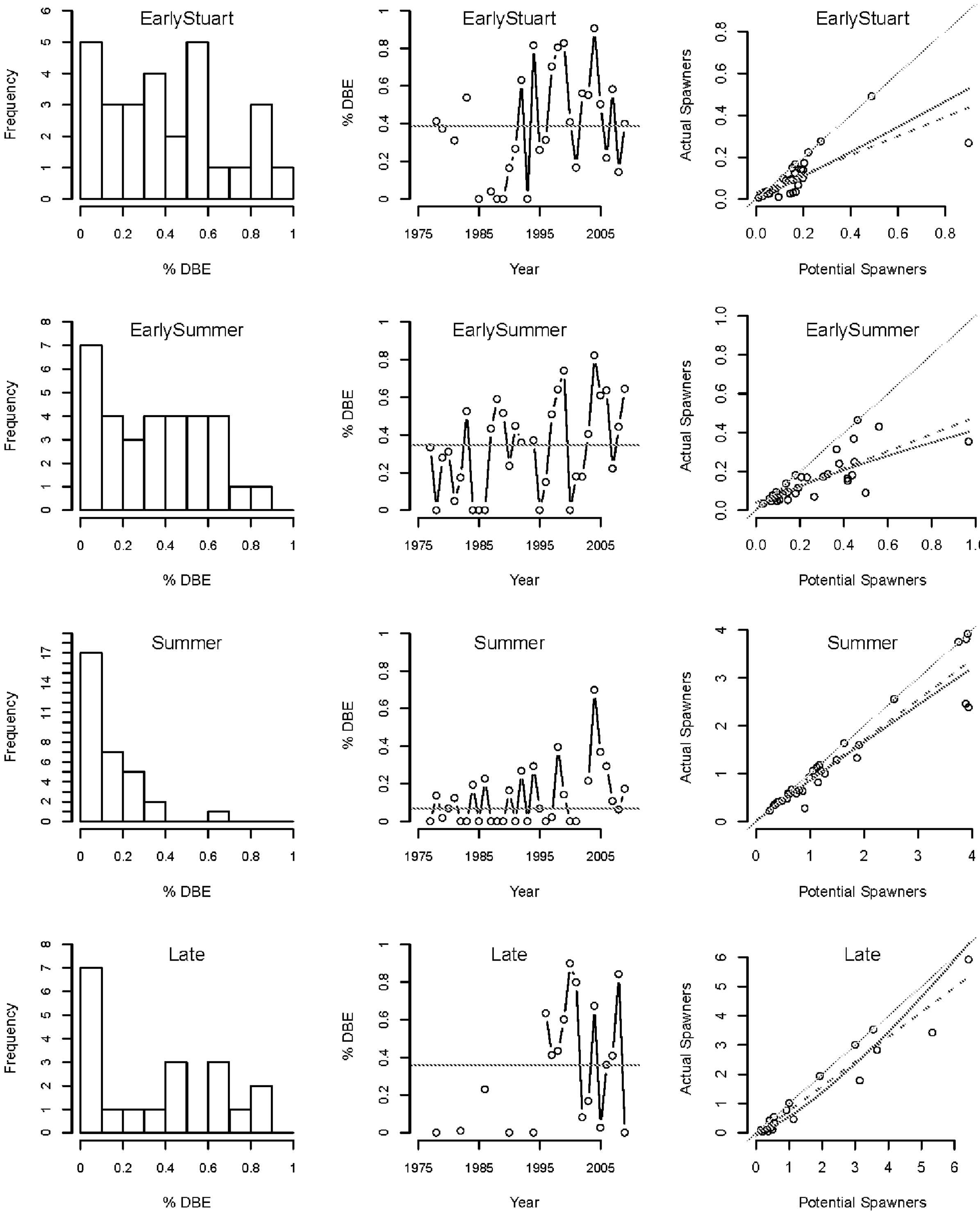


Figure 9: Patterns in the difference between estimates (DBE) of potential and actual spawners. The three panels for each management group show observed frequency (left) and time trend (middle) in observed % DBE, and a scatterplot (right) of actual vs. potential spawning escapement. Simple linear (dashed line) and log-linear (solid line) regression fits are included.

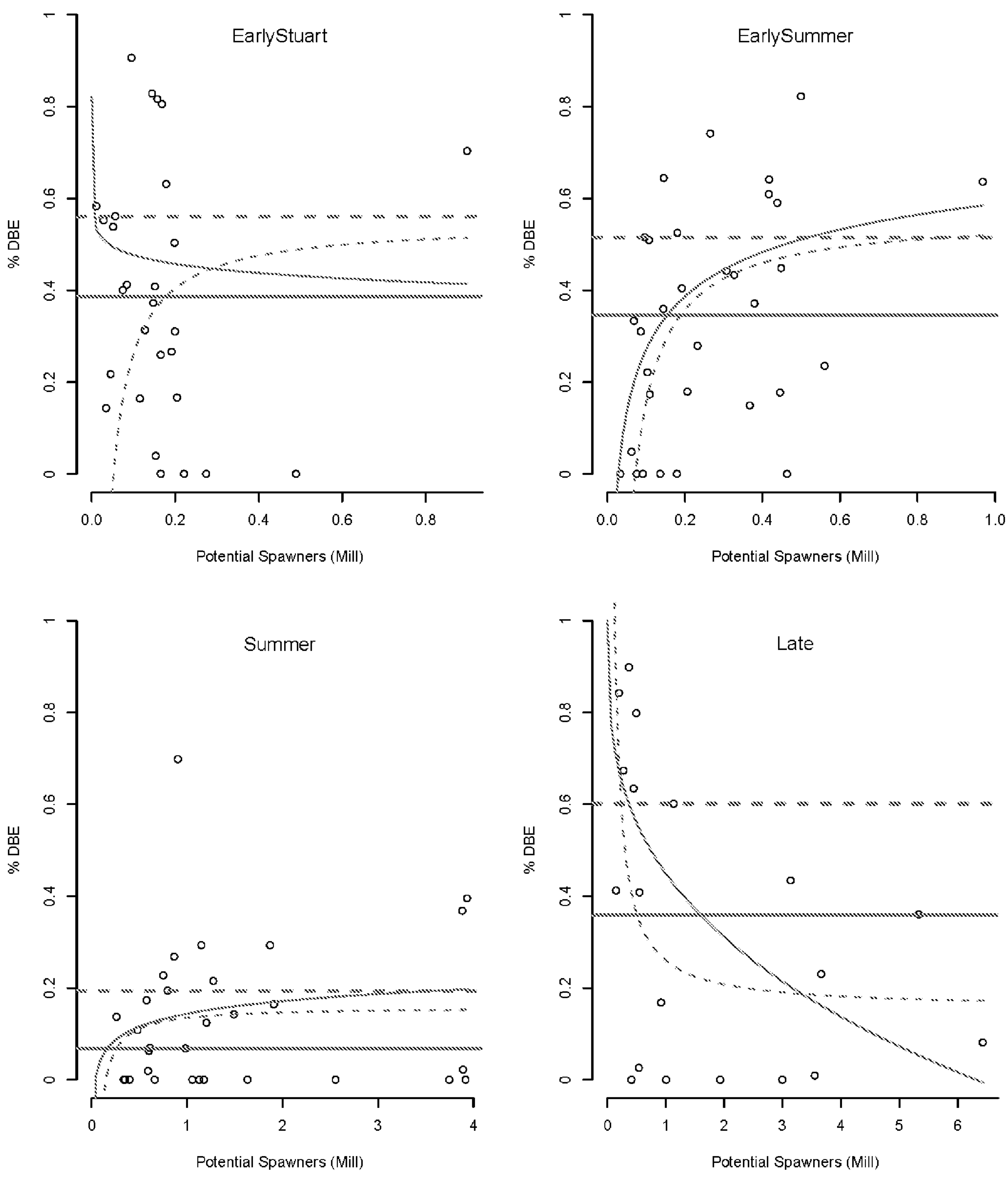


Figure 10: Four alternative assumptions about % DBE used in forward simulations.
The base case samples from the observed distribution of % DBE (median shown by thick solid line), with the alternative option to only sample from the worse half of the observations (median = thick dashed line). To reflect the possibility that harvest patterns influence the future distribution of % DBE, two additional options are included based on the linear (thin dashed line) and loglinear (thin solid line) fits shown in Figure 9.

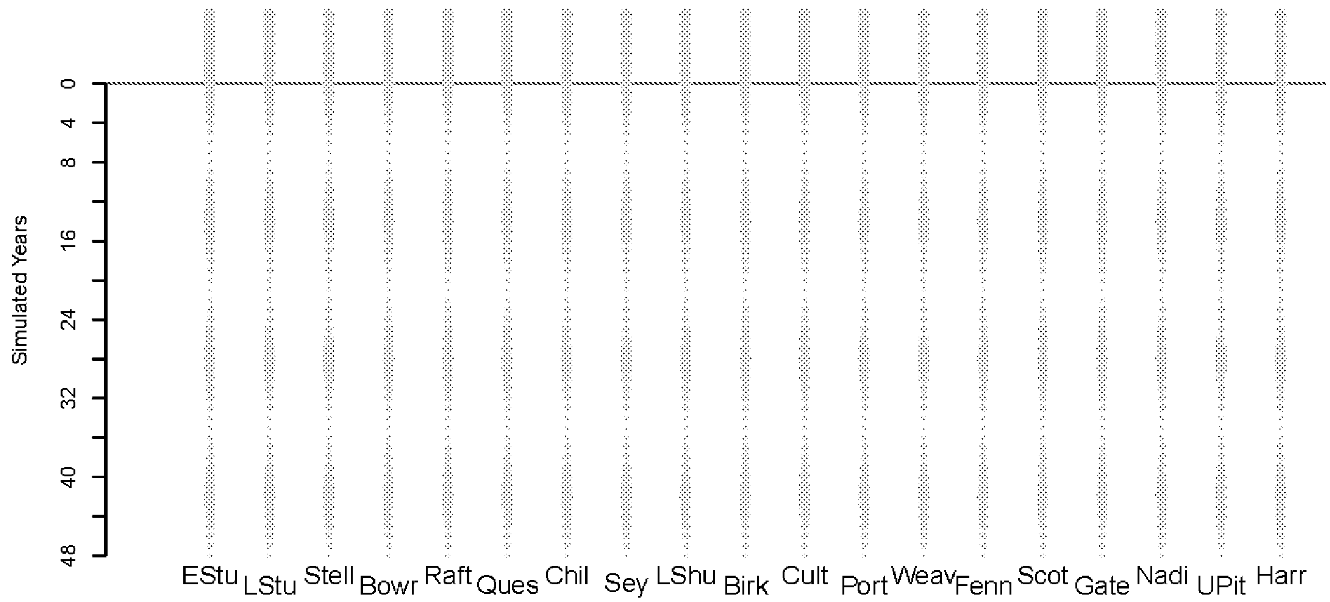


Figure 11: Sample pattern in productivity

The model allows users to specify hypothetical patterns of future productivity for each stock. One sample pattern with regular periods of reduced productivity is shown as an illustration. Larger dots indicate productivity closer to past observations. Initial seeding of forward simulations uses "like the past".

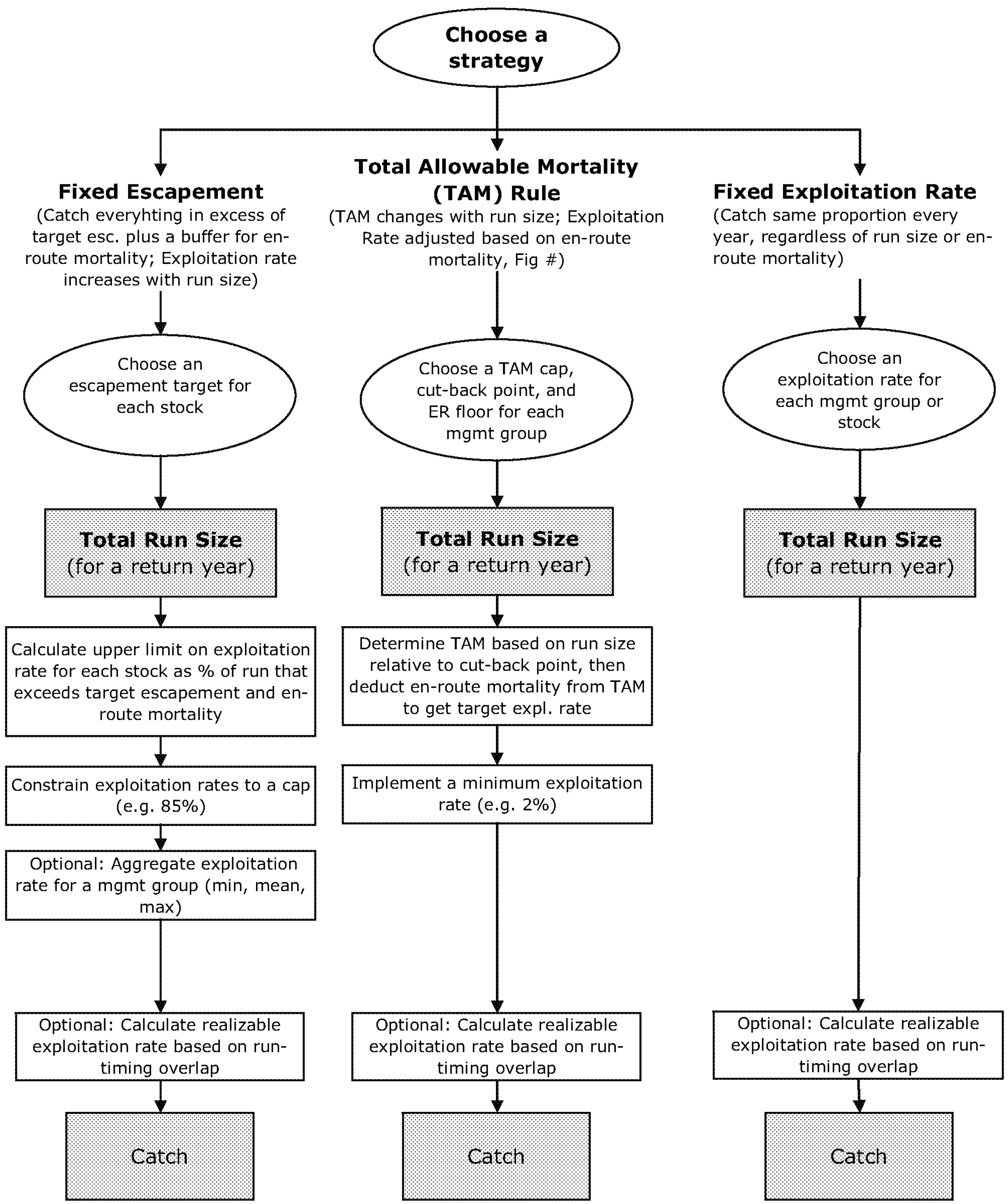
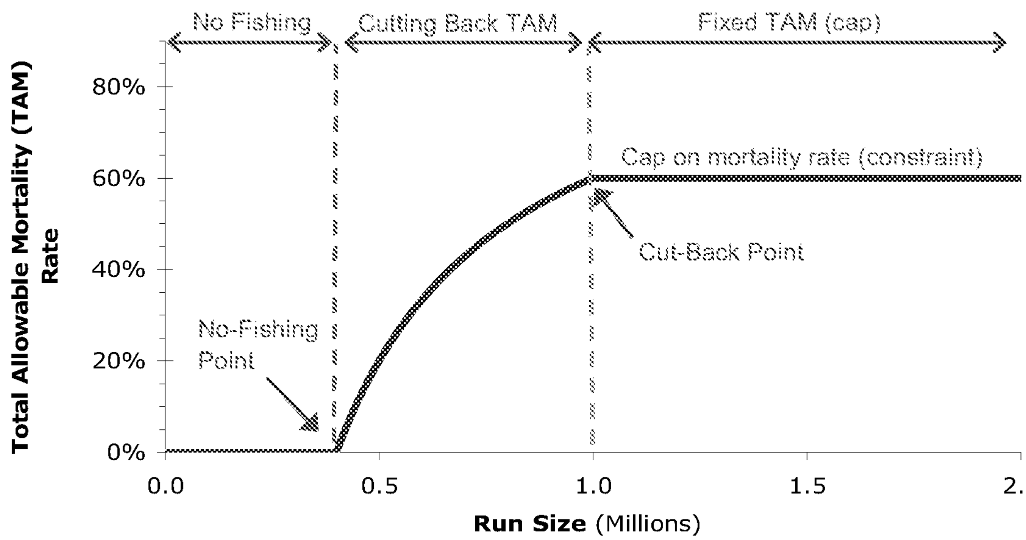


Figure 12: Flowchart of alternative escapement strategies.

A)



B)

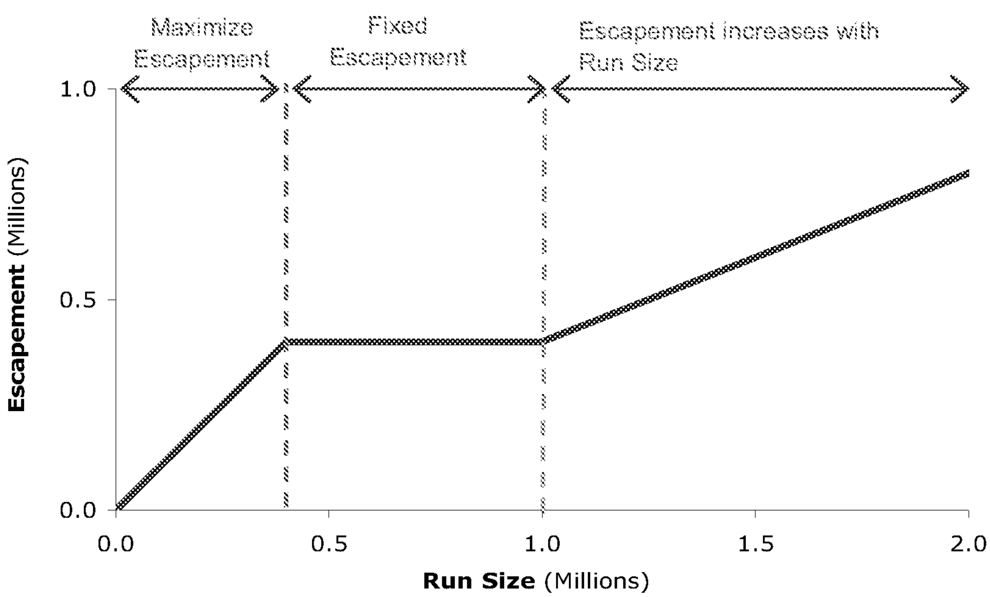


Figure 13: Shape of Total Allowable Mortality (TAM) rule.
Note: Optional floors on exploitation rate (e.g. 2%) are applied after the TAM rule, and are not shown on this figure.

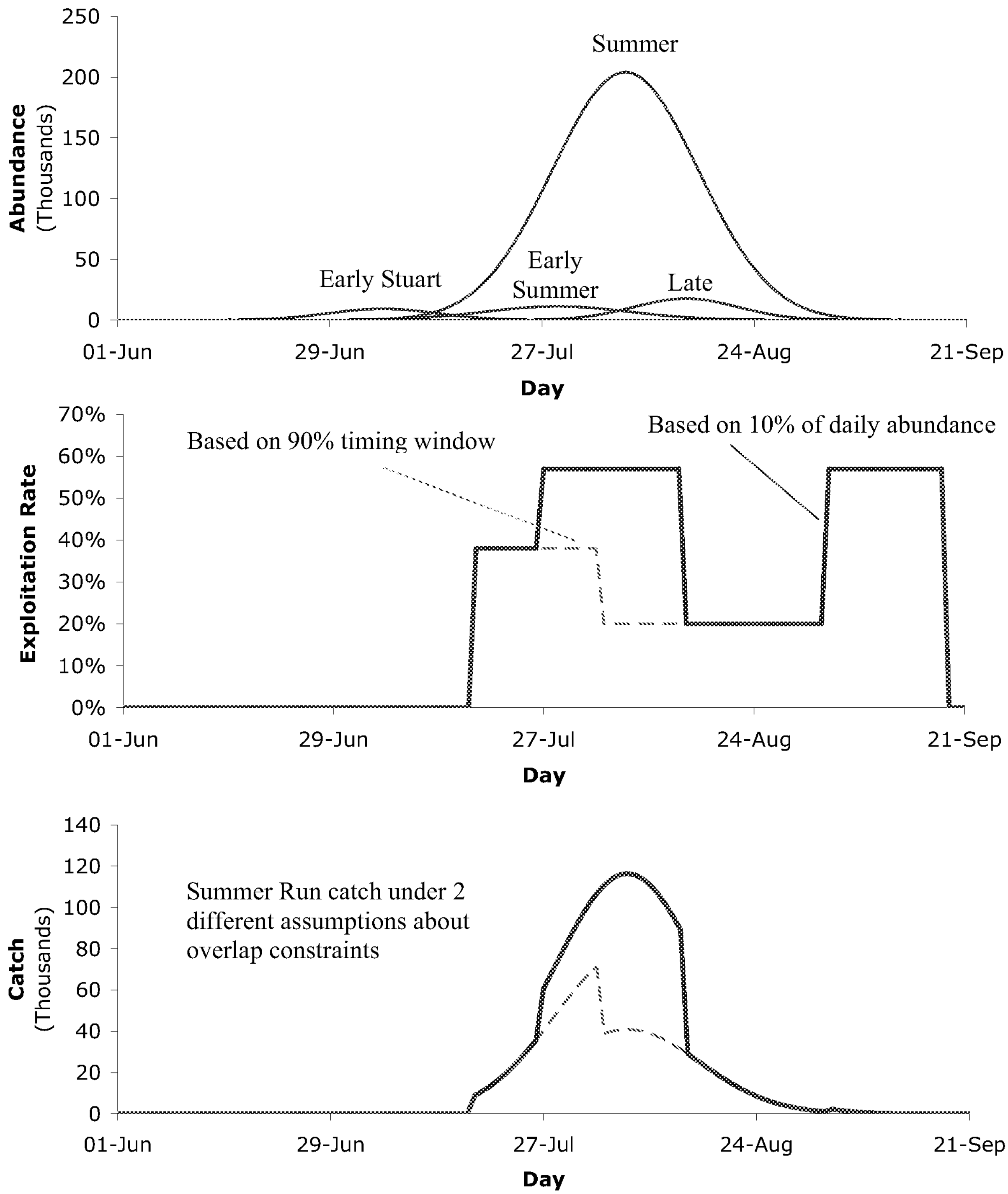


Figure 14: Two options for approximating the harvest constraint due to timing overlap.

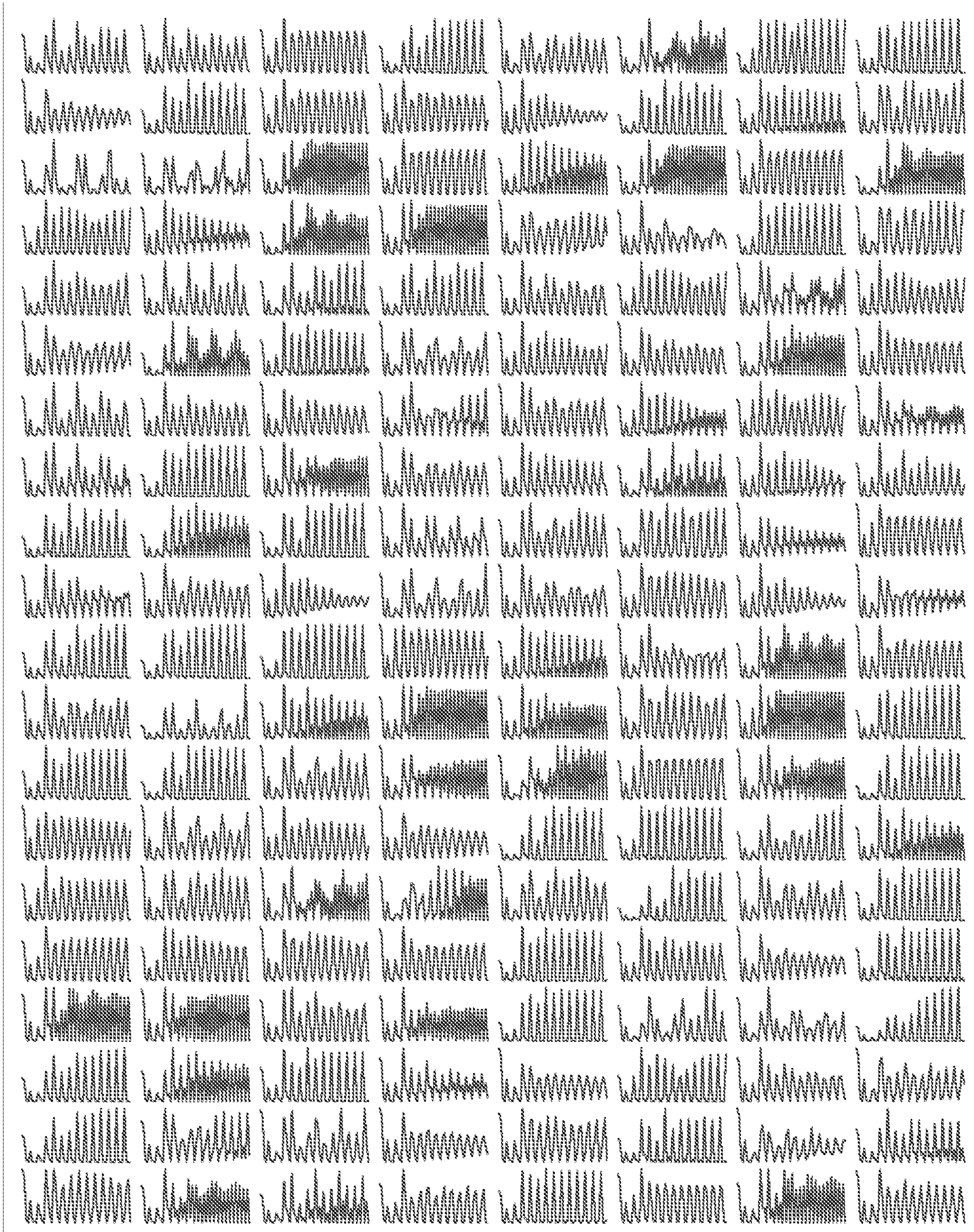


Figure 15: Larkin model illustration – Quesnel escapement trajectories
The sparklines show 160 sample trajectories, each one for a different set of spawner-recruit parameters sampled from the Bayesian posterior distribution (30% fixed ER, no random variation).

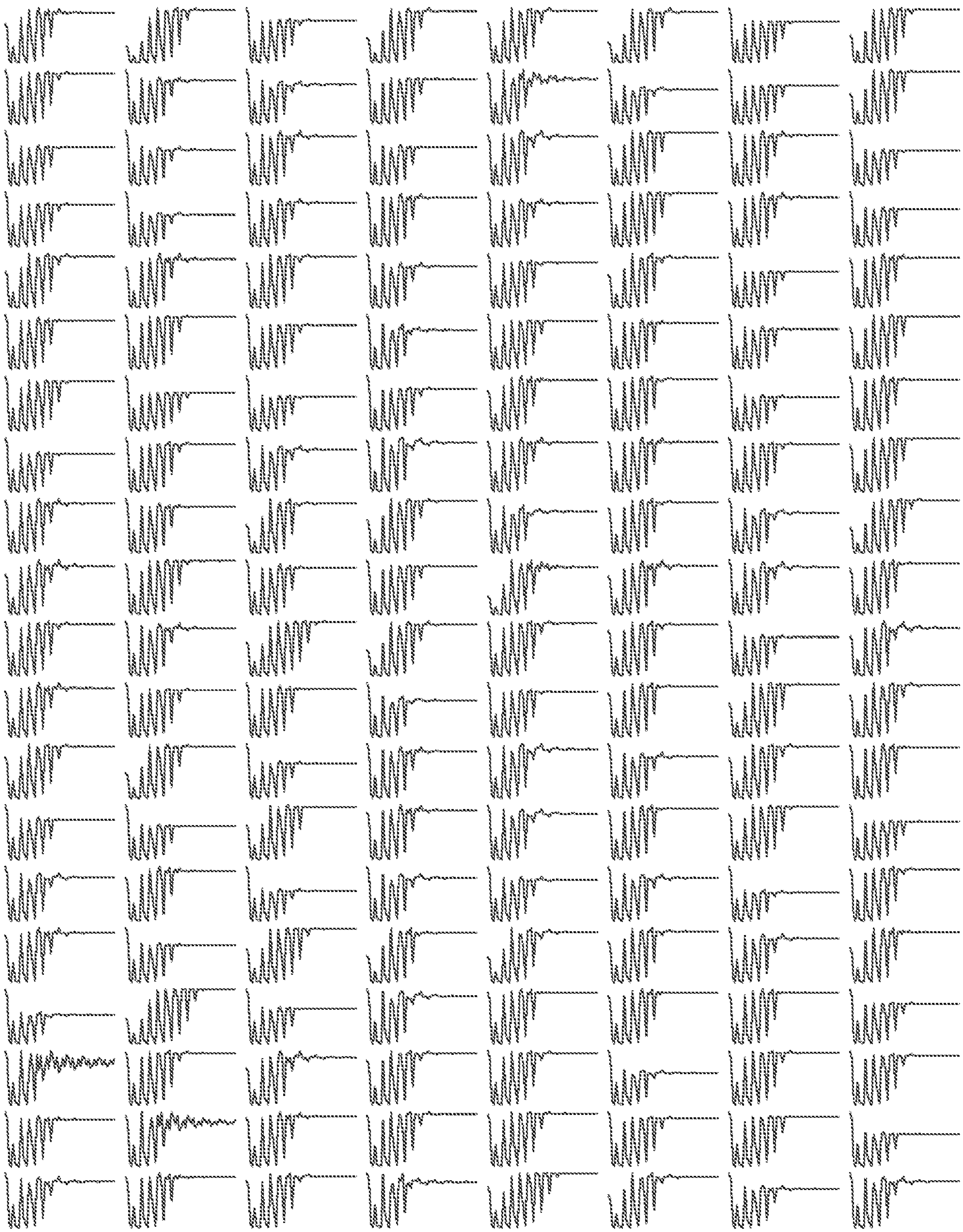


Figure 16: Ricker model illustration – Quesnel escapement trajectories
The sparklines show 160 sample trajectories, each one for a different set of spawner-recruit parameters sampled from the Bayesian posterior distribution (30% fixed ER, no random variation).

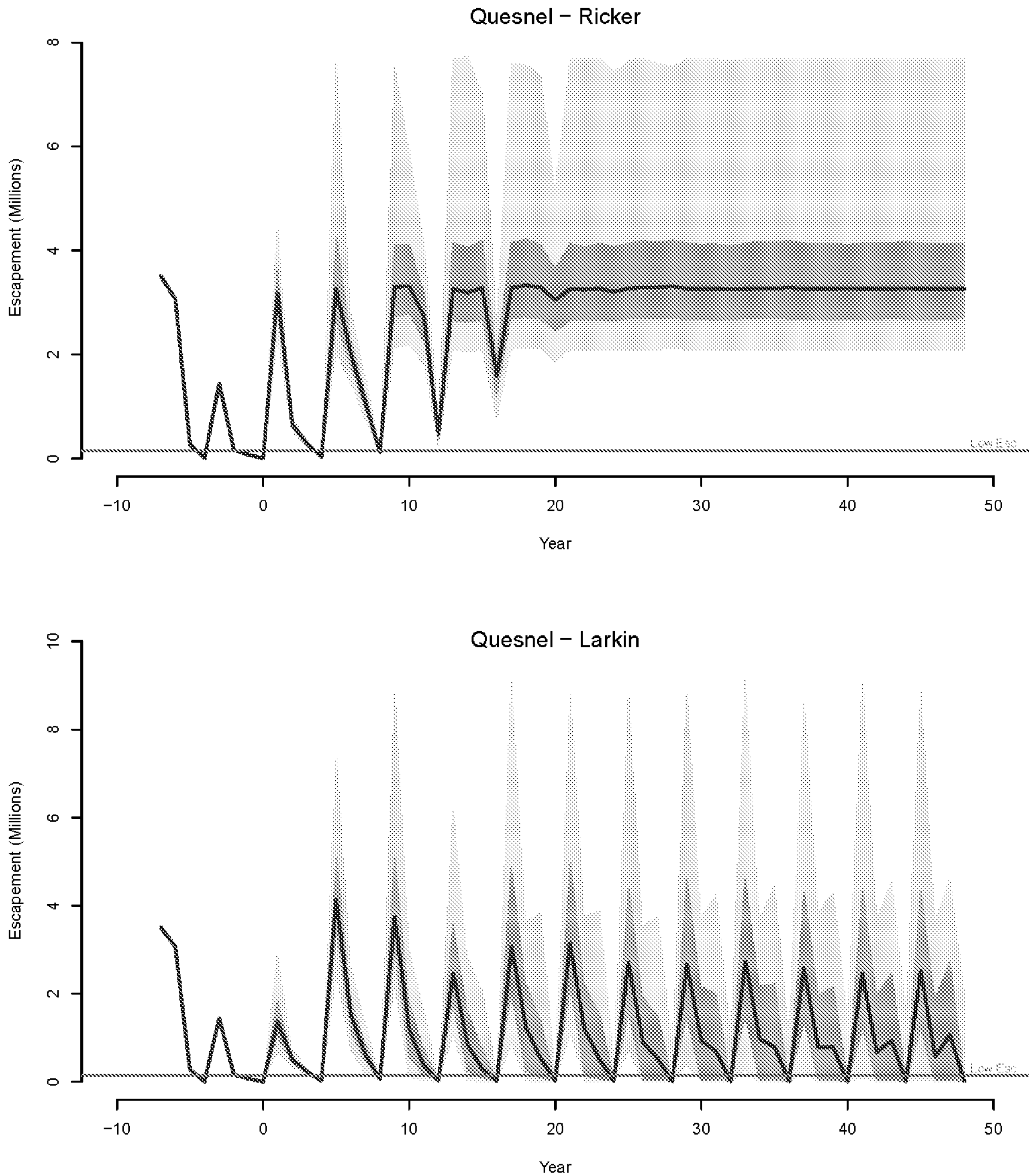


Figure 17: Escapement trajectory quantiles for Quesnel Ricker vs. Larkin
Summary of the sparklines in Figure 15 and Figure 16. (30% fixed ER, no random variation).

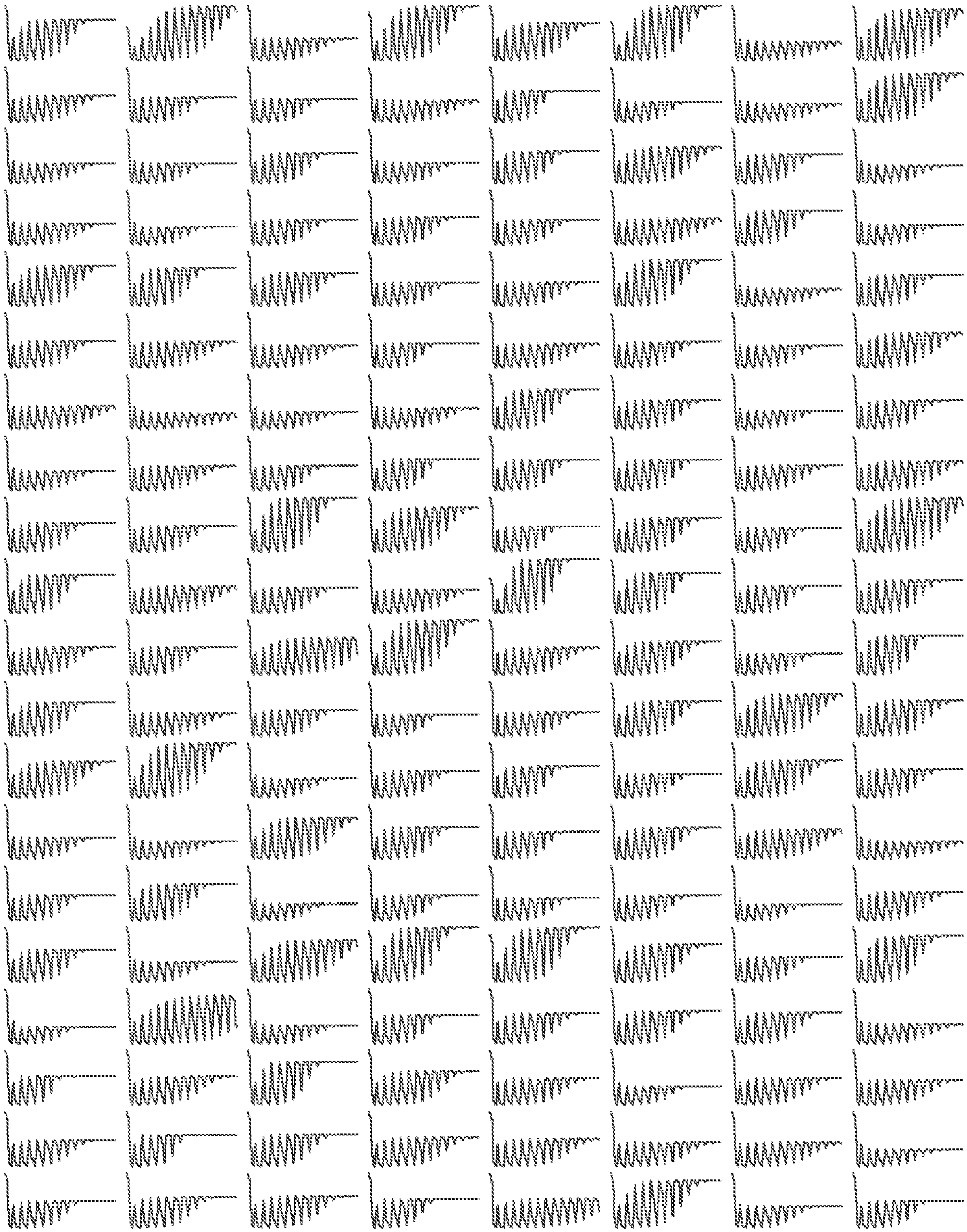


Figure 18: Ricker Model Illustration 2 – Quesnel Escapement Sparklines
Shows 160 sample trajectories, each one for a different set of par estimates. (60% fixed ER plus median en-route mortality, no random error)

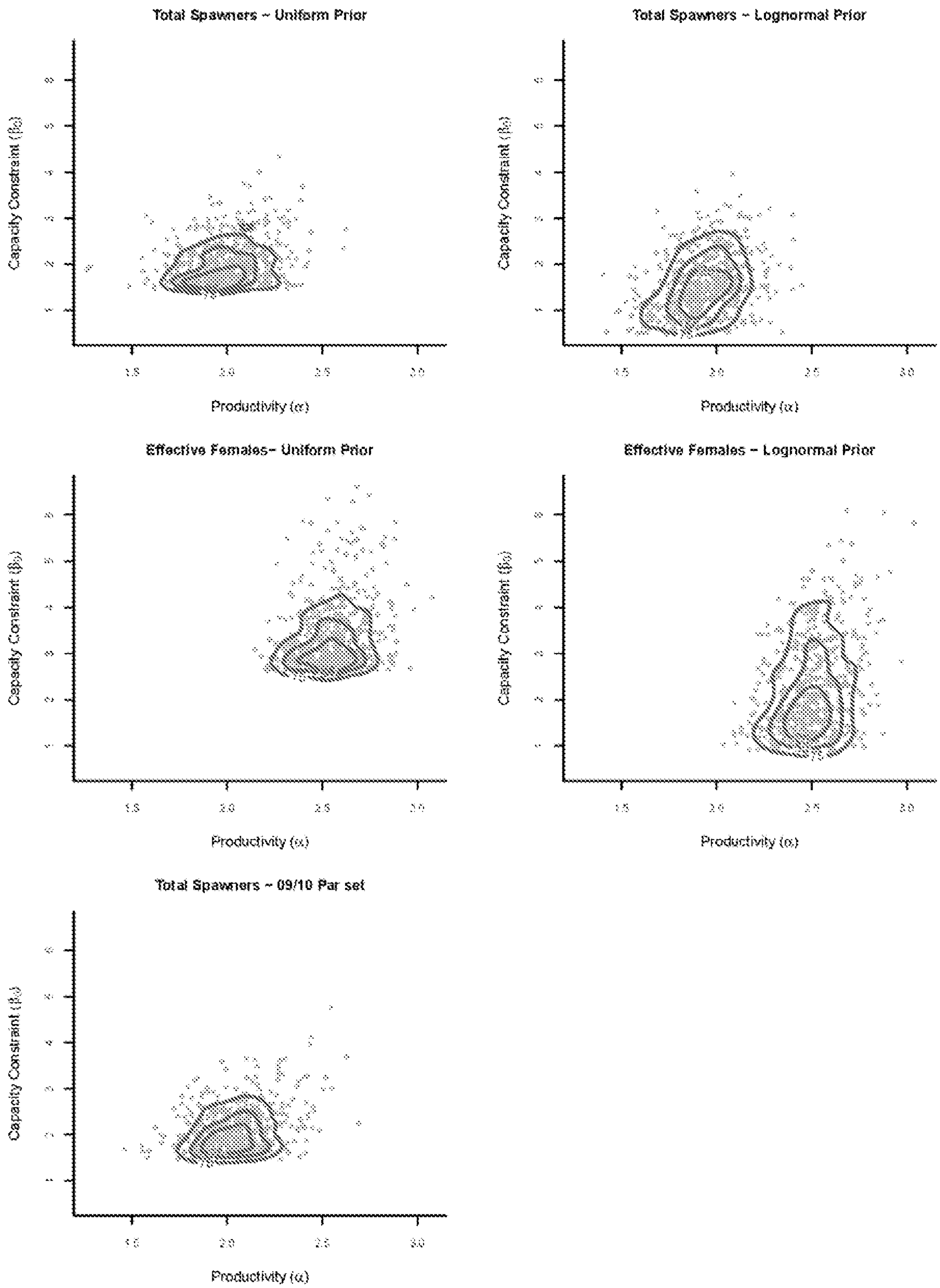


Figure 19: Alternative SR parameter estimates for Early Stuart

Each panel shows the joint distribution for estimates of productivity (α) and capacity constraint (β_0) sampled from the Bayesian posterior. Contour lines capture 1 quarter, half, and 3 quarters of the estimates. The 5 panels show parameter based on different data (rows) and different prior assumptions (columns). Appendix 5 includes the same set of figures for the 18 other stocks.

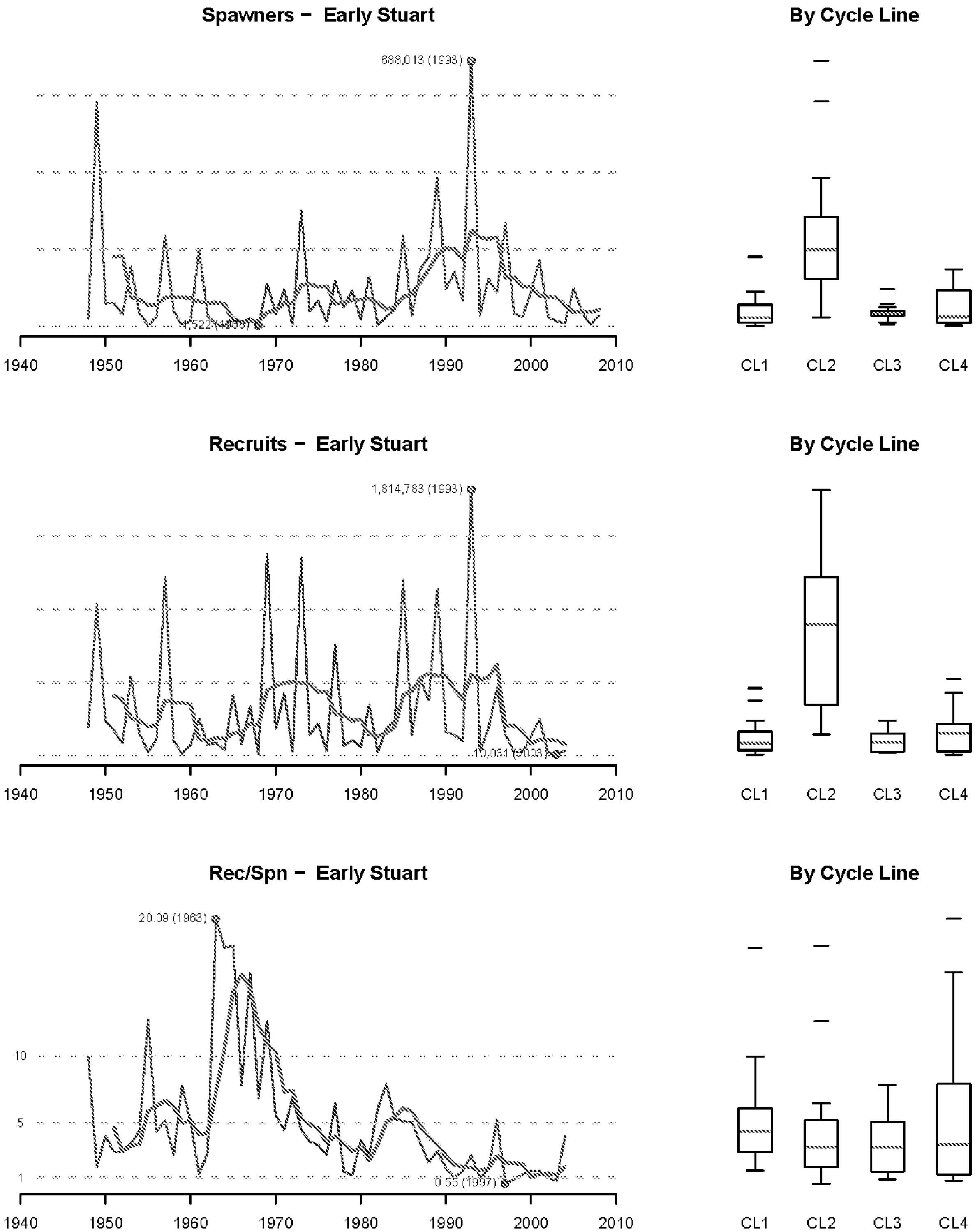


Figure 20: Early Stuart - Spawner-recruit data
Trend lines (in red) show 4yr running averages. Box plots show the range of observations for each 4yr cycle line. Appendix 3 lists the data. Appendix 4 includes the same figure for the other 18 stocks.

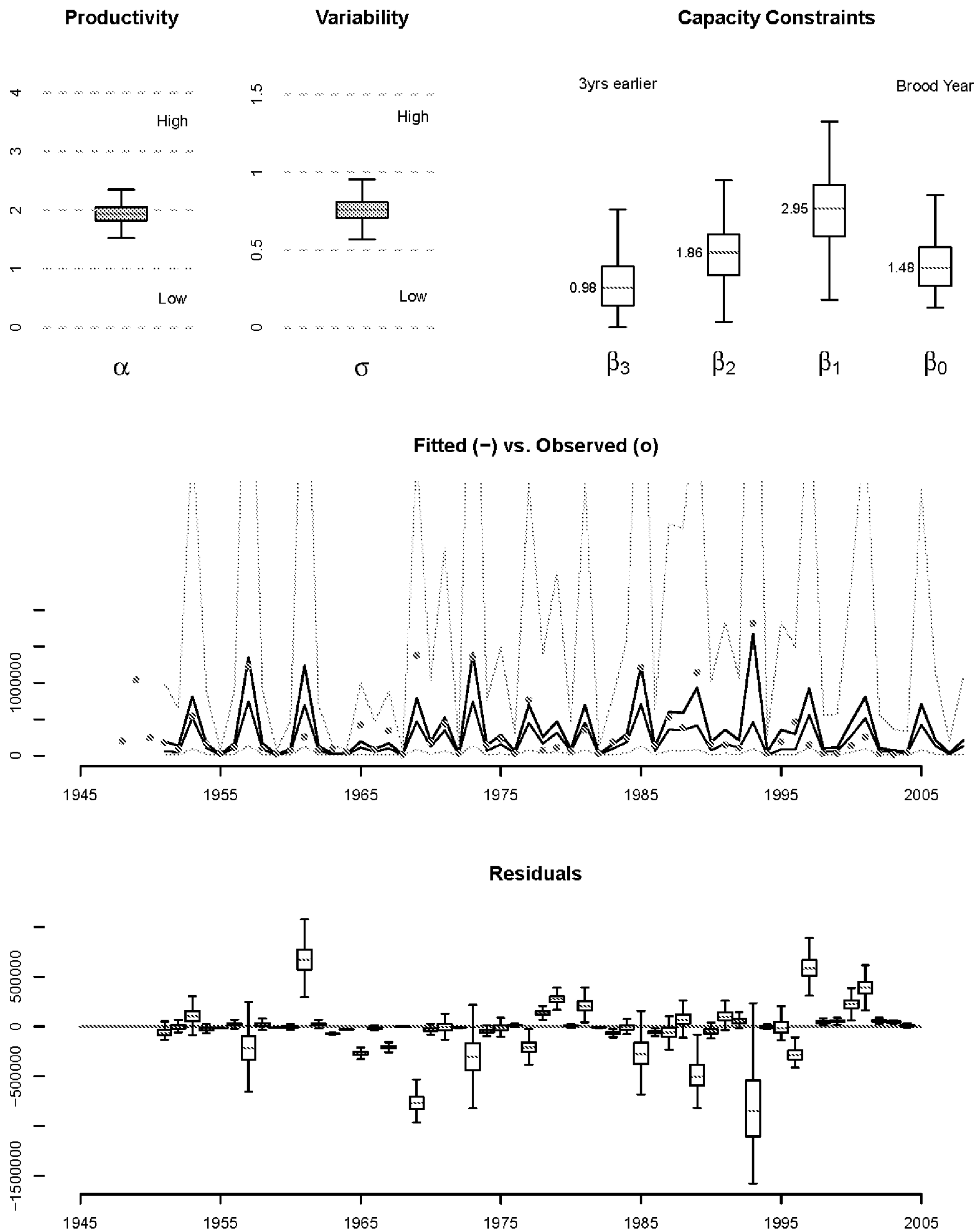


Figure 21: Early Stuart – Larkin Fit (3 lag terms)
Top row shows estimates for parameters in a full Larkin mode using total spawners. The middle panel shows observed recruitment (dots), recruitment modelled using alternative parameter estimates (thick lines) and uncertainty bands (thin lines). Bottom panel shows residuals (modelled – observed recruits).

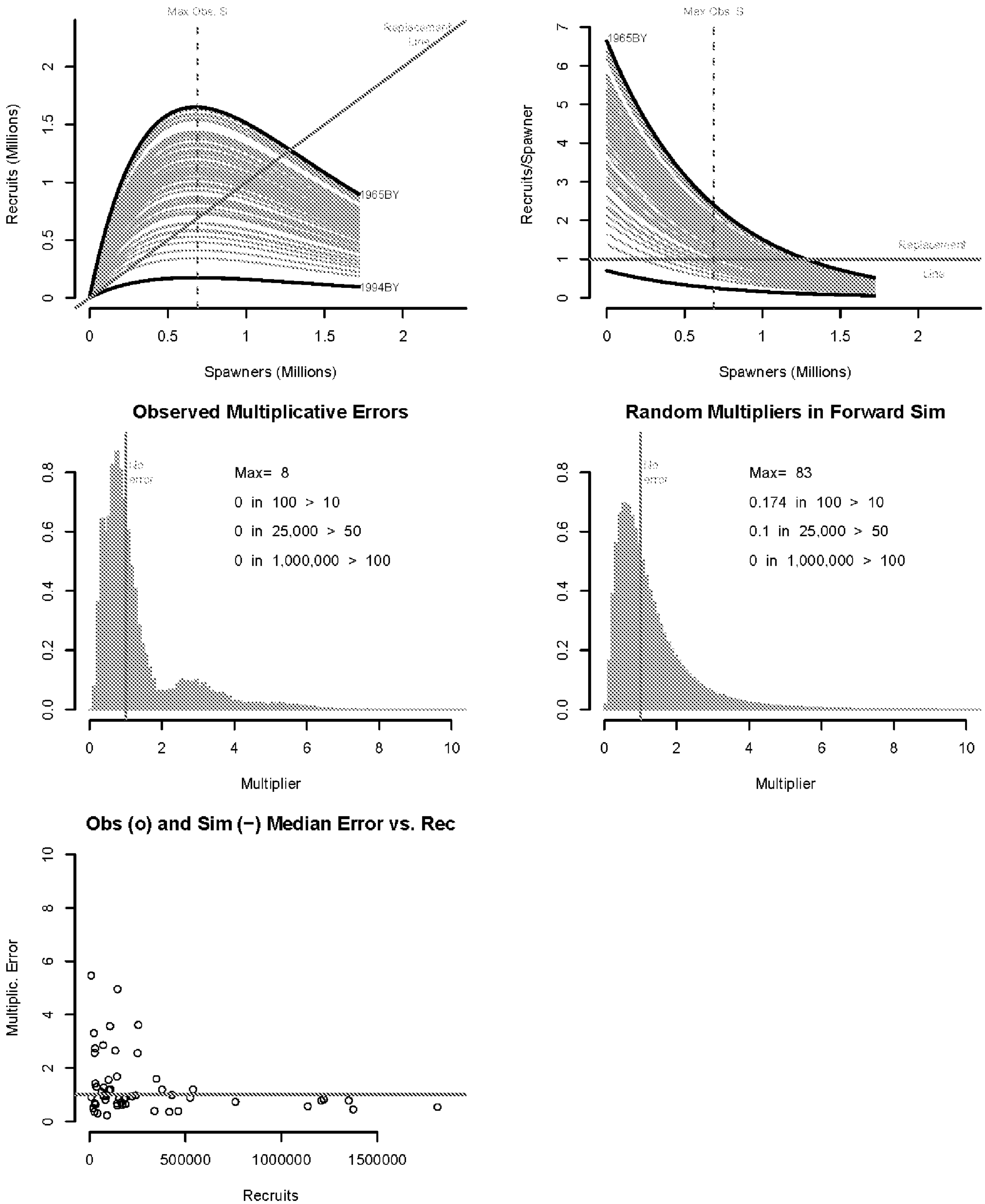


Figure 22: Early Stuart – Larkin Fit Diagnostics (3 lag terms)
Top row shows the recruitment curves for each year (i.e. modeled recruitment at different levels of spawner abundance). Recruitment curves shift depending on spawner abundance in the three previous years. Remaining diagnostics plots show error distributions. Note: Spawners = Total Spawners.

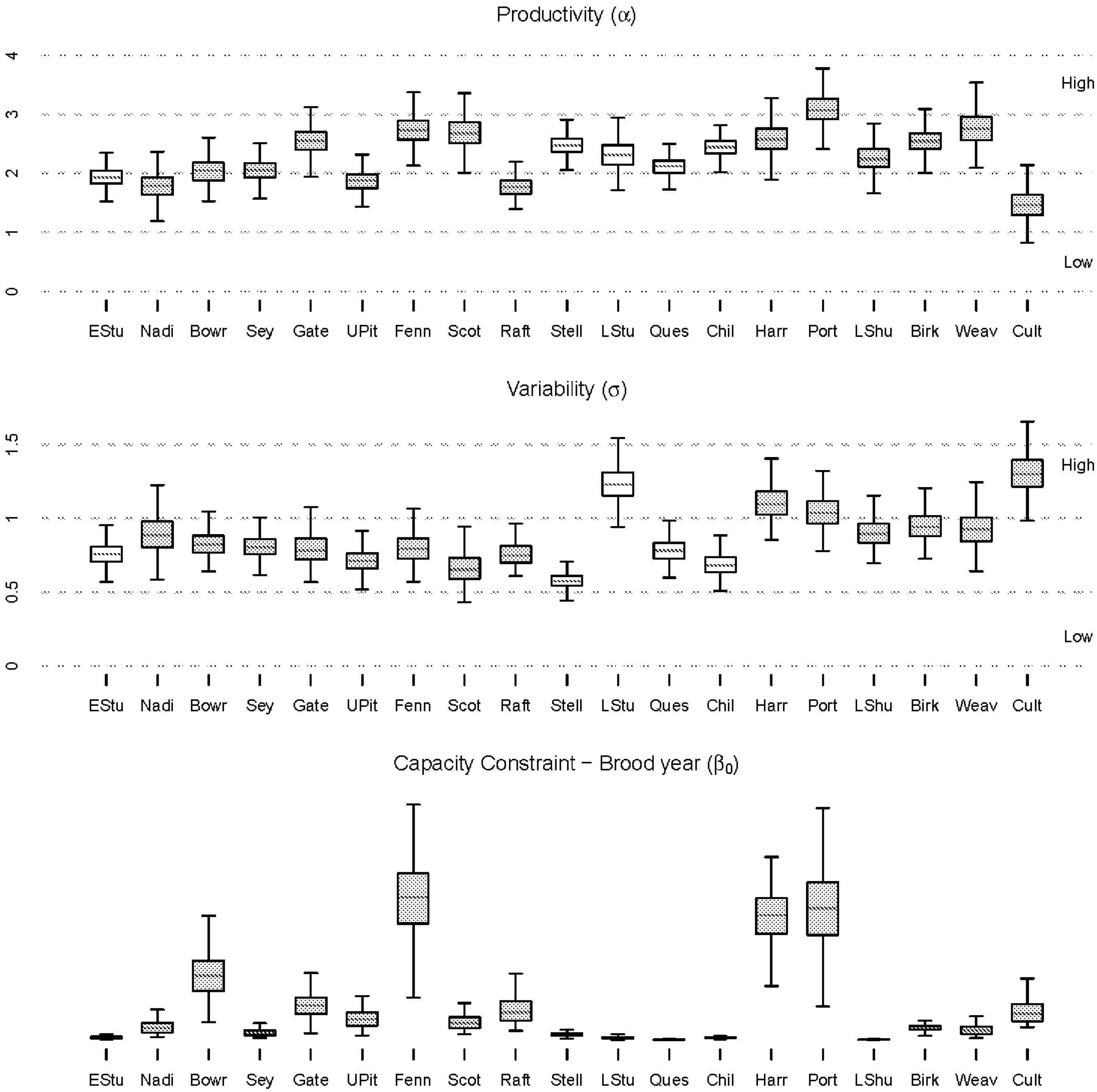


Figure 23: Parameter estimates for productivity, variability, and capacity – Larkin (3 lag terms) Distributions show 500 parameter sets sampled from the Bayesian posterior distribution (Section 2.2.5), based on log-normal priors for β_0 and uniform priors for the other β parameters. Boxes show the median and capture half of the sample. Whiskers mark the most extreme point within 1.5 box-lengths of the box. Stocks are sorted roughly in order of return timing. Management groups are marked by colour: Early Stuart (white), Early Summer (grey), Summer (white), Late (grey). All estimates using total spawner abundance.

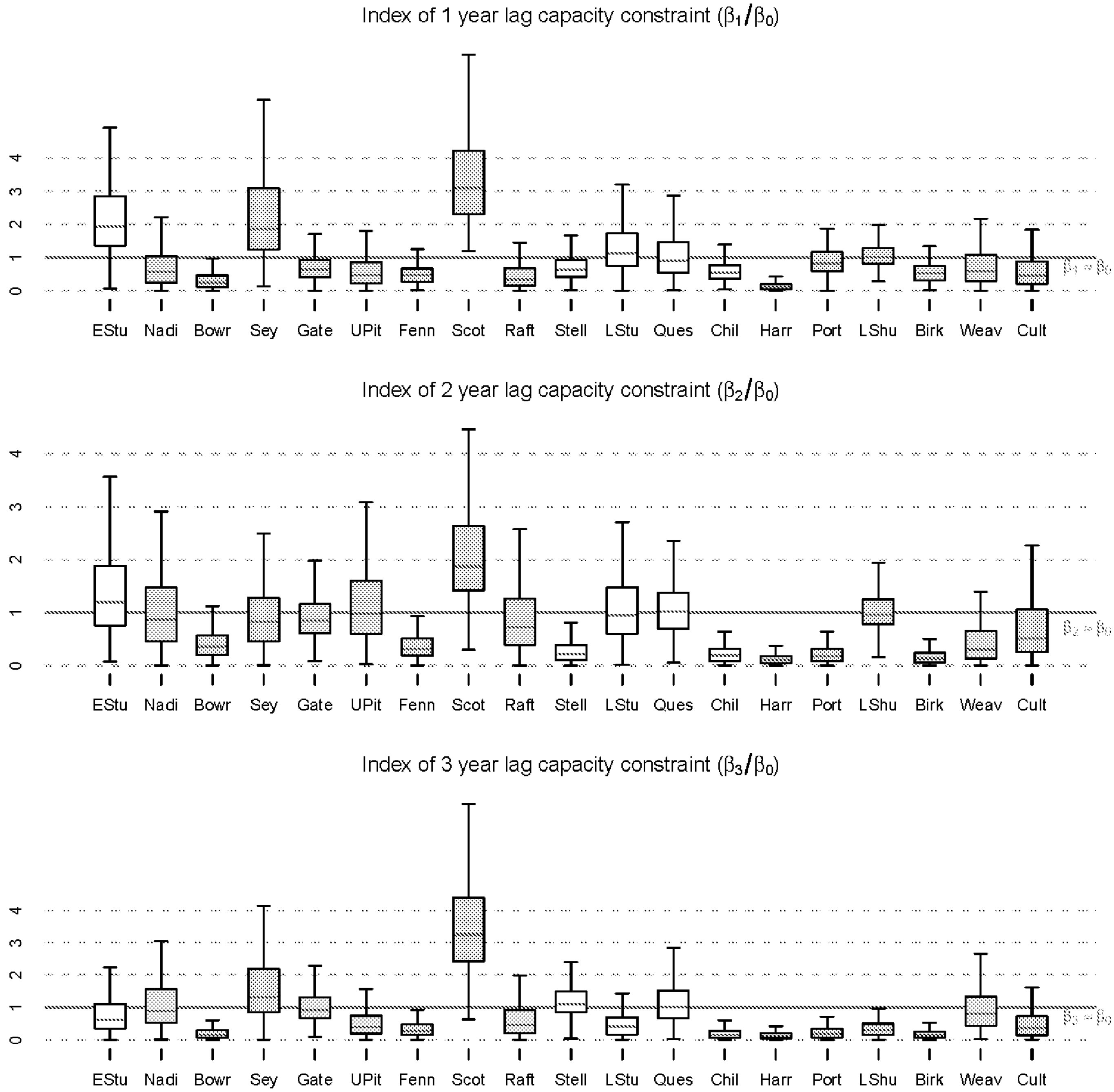


Figure 24: Parameter estimates for delayed-density effects - Larkin (3 lag terms)
Distributions show 500 parameter sets sampled from the Bayesian posterior distribution (Section 2.2.5), based on log-normal priors for β_0 and uniform priors for the other β parameters. Lag terms are scaled relative to β_0. Boxes show the median and capture half of the sample. Whiskers mark the most extreme point within 1.5 box-lengths of the box. Stocks are sorted roughly in order of return timing. Management groups are marked by colour: Early Stuart (white), Early Summer (grey), Summer (white), Late (grey). All estimates using total spawner abundance.

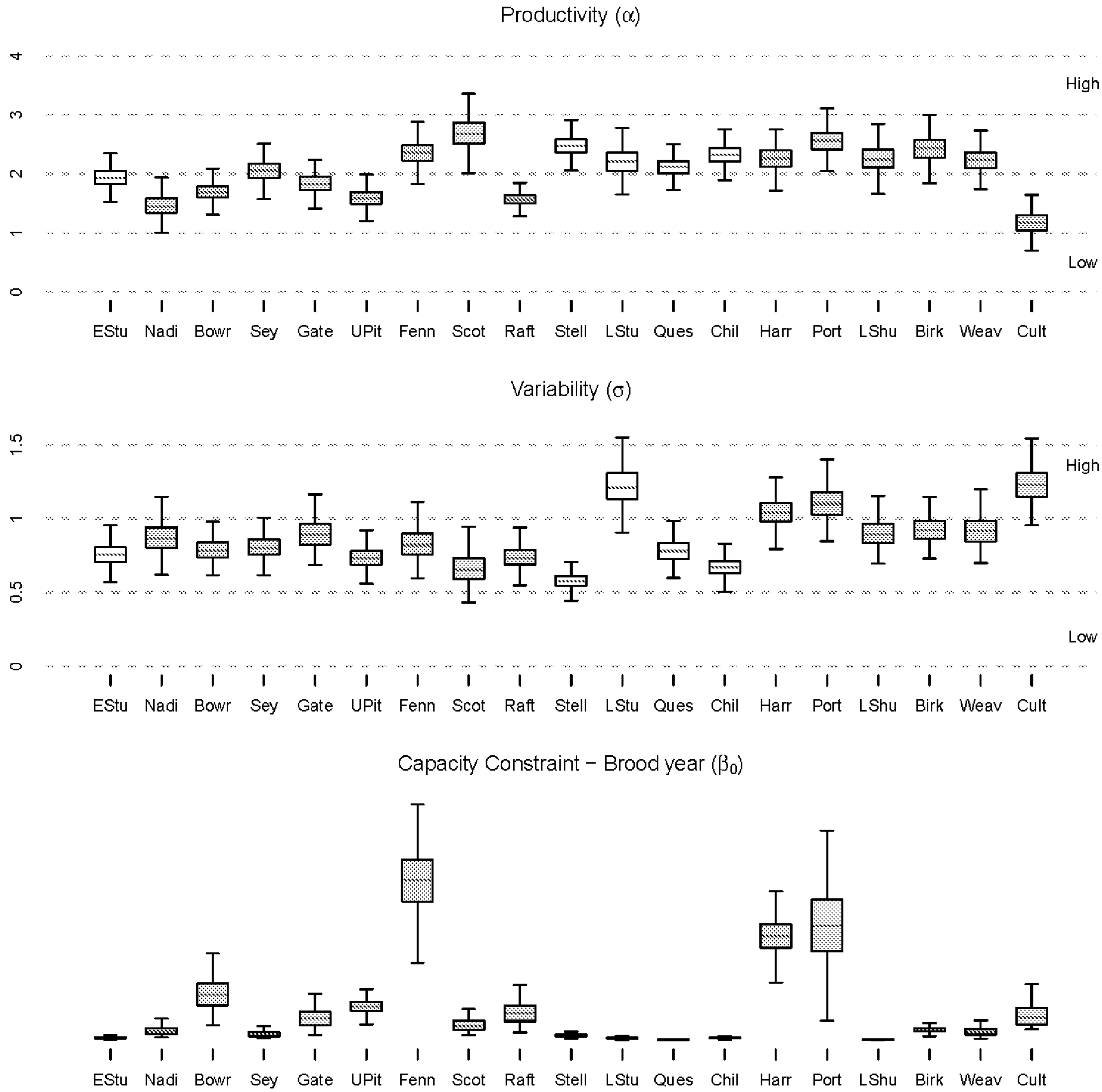


Figure 25: Parameter estimates for productivity, variability, and capacity – Best Fit
Distributions show 500 parameter sets sampled from the Bayesian posterior distribution (Section 2.2.5), based on log-normal priors for β_0 and uniform priors for the other β parameters. Boxes show the median and capture half of the sample. Whiskers mark the most extreme point within 1.5 box-lengths of the box. Stocks are sorted roughly in order of return timing. Management groups are marked by colour: Early Stuart (white), Early Summer (grey), Summer (white), Late (grey). All estimates using total spawner abundance.

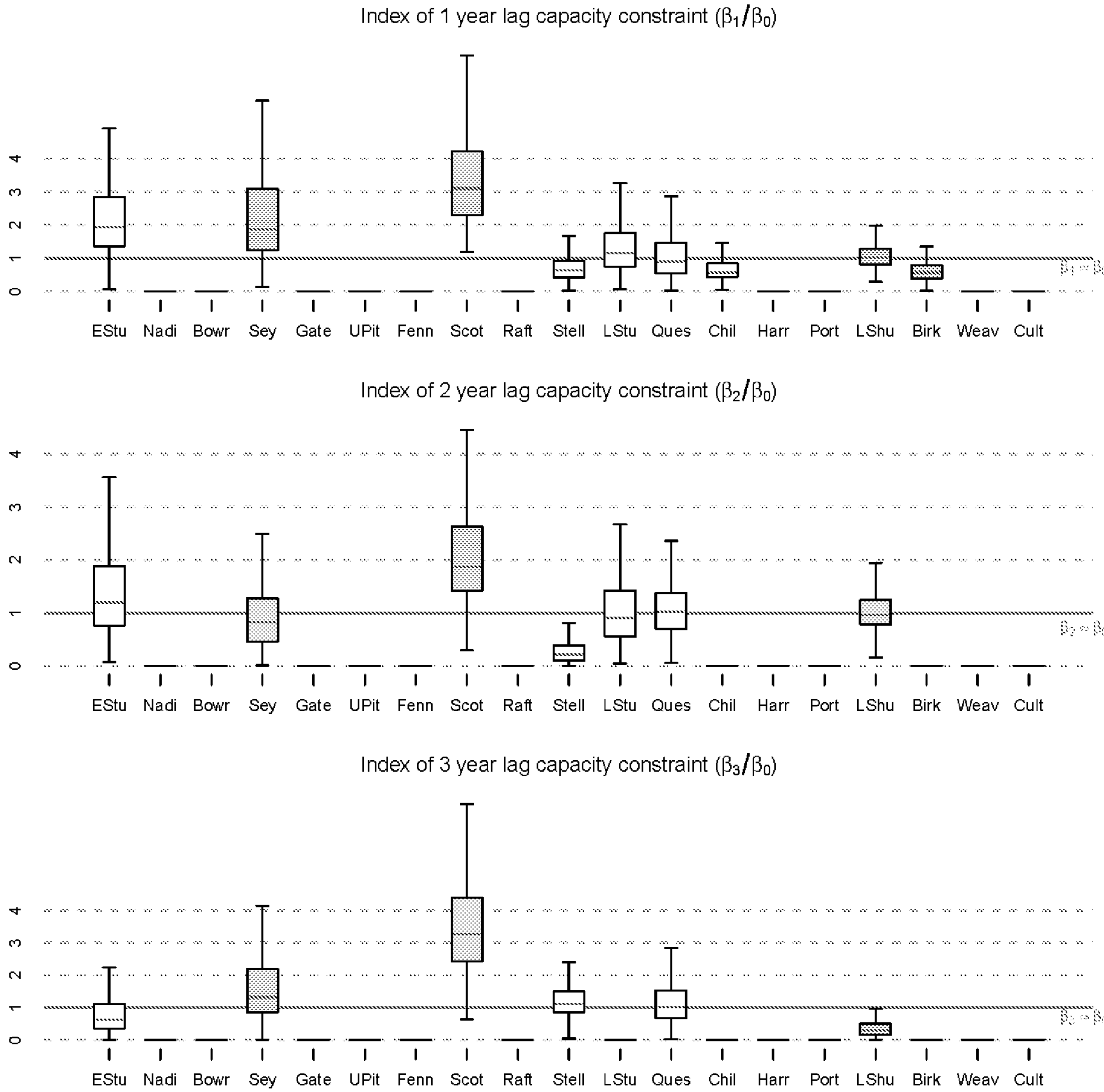


Figure 26: Parameter estimates for delayed-density effects – Best Fit
Distributions show 500 parameter sets sampled from the Bayesian posterior distribution (Section 2.2.5), based on log-normal priors for β_0 and uniform priors for the other β parameters. Lag terms are scaled relative to β_0. Boxes show the median and capture half of the sample. Whiskers mark the most extreme point within 1.5 box-lengths of the box. Stocks are sorted roughly in order of return timing. Management groups are marked by colour: Early Stuart (white), Early Summer (grey), Summer (white), Late (grey). All estimates using total spawner abundance.

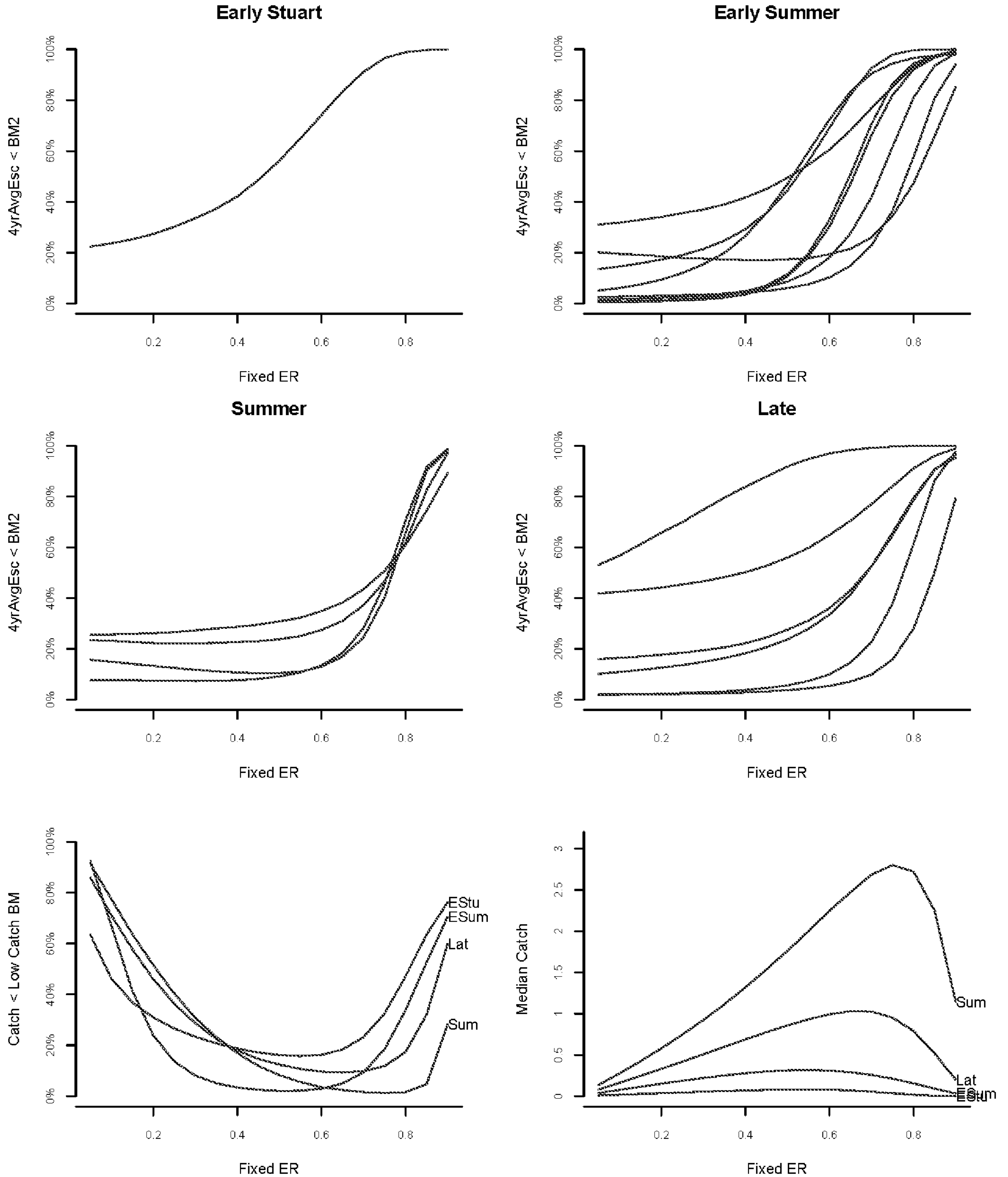


Figure 27: Changing fixed exploitation rates

The top four panels show Prob(4yr Avg Esc < BM2) for each stock, with BM 2 listed in Table 1. Bottom left panel show Prob(Catch < Low catch BM) for each management group, with low catch benchmarks listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

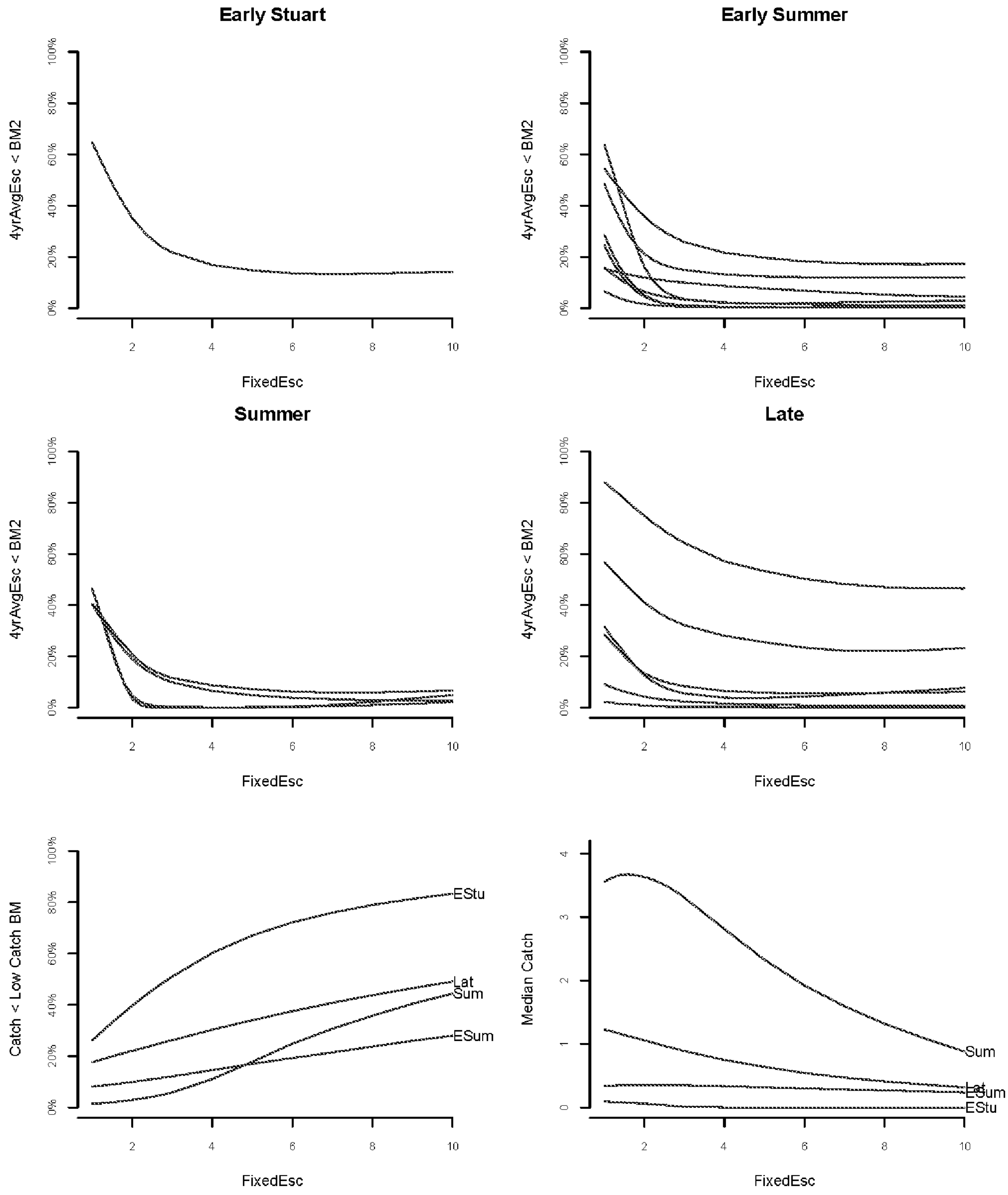


Figure 28: Changing fixed escapement targets – Manage individual stocks
Fixed escapement targets for each stock are expressed as multiples of BM2, listed in Table 1. The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with low catch benchmarks listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1) Note: low escapement benchmark from Table 1 not adjusted for % effective females.

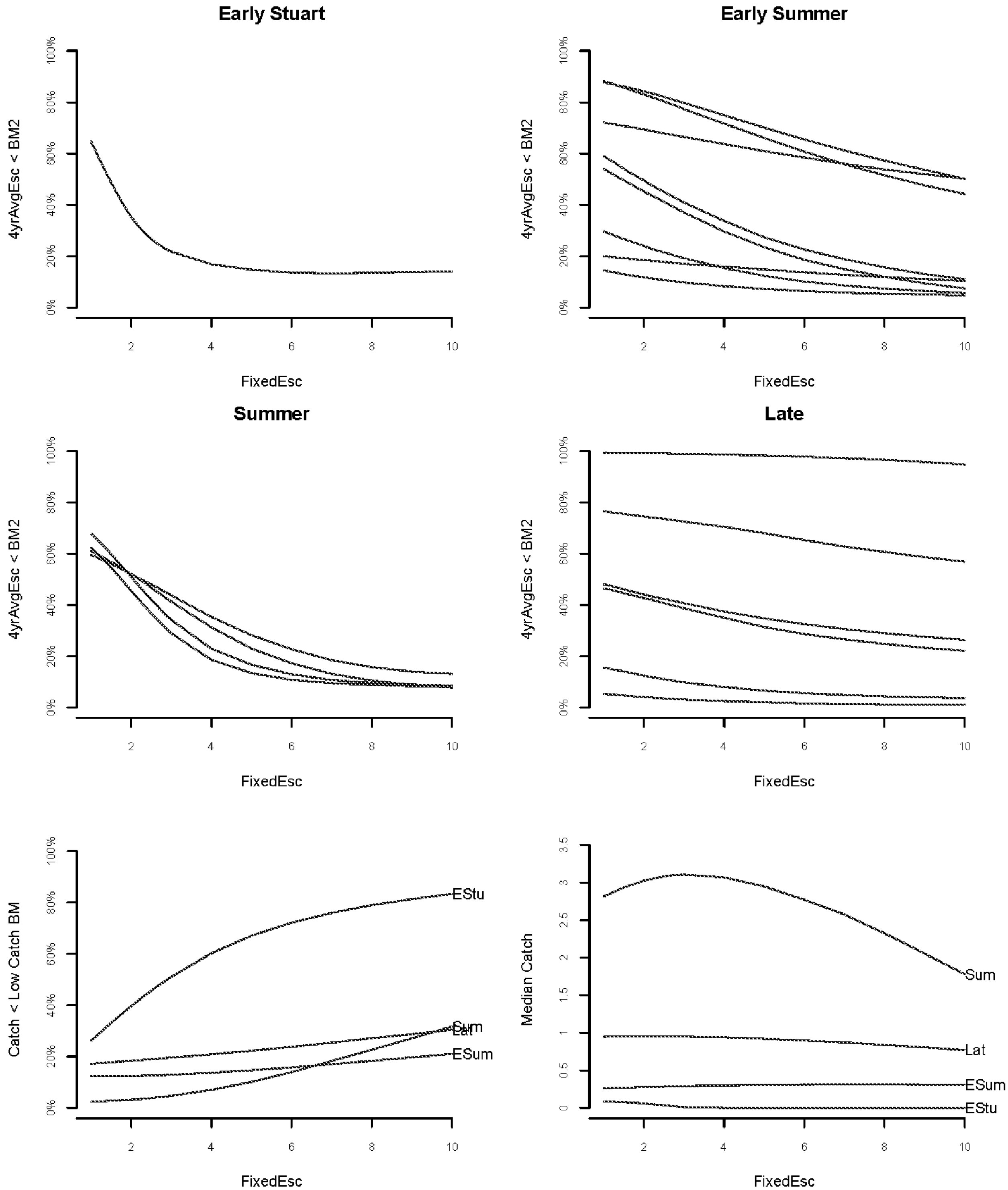


Figure 29: Changing fixed escapement targets – Manage to most productive stock in a group
Fixed escapement targets for each stock are expressed as multiples of BM2, listed in Table 1. The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with low catch benchmarks listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

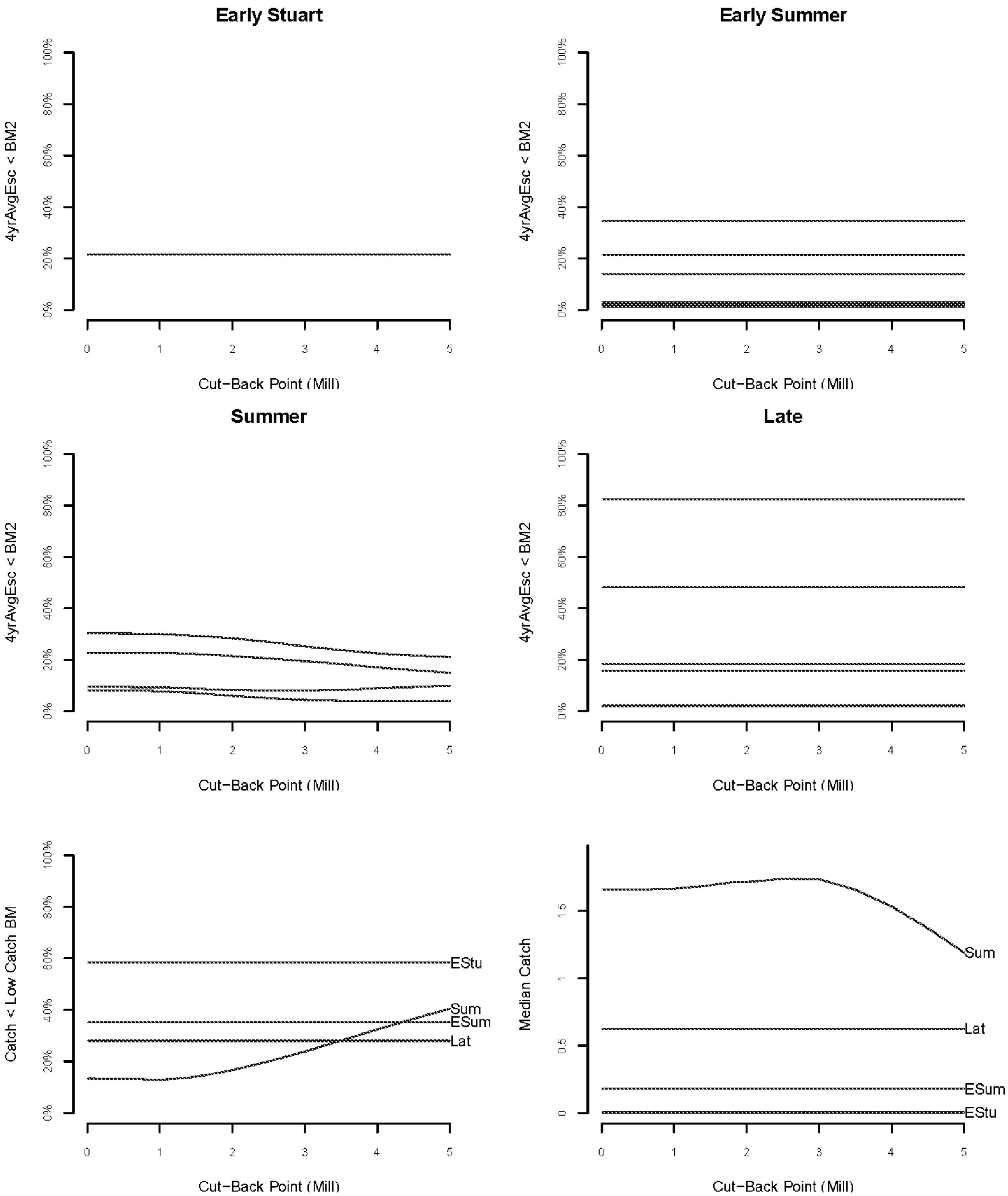


Figure 30: Changing cut-back point on Summer TAM rule.
Cut-back point is defined as in Figure 13. TAM rules for other management groups are as in 2009 management plan. The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

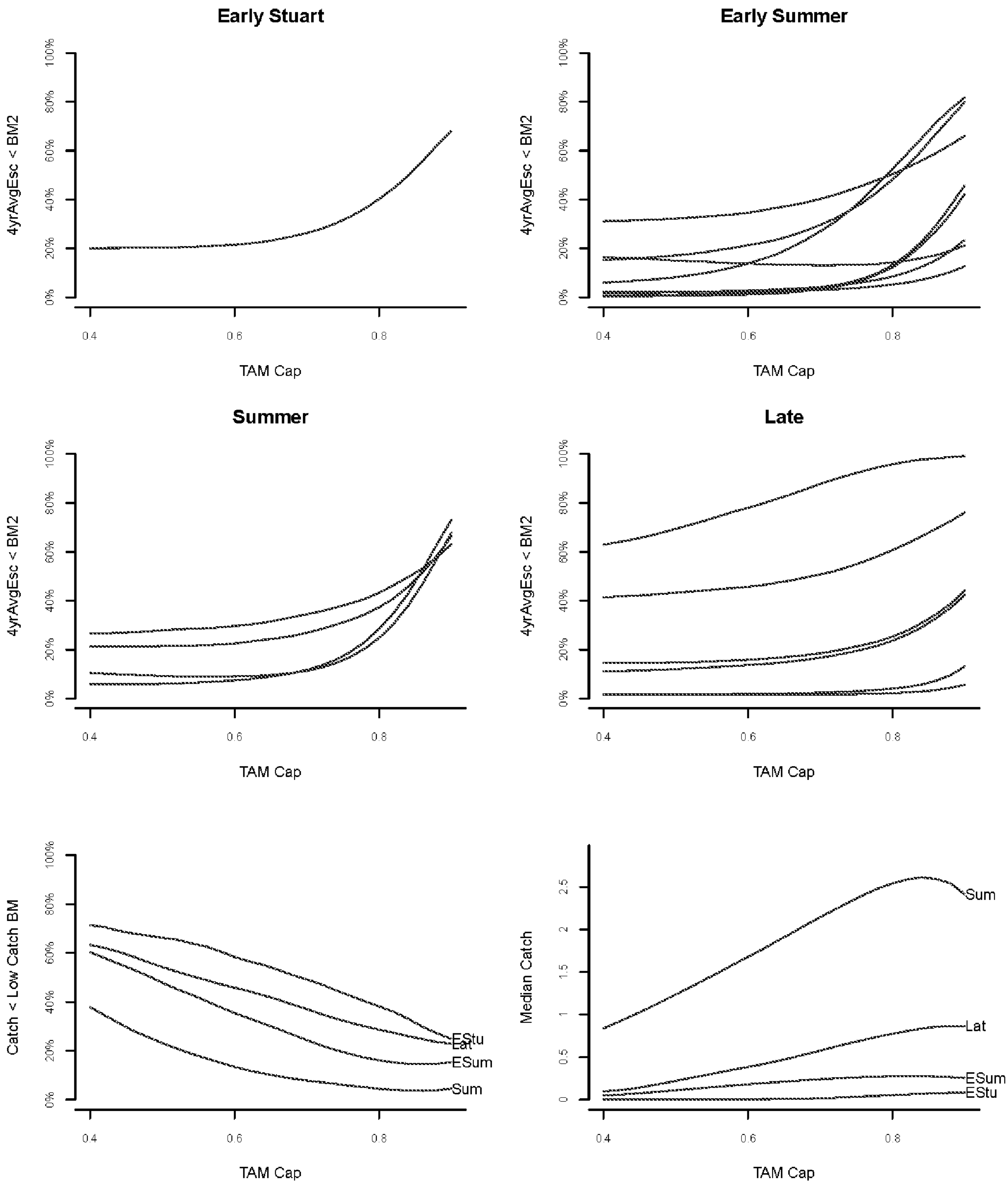


Figure 31: Changing cap on TAM rule

Cap is defined as in Figure 13. Cut-back points and ER floors are as in 2009 management plan. The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

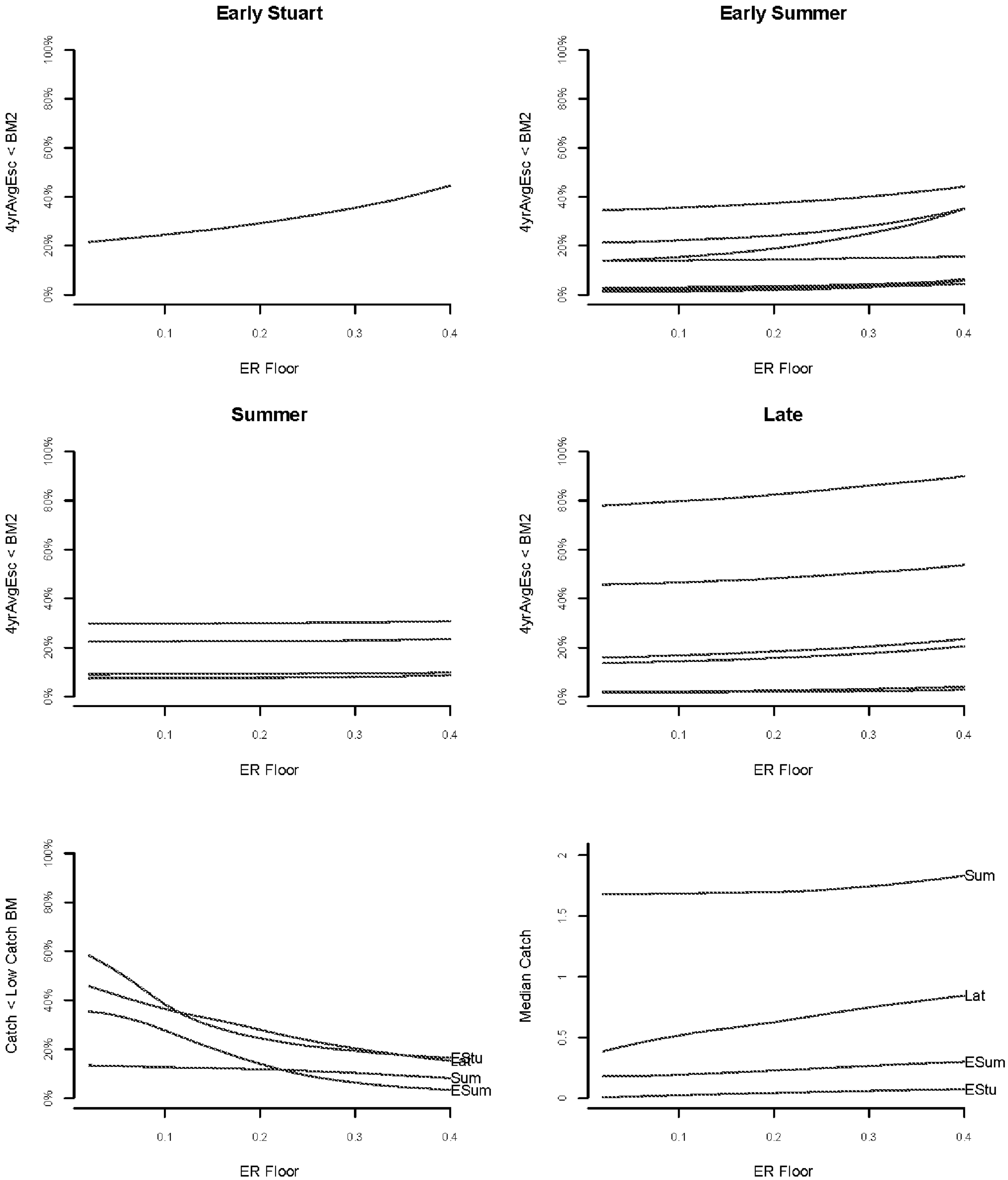


Figure 32: Changing exploitation rate floor on TAM rules
ER floor is defined as in Figure 12. Cut-back points and ER caps are as in 2009 management plan. The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

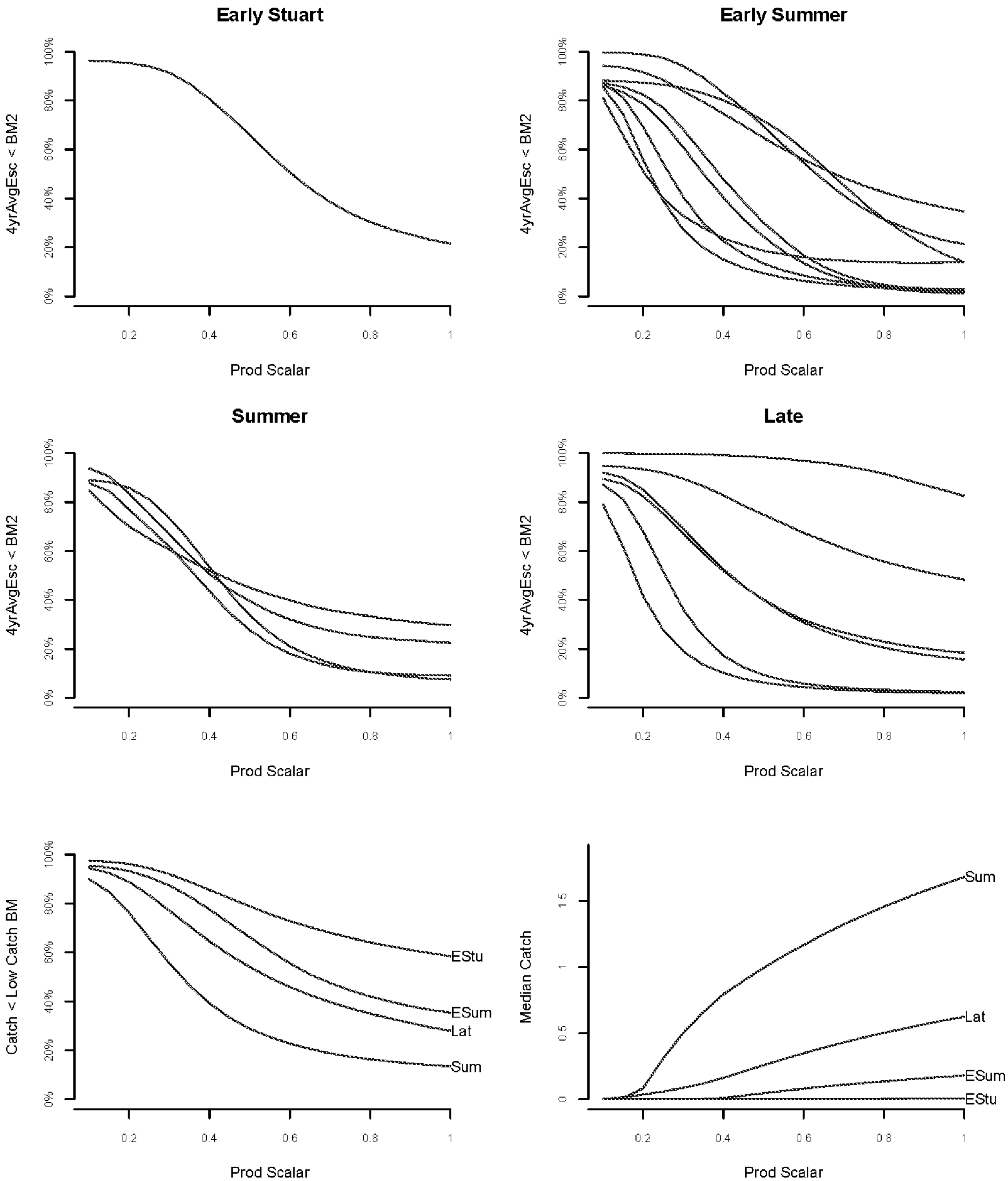


Figure 33: Reduced productivity scenarios – 2009 TAM Rules

The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Productivity ranges from "like the past" (scalar=1) to severe loss (scalar = 0.05, only 5% of a modeled recruits actually return). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

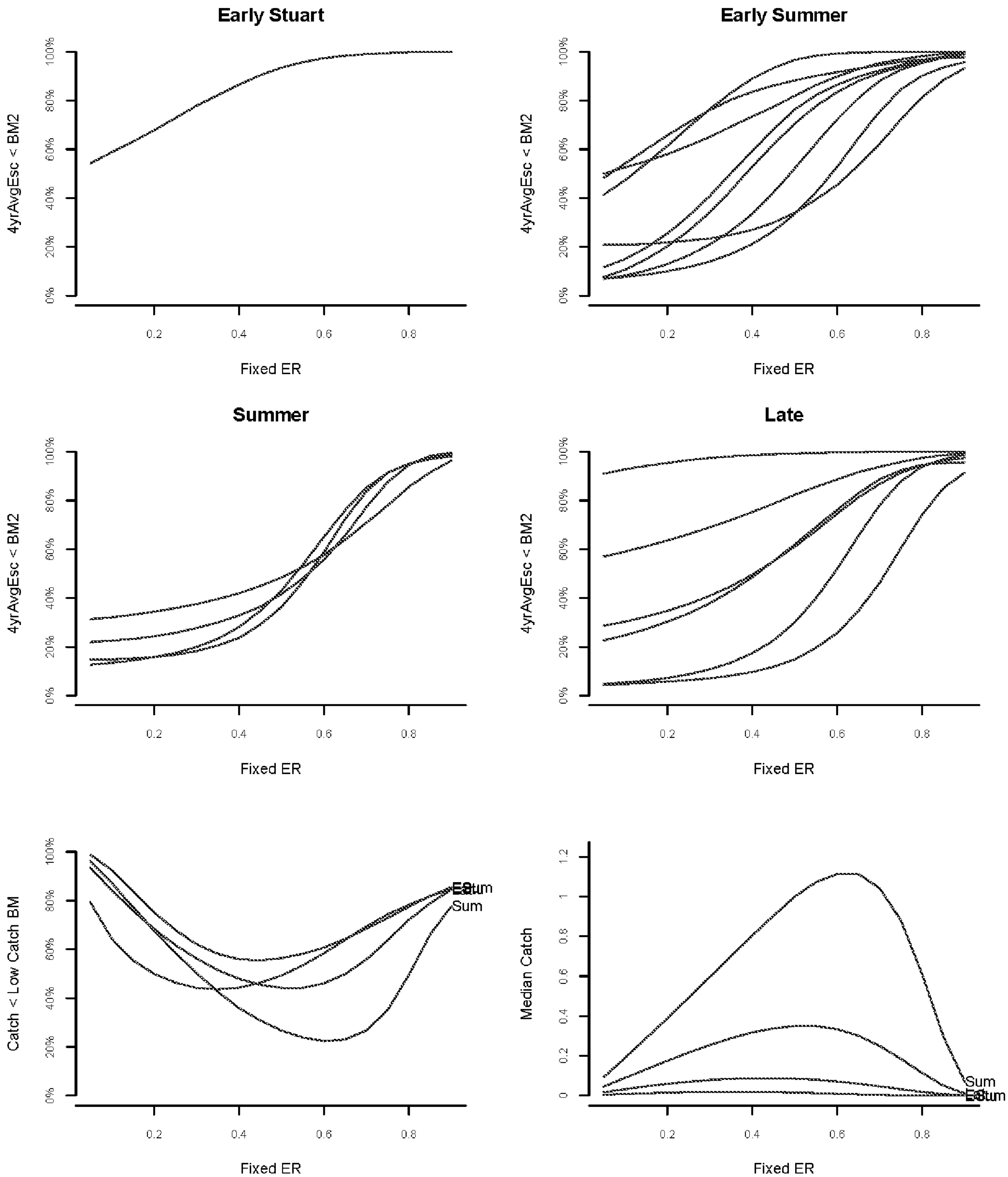


Figure 34: Reduced productivity scenarios – Changing Fixed ER, Half Productivity
The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

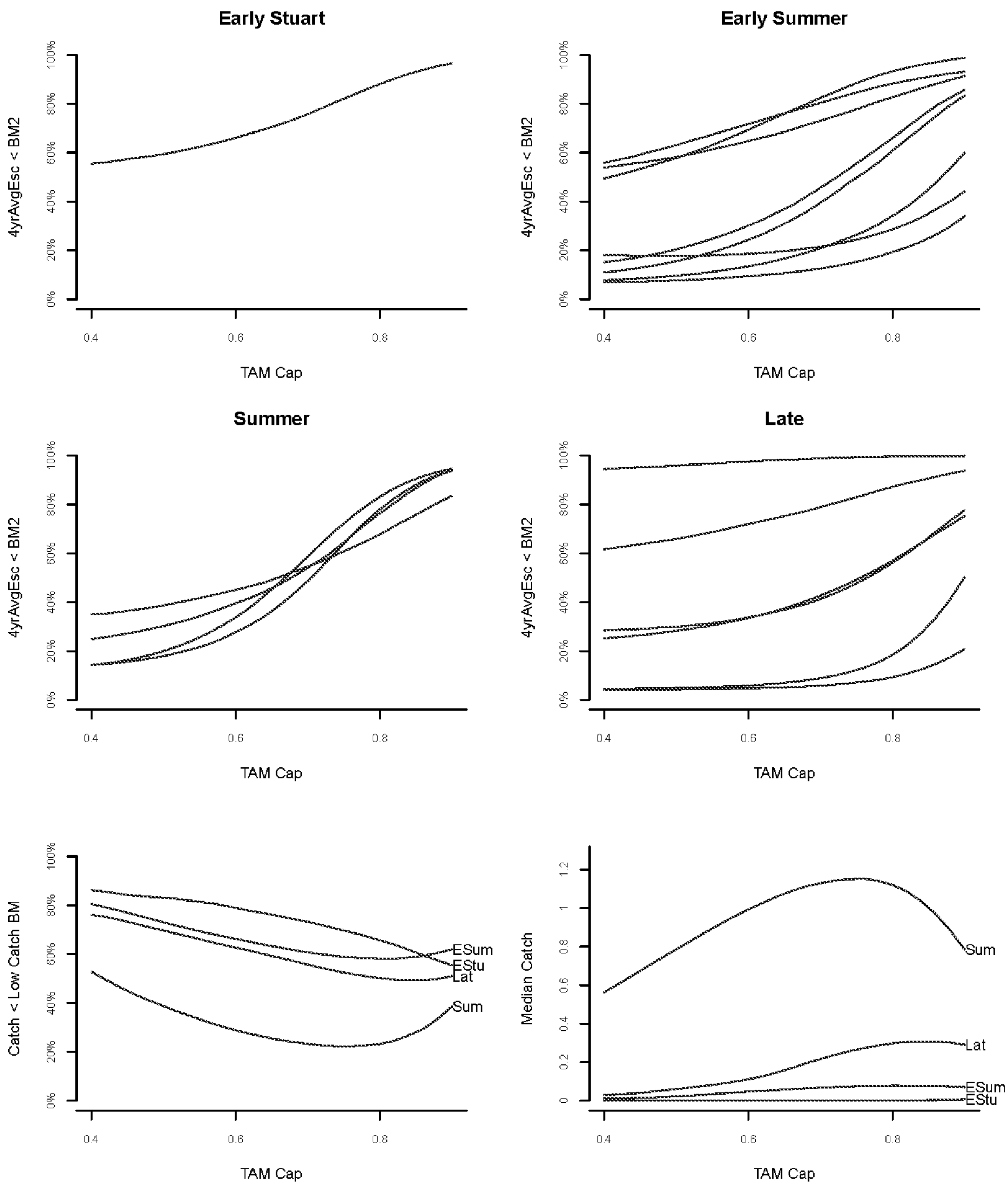


Figure 35: Reduced productivity scenarios – Changing TAM cap, Half Productivity
The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

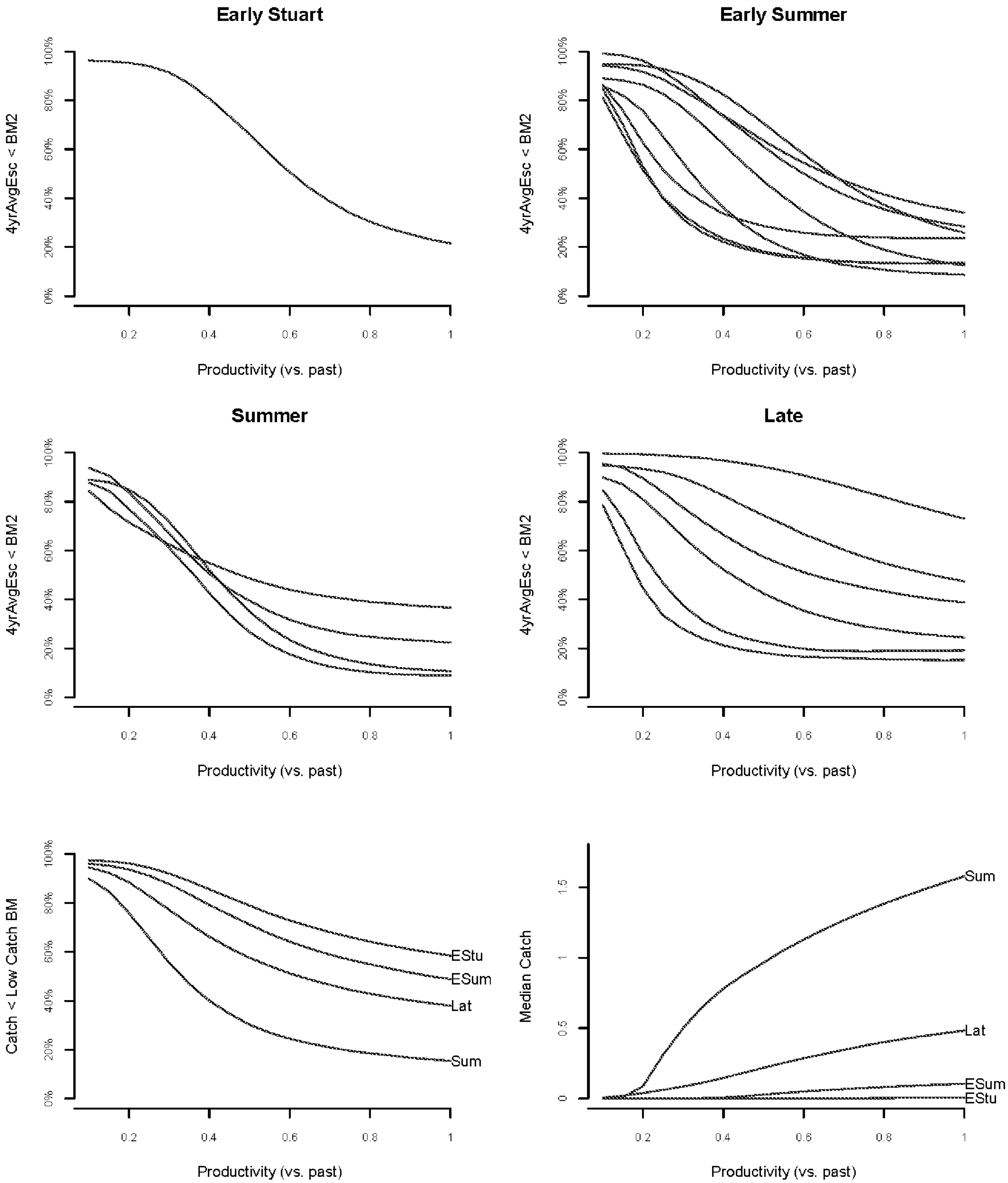


Figure 36: Reduced productivity scenarios – 2009 TAM rules, Full Larkin
The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

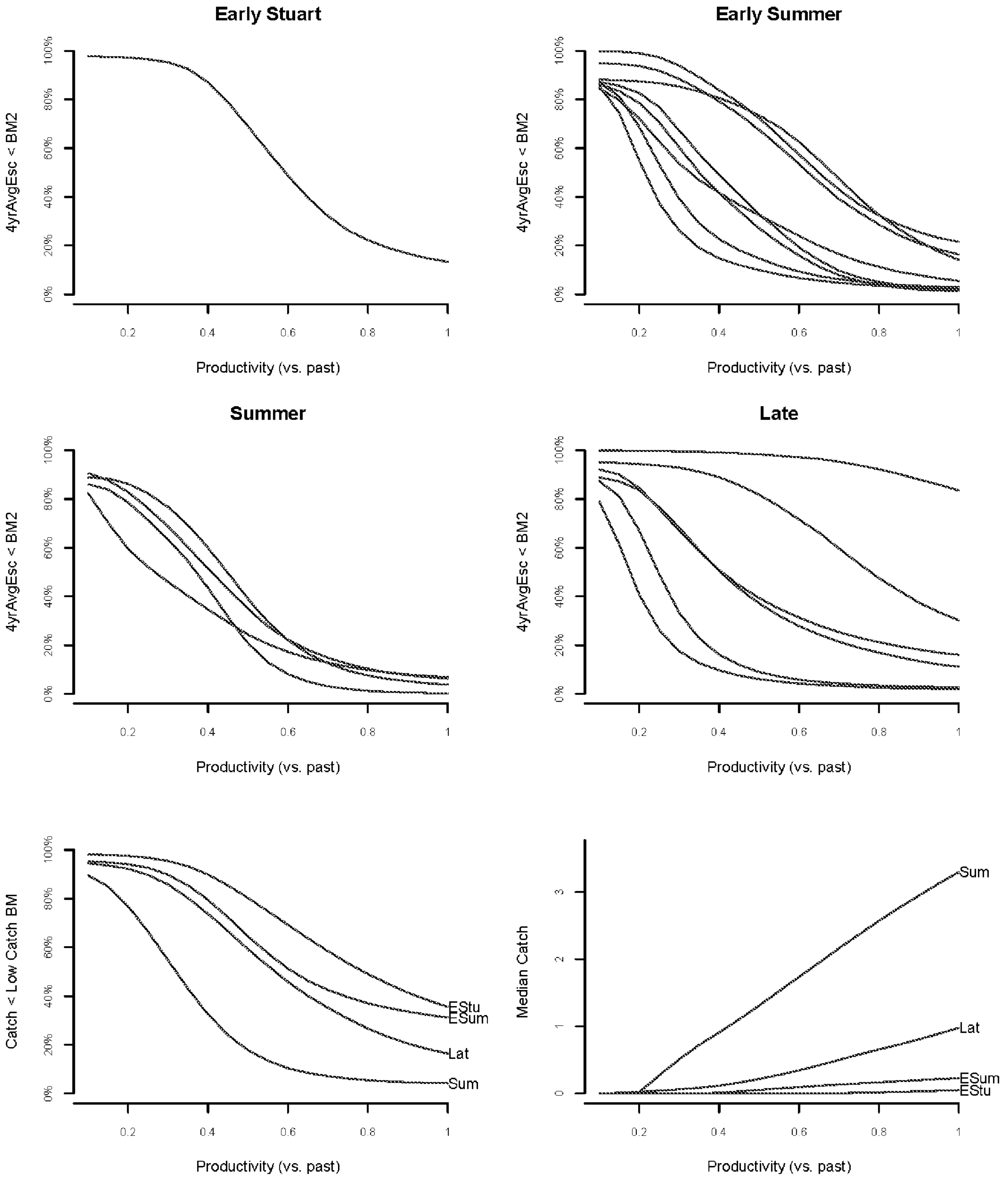


Figure 37: Reduced productivity scenarios – 2009 TAM rules, Ricker
The four top panels show Prob(4yr Avg Esc < BM2) for each stock. Bottom left panel shows Prob(Catch < Low catch BM) for each management group, with BM listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

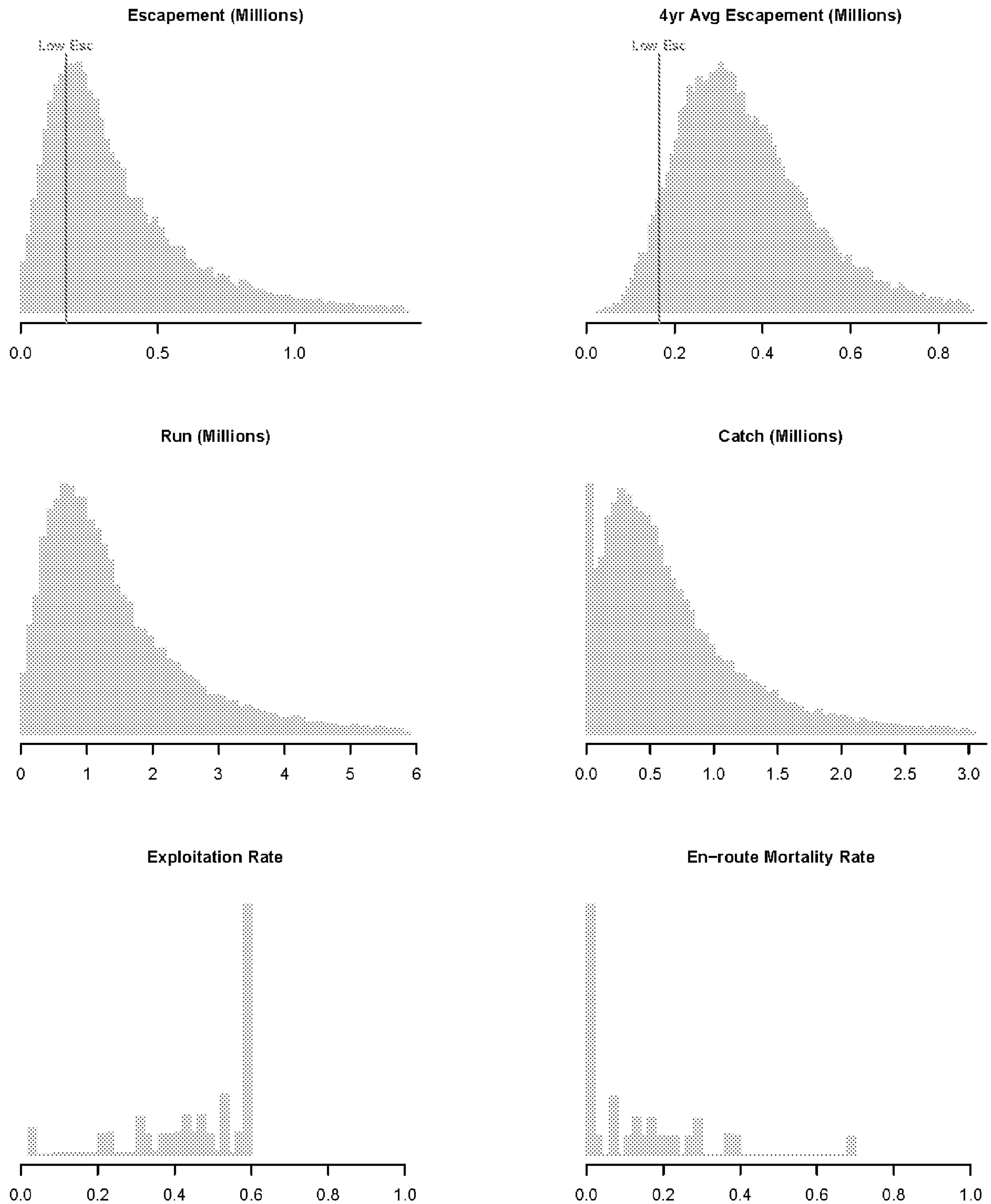


Figure 38: Simulated performance of Chilko (Base Case 1, 2009 TAM rule)
Histograms show distribution across 500 trajectories over 48 years. Exploitation rates mirror en-route mortality rates because target ER = total allowable mortality rate – en-route mortality rate. Simulations based on effective females. Note: low escapement benchmark from Table 1 not adjusted for % effective females.

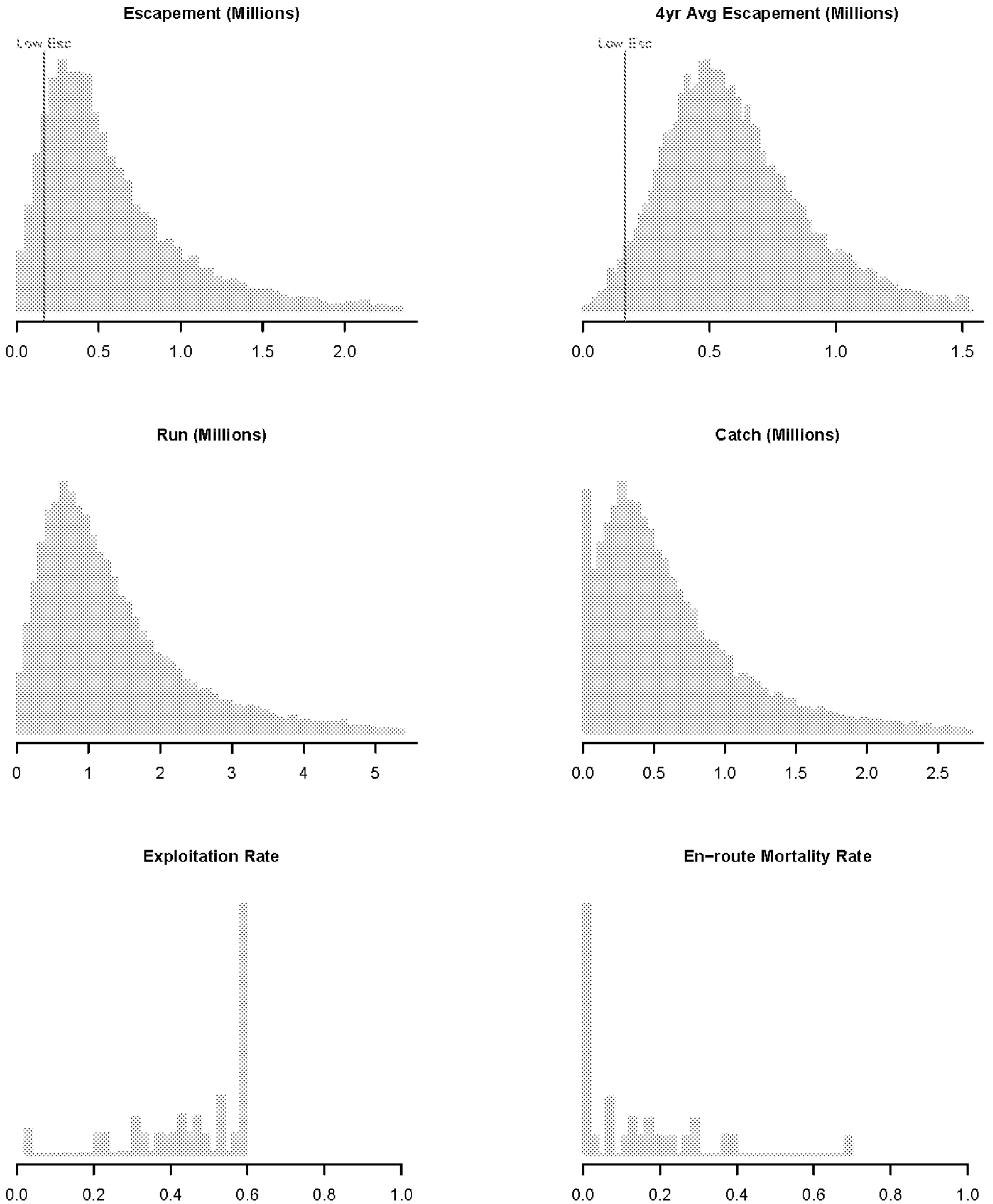


Figure 39: Simulated performance of Chilko (2009 TAM rule, Larkin 4, total spawners)
Same as Figure 38, except that spawner recruit dynamics are based on total spawners rather than effective females. Histograms show distribution across 500 trajectories over 48 years. Exploitation rates mirror en-route mortality rates because target ER = total allowable mortality rate – en-route mortality rate.

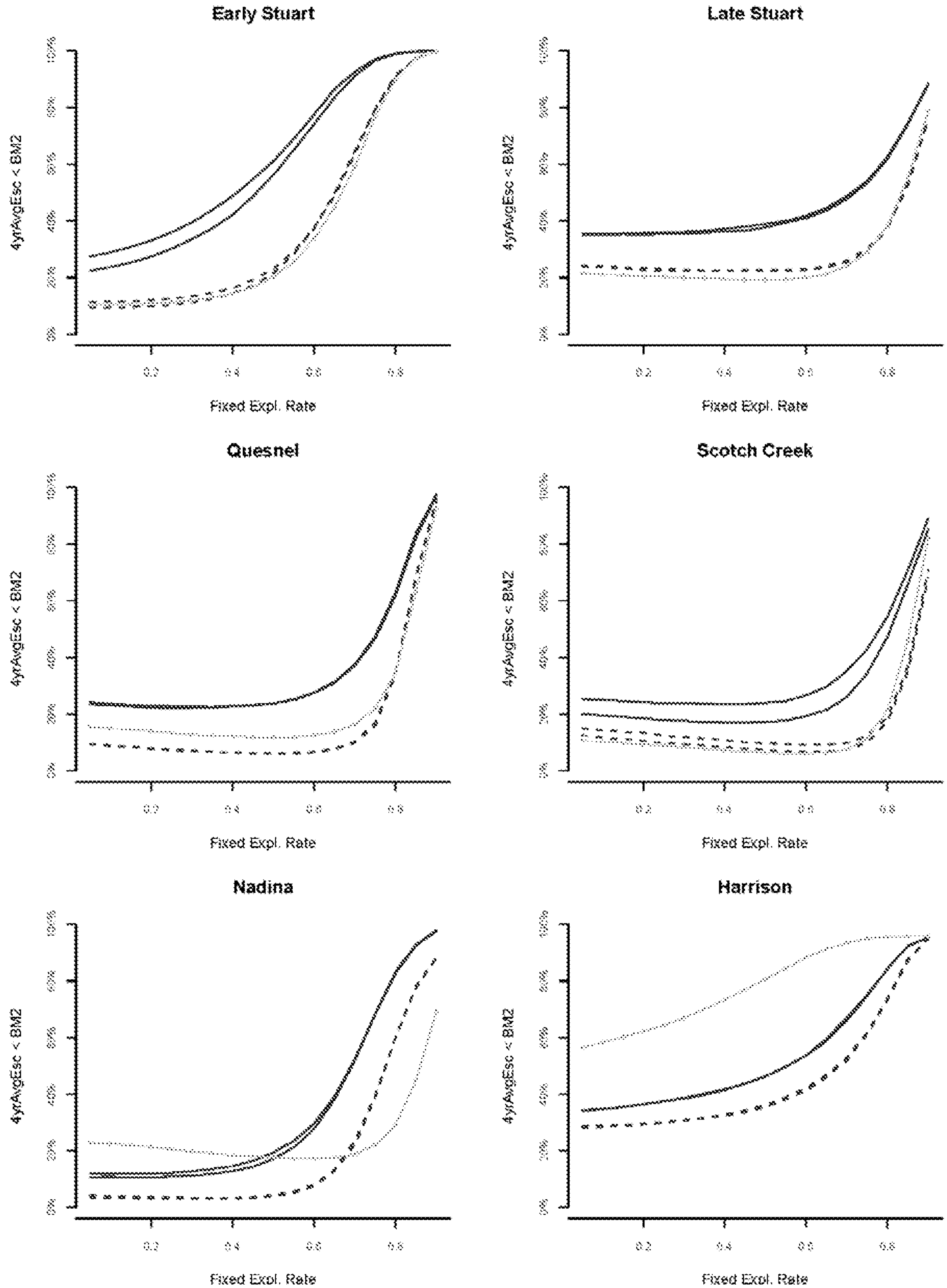


Figure 40: Effect of alternative parameter estimates on sensitivity to changing ER.
Each panel shows performance for 5 sets of SR parameters, based on effective female (solid) or total spawners (dashed). Two lines for each data type reflect alternative prior constraints. For comparison, the 2009/2010 parameter estimates are also shown (gray points). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

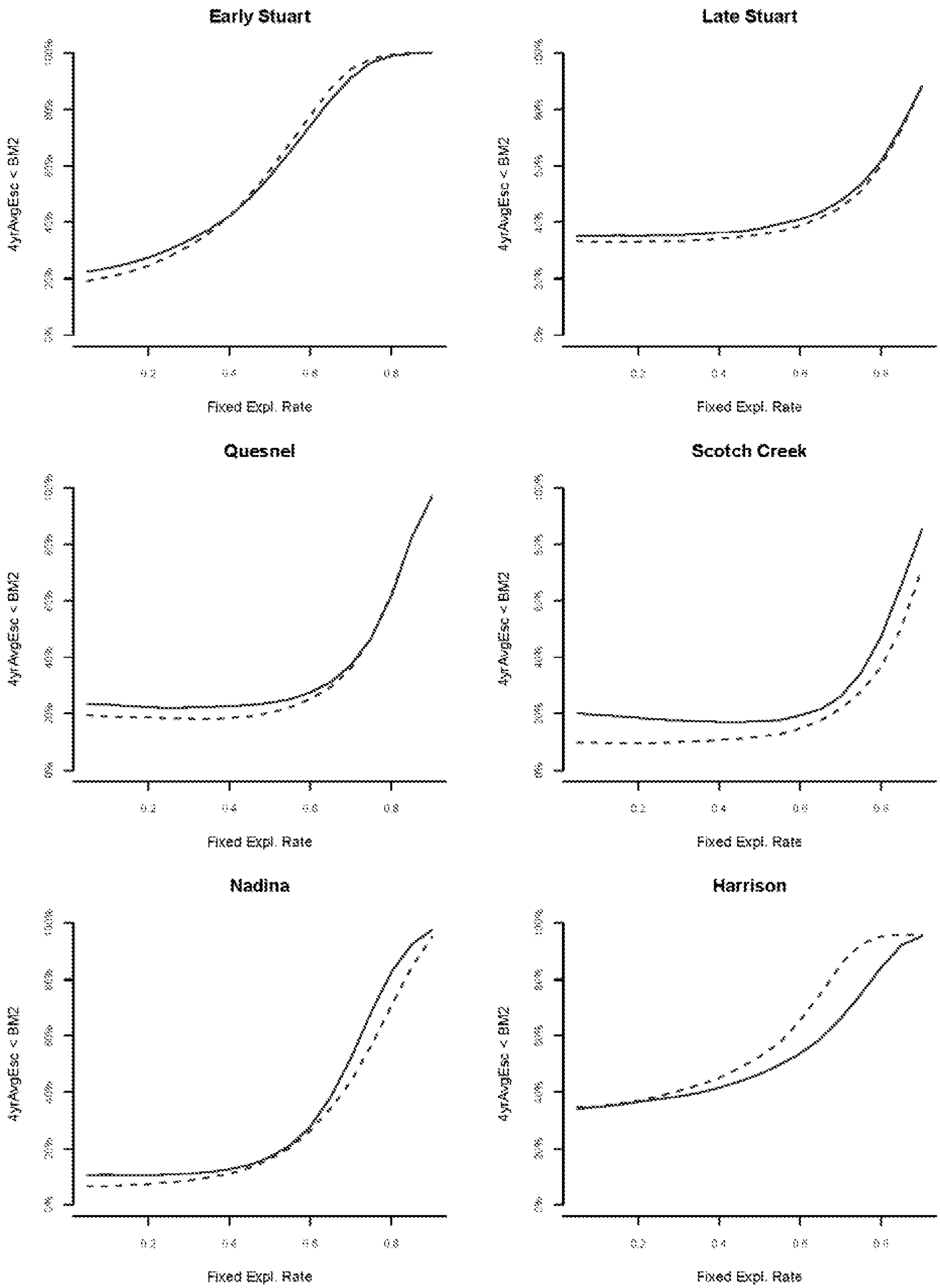


Figure 41: Effect of en-route mortality assumptions on sensitivity to changing ER.
Each panel shows performance when resampling DBE from the observed data (solid line) or using a lognormnal regression based on abundance. Note: low escapement benchmark from Table 1 not adjusted for % effective females.

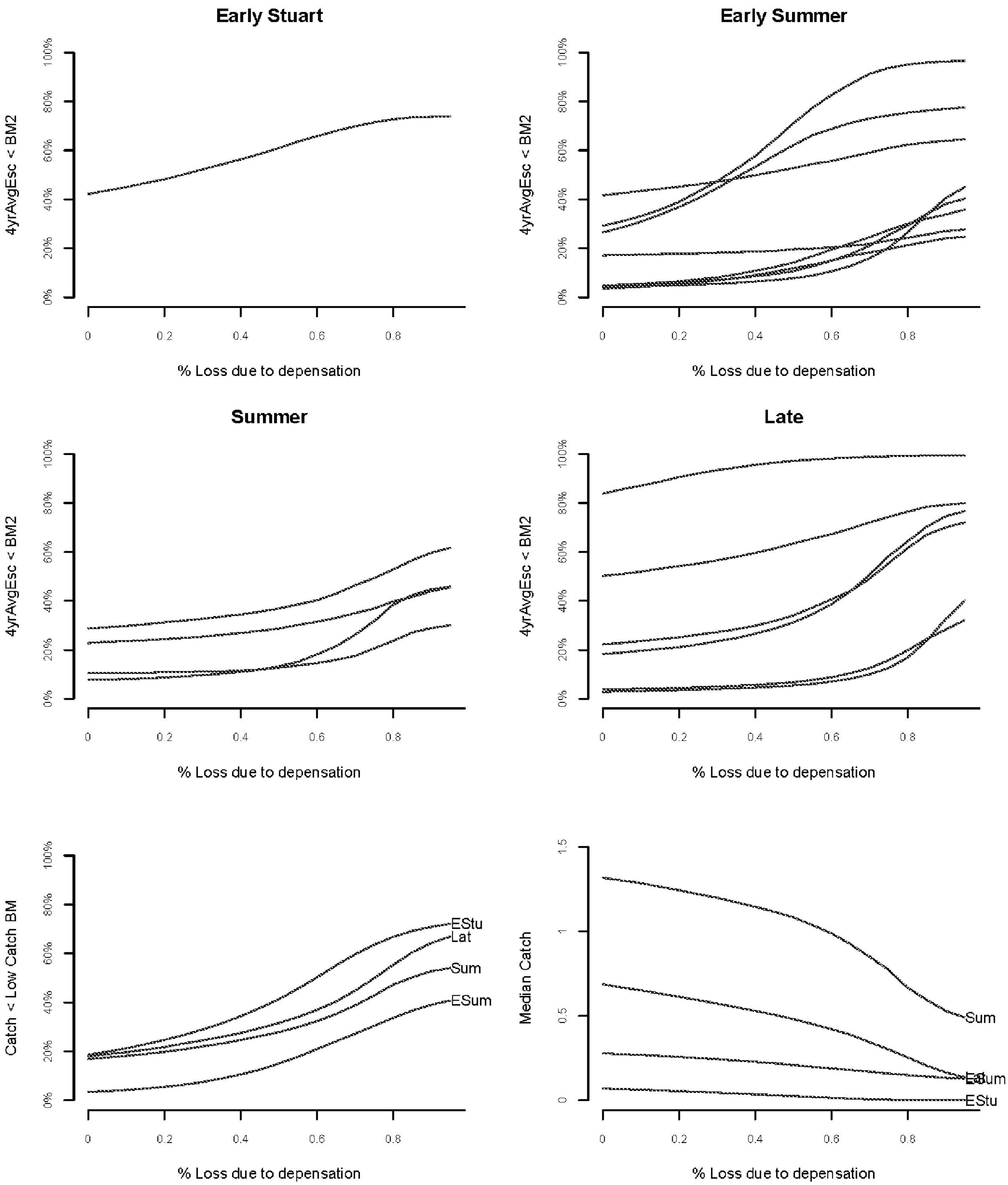


Figure 42: Effect of depensatory mortality assumptions on sensitivity to changing ER.
The top four panels show Prob(4yr Avg Esc < BM2) for each stock, with BM 2 listed in Table 1. Bottom left panel show Prob(Catch < Low catch BM) for each management group, with low catch benchmarks listed in Section 2.5. Bottom right shows median catch. All other settings as in Base Case 1 (Section 3.3.1). Note: low escapement benchmark from Table 1 not adjusted for % effective females.

Appendix 1 : WinBUGS code for estimating Larkin parameters

```
#Larkin Model

model{
   for( i in 4 : N) {
         R_Obs[i] ~ dlnorm(R[i],tau_R)        #  likelihood function
         R[i] <- RS_log[i] + log(S[i])        #  prediction model

         # Larkin model
         RS_log[i] <-alpha - beta0 * S[i] -beta1*S[i-1] -beta2*S[i-2]-beta3*S[i-3]

         #  model checking section (residuals, replicated data, p-values)
         resid[i] <- log(R_Obs[i]) - R[i]
         Rep[i] ~ dlnorm(R[i],tau_R)
         Pvalue[i] <- step(Rep[i]-log(R_Obs[i]) )
   }

# Larkin model priors
   alpha ~ dnorm(0,0.001)           # prior for Larkin α

   beta0 <- 1/Smax                  # relationship between capacity parameter and the
                                      number of spawners at maximum recruitment
   Smax~ dlnorm(log_Shi,1)I(,sShi)     # prior for Larkin β0 with upper constraint sShi
   sShi <- 3*Shi                    # upper constraint – 3 times highest number of
                                      spawners in dataset
   log_Shi<- log(Shi)               # mean for lognormal prior for β0

   beta1 ~ dunif(0,100)             # prior for Larkin β1
   beta2 ~ dunif(0,100)             # prior for Larkin β2
   beta3 ~ dunif(0,100)             # prior for Larkin β3

   tau_R ~ dgamma(0.001,0.001)      # prior for precision parameter
   sigma <- 1 / sqrt(tau_R)         # transform precision to standard deviation
}
```

WinBUGS notation	Description
data based inputs	
R_Obs[i]	observed recruits from broodyear i
S[i]	spawners on the grounds in year i
Shi	highest number of spawners in dataset

Appendix 2: Detailed Bayes DIC results.

Bayes DIC Values

ID	Stock	Larkin	Ricker	lag 1	lag 1&2	lag 1&3	lag 2	lag 2&3	lag 3
1	Early Stuart	**-87.96**	-80.245						
2	Late Stuart	-38.594	-37.487		**-39.85**	-37.147			
3	Stellako	**-13.41**	-0.329			-14.232			
4	Bowron	-259.97	**-275.8**						
5	Raft	-291.69	**-304.9**		-292.62		-294.11	-293.17	
6	Quesnel	**-168.9**	-167.35						
7	Chilko	113.327	121.305		**110.37**				
8	Seymour	**-160.7**	-160						
9	Late Shuswap	**-35.42**	-24.956		-35.964				
10	Birkenhead	6.798	6.271	**3.741**					
11	Cultus	-280.33	**-296.2**						
12	Portage	-220.74	**-241.4**	-223.62					
13	Weaver	7.196	**0.702**			5.334			4.492
14	Fennell	-199.14	**-218**						
15	Scotch	**-118.8**	-118.2						
16	Gates	-153.04	**-167.4**						
17	Nadina	-113.95	**-126.8**					-115.69	
18	Upper Pitt	-190.23	**-195.6**				-191.74		
19	Harrison	-201.9	**-218.3**						

123 Best-fit model
Close to best-fit model

Appendix 3 : Spawner-recruit data

1 **Early Stuart** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	1,671,741	688,013	386,816	1,814,783
Avg	315,809	93,389	44,030	313,620
Min	12,731	1,522	793	10,031

Year	Run	Spawners	Effective Females	Recruits
1948	NA	19,979	10,859	198,153
1949	NA	582,228	168,471	1,036,926
1950	NA	59,104	25,658	241,666
1951	NA	60,423	29,787	173,654
1952	NA	29,925	15,483	88,600
1953	1,048,757	154,036	78,332	540,891
1954	241,825	35,050	18,010	155,823
1955	158,998	2,159	1,397	27,467
1956	93,523	25,020	16,662	110,394
1957	548,612	234,850	119,278	1,222,913
1958	157,678	38,807	22,196	103,107
1959	26,525	2,670	1,297	20,835
1960	103,397	14,447	7,401	74,149
1961	1,225,877	198,921	87,809	255,842
1962	108,532	26,716	14,075	75,785
1963	14,944	4,607	2,590	92,554
1964	76,708	2,390	1,300	42,887
1965	256,325	23,045	11,242	417,211
1966	71,082	10,830	5,959	84,786
1967	99,548	21,044	11,167	339,693
1968	28,197	1,522	793	10,423
1969	432,919	109,655	48,687	1,375,518
1970	84,989	32,578	15,806	182,136
1971	326,153	95,940	45,612	431,210
1972	24,188	4,657	2,253	32,232
1973	1,367,393	299,892	153,870	1,352,015
1974	187,232	39,518	21,603	145,244
1975	426,227	65,752	26,248	223,085
1976	44,187	11,761	6,792	31,877
1977	1,343,698	117,445	53,381	761,694
1978	146,425	50,004	20,005	72,852
1979	222,745	92,746	36,172	107,936
1980	32,300	16,939	7,361	63,501
1981	755,703	129,457	67,227	350,141
1982	80,159	4,557	2,158	27,816
1983	90,997	23,867	13,121	188,892
1984	56,091	45,201	21,868	242,028
1985	356,844	234,219	116,610	1,208,877
1986	46,024	28,584	15,219	145,942
1987	178,007	148,194	75,970	525,920
1988	223,990	179,807	88,069	379,269
1989	1,211,856	384,799	211,039	1,138,789
1990	154,872	97,035	47,063	166,086
1991	512,486	141,119	85,454	144,459
1992	350,827	66,098	36,564	100,376
1993	1,151,645	688,013	386,816	1,814,783
1994	204,097	29,125	14,498	29,030
1995	138,323	122,856	57,322	189,600
1996	96,397	87,570	41,063	464,146
1997	1,671,741	266,941	73,417	147,572
1998	189,780	32,570	9,375	28,692
1999	171,629	24,552	8,189	30,566
2000	378,192	89,858	35,334	135,874
2001	214,191	170,981	82,849	252,006
2002	62,663	24,637	12,939	24,566
2003	30,276	13,166	6,932	10,031
2004	137,101	9,281	5,253	37,815
2005	219,696	98,537	51,183	NA
2006	55,988	35,816	15,914	NA
2007	12,731	5,347	2,376	NA
2008	34,036	29,867	14,446	NA

2 **Late Stuart** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	5,163,174	1,363,826	744,565	5,327,124
Avg	567,905	132,071	67,026	558,360
Min	2,147	35	16	327

Year	Run	Spawners	Effective Females	Recruits
1948	NA	NA	NA	327
1949	NA	107,752	39,085	1,530,202
1950	NA	5,843	1,834	39,681
1951	NA	4,364	1,247	63,810
1952	NA	35	16	3,973
1953	1,527,145	368,634	78,689	1,552,239
1954	36,886	5,470	2,687	137,965
1955	58,590	7,582	3,274	51,345
1956	12,413	913	466	46,102
1957	1,548,251	531,108	300,029	1,329,884
1958	138,477	23,619	13,152	54,677
1959	52,900	8,225	4,090	7,392
1960	15,466	2,396	1,307	9,617
1961	1,360,396	410,887	194,469	778,478
1962	55,027	18,643	9,073	45,069
1963	7,080	3,222	1,092	12,049
1964	8,034	1,816	824	3,101
1965	773,362	214,943	122,789	1,124,519
1966	51,082	9,027	4,164	74,079
1967	13,888	1,629	897	16,556
1968	2,147	389	179	31,299
1969	1,103,957	207,014	114,306	1,625,590
1970	94,021	14,978	8,027	70,838
1971	8,145	1,535	725	66,770
1972	40,187	7,341	3,411	18,766
1973	1,607,170	214,230	116,706	666,098
1974	91,651	14,190	7,371	50,716
1975	65,527	14,229	5,679	215,116
1976	16,470	2,898	1,674	3,339
1977	661,599	146,459	75,890	1,357,741
1978	56,784	12,738	7,115	79,447
1979	215,365	31,918	16,711	6,854
1980	3,921	946	286	21,440
1981	1,314,560	249,494	120,124	2,033,901
1982	113,596	16,758	8,681	60,989
1983	15,782	2,246	1,451	17,944
1984	21,440	1,228	672	14,744
1985	1,978,203	274,621	159,101	3,507,629
1986	107,988	28,715	15,044	816,561
1987	23,116	6,472	2,393	380,071
1988	26,026	7,117	3,638	208,786
1989	3,367,350	575,697	327,096	5,327,124
1990	858,898	189,079	111,747	389,823
1991	376,655	76,860	40,200	109,581
1992	322,645	19,513	12,422	135,399
1993	5,163,174	1,363,826	744,565	3,764,256
1994	517,217	76,462	40,717	115,440
1995	108,095	34,362	17,181	133,454
1996	150,838	62,991	27,297	1,023,000
1997	3,255,574	907,652	415,149	430,895
1998	620,406	138,397	67,836	277,262
1999	100,749	61,574	33,801	133,622
2000	849,458	454,397	226,267	913,822
2001	564,418	351,569	179,540	505,343
2002	343,512	34,498	17,820	125,952
2003	131,907	36,647	19,212	21,783
2004	884,765	83,418	51,370	284,071
2005	458,862	293,124	164,657	NA
2006	211,304	27,504	14,283	NA
2007	20,631	8,487	4,144	NA
2008	269,580	146,569	57,879	NA

3 **Stellako** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	1,852,392	371,604	200,541	1,904,124
Avg	469,977	105,909	52,692	465,579
Min	59,073	15,763	9,242	49,132

Year	Run	Spawners	Effective Females	Recruits
1948	NA	15,763	9,242	207,177
1949	NA	104,720	40,228	179,876
1950	NA	145,021	77,415	939,117
1951	NA	96,076	51,413	455,367
1952	NA	40,384	19,920	110,701
1953	200,034	42,134	20,388	174,245
1954	910,135	141,859	72,273	1,211,299
1955	384,791	51,739	29,937	629,796
1956	195,306	38,438	22,276	246,735
1957	176,197	38,522	18,044	151,843
1958	1,158,256	112,251	61,581	340,460
1959	670,552	79,305	41,872	541,420
1960	247,499	38,880	22,718	164,514
1961	171,234	46,863	18,136	147,402
1962	331,106	124,485	44,532	589,505
1963	531,152	138,794	41,535	727,926
1964	170,113	30,890	16,182	177,837
1965	158,301	39,385	20,479	243,651
1966	583,074	101,529	51,509	359,906
1967	731,057	91,480	32,467	550,524
1968	184,315	30,368	13,680	129,822
1969	238,902	49,211	25,629	253,245
1970	348,976	45,797	26,727	234,108
1971	554,728	39,691	20,147	509,267
1972	144,381	36,700	20,386	756,214
1973	240,736	30,404	15,424	85,901
1974	246,689	41,275	23,718	303,122
1975	513,105	175,941	68,451	1,904,124
1976	711,237	150,734	65,299	244,357
1977	122,420	23,047	10,894	265,700
1978	295,694	58,898	32,528	437,405
1979	1,852,392	290,042	152,583	623,924
1980	284,339	72,050	28,477	755,406
1981	237,504	21,826	12,030	285,898
1982	445,024	69,420	34,888	357,773
1983	526,984	121,692	61,357	1,257,480
1984	681,128	60,957	32,672	1,011,189
1985	455,291	42,099	21,968	128,742
1986	362,232	77,177	44,611	561,845
1987	1,144,418	211,085	98,179	435,676
1988	903,283	367,702	200,541	991,499
1989	364,112	43,179	15,926	222,287
1990	476,408	93,920	56,536	951,836
1991	470,053	94,884	54,400	336,569
1992	648,446	97,979	55,190	868,461
1993	553,471	91,071	42,858	309,844
1994	956,333	136,709	63,628	682,889
1995	388,978	122,676	41,176	183,959
1996	771,677	332,207	167,671	811,994
1997	202,078	55,357	23,264	125,173
1998	835,157	185,641	97,011	637,997
1999	216,713	138,137	66,125	174,462
2000	692,039	371,604	195,418	717,671
2001	245,067	151,409	61,635	287,128
2002	561,079	322,711	177,668	248,375
2003	277,491	78,093	43,879	49,132
2004	678,056	86,688	53,805	248,252
2005	273,546	175,299	102,347	NA
2006	307,985	147,189	79,884	NA
2007	59,073	41,328	19,649	NA
2008	228,384	159,737	73,837	NA

4 **Bowron** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	207,472	35,000	16,178	214,316
Avg	39,575	9,577	4,559	40,345
Min	3,098	836	275	3,822

Year	Run	Spawners	Effective Females	Recruits
1948	NA	25,205	12,826	80,266
1949	NA	22,283	10,721	62,791
1950	NA	16,146	7,298	75,548
1951	NA	21,731	10,039	103,821
1952	NA	18,645	8,568	43,304
1953	63,296	13,277	5,734	75,579
1954	65,743	10,515	4,566	66,916
1955	113,084	9,350	4,471	96,955
1956	36,995	6,994	3,639	38,484
1957	77,555	12,011	6,416	41,966
1958	67,991	14,843	8,297	18,155
1959	95,916	29,247	14,614	61,865
1960	31,875	7,620	3,506	17,733
1961	51,949	7,449	3,675	28,148
1962	18,914	6,286	3,219	21,327
1963	56,625	25,141	11,468	214,316
1964	22,678	1,500	690	27,507
1965	27,292	2,659	1,170	17,849
1966	20,163	2,470	1,151	22,249
1967	207,472	31,695	13,991	206,494
1968	34,781	3,611	1,710	44,642
1969	18,861	3,872	1,936	17,211
1970	22,349	1,305	497	16,197
1971	194,910	25,497	10,761	124,507
1972	49,906	4,138	1,969	16,971
1973	23,623	4,558	2,012	10,662
1974	17,034	1,850	1,046	17,431
1975	124,161	29,700	14,735	122,780
1976	17,206	2,250	1,069	7,112
1977	10,649	2,500	1,214	15,396
1978	15,948	3,141	1,678	40,627
1979	123,471	35,000	16,178	29,984
1980	8,028	2,894	1,376	45,170
1981	5,875	1,170	562	16,532
1982	49,424	1,647	990	5,277
1983	16,438	6,451	3,484	38,556
1984	53,651	10,461	4,909	50,603
1985	20,513	6,395	3,030	19,177
1986	4,891	3,118	1,396	21,198
1987	38,820	11,071	5,660	22,592
1988	46,654	12,780	7,405	13,050
1989	22,328	2,534	1,367	12,842
1990	23,422	7,860	5,065	31,130
1991	18,807	4,920	2,460	48,807
1992	15,958	2,560	1,117	12,883
1993	6,326	1,184	592	20,467
1994	26,858	4,380	1,845	10,849
1995	59,839	34,417	13,487	27,391
1996	11,707	8,176	4,054	26,776
1997	19,274	4,811	2,119	5,024
1998	10,289	4,751	2,830	17,001
1999	29,198	8,238	3,295	19,734
2000	22,954	13,440	6,720	25,283
2001	7,416	5,842	2,752	6,825
2002	14,961	8,770	4,505	7,674
2003	25,463	6,752	3,038	3,822
2004	23,887	836	418	6,225
2005	5,829	1,649	825	NA
2006	9,671	1,501	614	NA
2007	4,157	2,069	1,023	NA
2008	3,098	1,005	275	NA

5 **Raft** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	142,932	66,292	27,668	115,396
Avg	31,958	8,849	4,127	32,933
Min	1,510	464	198	1,461

Year	Run	Spawners	Effective Females	Recruits
1948	NA	10,359	5,524	63,337
1949	NA	6,113	2,109	39,626
1950	NA	6,404	1,917	45,556
1951	NA	8,544	3,365	47,653
1952	NA	15,617	5,116	51,182
1953	37,449	7,904	3,600	32,124
1954	42,435	9,988	5,352	50,488
1955	40,631	5,079	2,905	60,522
1956	59,176	9,037	5,180	27,140
1957	35,526	6,860	3,314	21,015
1958	40,810	10,214	6,235	23,143
1959	63,790	10,210	5,232	23,614
1960	25,425	5,513	2,690	16,948
1961	28,760	7,293	3,014	24,325
1962	24,602	7,613	4,197	40,549
1963	21,010	8,683	2,693	9,817
1964	17,944	5,177	2,666	48,724
1965	24,308	6,624	2,669	20,626
1966	39,740	6,244	2,666	23,539
1967	12,152	1,279	358	9,658
1968	41,065	8,089	3,455	106,397
1969	27,547	5,537	2,577	14,370
1970	22,206	4,462	1,205	8,860
1971	11,060	801	223	12,361
1972	102,664	11,048	4,507	57,821
1973	15,727	2,714	1,345	9,361
1974	12,043	2,383	1,479	12,223
1975	10,180	2,609	1,391	6,716
1976	59,753	8,665	3,976	19,926
1977	2,583	617	198	5,917
1978	19,271	2,493	1,343	18,748
1979	6,164	1,758	693	3,039
1980	19,616	5,418	2,056	51,723
1981	4,312	815	312	8,639
1982	15,077	2,992	1,533	3,770
1983	7,902	2,780	1,821	5,601
1984	49,712	19,086	6,701	47,055
1985	11,150	3,637	1,922	4,533
1986	3,791	2,095	1,080	3,013
1987	4,441	1,436	723	3,820
1988	35,407	19,851	9,207	50,175
1989	16,868	1,647	925	11,299
1990	4,598	630	412	2,544
1991	1,510	464	264	1,461
1992	44,211	8,236	4,112	67,359
1993	15,749	5,047	2,934	33,202
1994	5,545	1,712	800	28,472
1995	1,848	1,040	682	27,270
1996	65,906	46,592	21,381	112,592
1997	24,410	6,093	2,367	51,264
1998	15,571	7,198	3,585	16,238
1999	47,072	6,979	3,499	61,149
2000	93,799	66,292	27,668	115,396
2001	48,675	32,498	16,025	96,695
2002	30,278	18,369	8,402	42,833
2003	37,804	10,040	4,890	8,475
2004	142,932	5,611	3,244	67,284
2005	87,357	26,456	16,967	NA
2006	37,794	6,073	3,442	NA
2007	25,240	14,353	8,064	NA
2008	47,043	10,406	3,562	NA

6 **Quesnel** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	12,161,405	3,510,789	1,740,472	12,544,246
Avg	1,380,161	365,248	177,480	1,356,472
Min	194	49	9	165

Year	Run	Spawners	Effective Females	Recruits
1948	NA	100	48	618
1949	NA	30,664	19,209	486,378
1950	NA	398	264	2,048
1951	NA	49	9	413
1952	NA	184	51	562
1953	463,443	110,917	47,564	610,245
1954	2,014	299	146	10,692
1955	413	63	30	180
1956	6,464	80	38	1,133
1957	604,123	223,667	134,562	999,533
1958	10,912	1,863	1,269	3,412
1959	198	65	29	165
1960	10,894	292	123	1,475
1961	989,607	302,565	69,990	1,240,890
1962	3,536	1,078	566	7,287
1963	194	83	40	956
1964	45,950	254	77	2,812
1965	1,195,837	364,706	105,401	1,667,172
1966	7,859	1,753	1,040	7,462
1967	956	119	24	1,761
1968	16,973	699	333	428
1969	1,652,135	278,961	78,639	1,640,832
1970	7,953	1,368	388	20,339
1971	2,146	171	16	747
1972	6,910	111	46	865
1973	1,626,582	278,311	112,538	2,336,434
1974	28,107	4,459	2,587	31,024
1975	756	193	105	1,865
1976	6,497	305	209	1,233
1977	2,326,885	516,199	160,712	3,878,522
1978	33,233	8,614	4,349	196,724
1979	3,564	511	238	6,011
1980	9,679	308	98	2,446
1981	3,810,928	748,621	332,306	9,786,652
1982	245,363	39,841	20,053	555,386
1983	12,612	2,155	1,098	40,412
1984	25,962	914	551	6,953
1985	9,553,856	1,349,263	694,708	12,544,246
1986	712,295	181,467	94,844	2,532,784
1987	87,912	20,546	11,238	176,592
1988	46,737	6,832	4,185	26,342
1989	12,161,405	1,870,820	940,610	10,641,495
1990	2,716,516	488,259	259,597	3,283,634
1991	287,552	46,259	24,862	151,175
1992	96,025	5,862	3,046	29,214
1993	10,340,080	2,620,454	1,507,416	6,851,040
1994	3,236,300	659,499	356,244	2,477,091
1995	436,433	216,109	116,916	167,306
1996	82,090	41,187	21,719	90,690
1997	6,446,284	1,858,652	904,886	4,692,773
1998	2,666,551	1,179,252	534,587	4,739,875
1999	332,450	189,360	106,950	810,586
2000	117,802	63,703	37,162	53,810
2001	4,381,602	3,510,789	1,740,472	3,701,006
2002	4,800,147	3,062,151	1,312,599	640,265
2003	853,991	279,170	148,465	143,876
2004	271,722	10,222	6,628	13,042
2005	3,592,160	1,447,381	777,707	NA
2006	723,165	169,768	90,415	NA
2007	119,068	75,100	33,777	NA
2008	68,161	7,091	2,471	NA

7 **Chilko** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	4,628,365	1,037,737	597,558	4,795,406
Avg	1,425,480	369,370	192,833	1,430,531
Min	151,720	17,308	6,555	69,453

Year	Run	Spawners	Effective Females	Recruits
1948	NA	670,622	364,597	1,946,691
1949	NA	58,247	33,029	621,714
1950	NA	17,308	6,555	205,875
1951	NA	98,315	57,564	748,718
1952	NA	485,585	233,628	1,857,583
1953	828,243	200,691	94,471	618,675
1954	244,883	34,296	21,247	710,516
1955	688,801	121,167	75,834	1,513,275
1956	1,860,093	646,906	368,607	2,435,670
1957	604,179	138,464	83,128	138,228
1958	767,760	120,104	70,433	428,280
1959	1,486,547	463,060	272,891	2,212,583
1960	2,451,526	426,546	244,864	1,053,335
1961	163,316	39,101	15,038	69,453
1962	324,550	77,713	42,125	985,544
1963	2,231,435	998,231	57,163	1,205,462
1964	1,067,200	238,272	131,590	2,040,082
1965	151,720	35,335	20,813	158,944
1966	1,014,263	209,619	107,541	889,200
1967	1,138,362	174,715	90,006	2,004,710
1968	1,873,102	413,862	181,912	2,474,941
1969	379,359	70,902	25,519	402,359
1970	791,502	135,388	50,923	694,456
1971	2,102,377	157,193	90,831	852,842
1972	2,391,956	562,650	332,353	2,109,408
1973	464,529	55,675	30,231	246,553
1974	722,240	110,026	71,126	712,467
1975	838,396	244,631	133,782	1,513,246
1976	1,998,190	384,390	228,326	1,699,113
1977	348,080	51,330	20,385	199,200
1978	702,183	146,842	85,570	1,265,579
1979	1,458,363	258,391	147,920	1,713,709
1980	1,735,811	497,759	293,204	4,439,552
1981	238,521	34,540	20,164	208,706
1982	1,184,116	249,578	142,515	1,597,805
1983	1,716,873	382,833	213,715	2,115,342
1984	4,010,144	580,178	283,146	670,556
1985	742,139	71,975	34,995	571,832
1986	1,425,020	293,804	165,504	4,795,406
1987	1,922,927	421,015	268,105	4,417,861
1988	850,928	363,389	206,156	3,296,360
1989	572,218	63,268	42,813	3,117,371
1990	4,628,365	825,837	497,975	2,628,585
1991	4,369,936	1,037,737	597,558	1,382,549
1992	3,365,275	511,267	319,943	1,866,349
1993	3,341,605	555,226	322,283	3,963,871
1994	2,512,232	450,745	253,982	1,419,987
1995	1,329,086	544,364	298,077	1,271,922
1996	2,043,114	974,846	504,519	1,362,079
1997	3,480,174	985,827	509,295	885,013
1998	1,899,495	879,010	467,670	533,331
1999	1,122,964	891,567	432,593	1,570,589
2000	1,399,857	758,941	395,550	498,325
2001	850,849	668,671	331,293	1,158,636
2002	646,856	382,753	215,118	1,238,733
2003	1,562,429	608,321	334,956	382,228
2004	543,576	91,909	49,198	418,840
2005	1,075,508	535,967	285,103	NA
2006	1,276,778	468,947	261,967	NA
2007	437,555	305,853	156,566	NA
2008	449,387	249,863	68,851	NA

8 **Seymour** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	823,255	272,041	108,279	824,169
Avg	134,308	32,080	15,051	132,489
Min	7,831	1,323	311	1,944

Year	Run	Spawners	Effective Females	Recruits
1948	NA	3,889	1,280	29,658
1949	NA	10,772	3,476	34,705
1950	NA	11,049	4,697	162,026
1951	NA	24,320	11,505	68,943
1952	NA	5,963	2,780	11,249
1953	26,526	5,692	2,907	45,268
1954	169,597	24,774	12,852	461,522
1955	68,057	8,971	5,178	310,002
1956	12,160	2,490	1,102	12,763
1957	69,000	10,870	7,416	24,583
1958	429,330	78,371	44,285	195,518
1959	317,483	52,310	25,773	175,980
1960	12,088	2,901	1,862	8,837
1961	20,357	3,622	1,957	32,923
1962	201,147	57,836	28,664	176,546
1963	175,764	71,654	26,742	114,086
1964	9,120	2,745	1,321	18,498
1965	28,815	6,089	2,550	34,890
1966	177,006	28,698	12,943	141,828
1967	116,094	13,361	7,264	220,851
1968	19,851	3,838	2,064	22,108
1969	35,869	7,176	3,276	14,875
1970	139,811	11,971	3,603	226,369
1971	218,158	19,028	9,463	135,310
1972	26,273	2,802	1,418	56,785
1973	15,232	2,704	1,150	24,800
1974	225,046	44,588	25,868	248,730
1975	134,549	36,828	16,844	180,684
1976	58,818	8,306	4,898	18,422
1977	25,734	5,709	2,883	70,046
1978	249,042	62,808	30,757	261,925
1979	175,050	49,306	24,866	135,614
1980	22,335	8,309	4,616	52,848
1981	54,756	11,359	5,354	30,875
1982	272,372	63,271	27,219	508,455
1983	97,986	29,831	14,014	272,460
1984	87,664	17,172	9,148	36,017
1985	36,716	5,620	2,684	43,576
1986	499,854	126,166	57,069	824,169
1987	274,809	84,315	41,081	442,220
1988	44,371	16,781	7,989	10,843
1989	33,250	5,507	2,864	18,877
1990	823,255	272,041	108,279	278,827
1991	427,423	128,253	60,845	95,565
1992	34,900	5,742	3,586	17,906
1993	20,761	10,119	4,950	8,716
1994	272,278	64,038	19,151	172,547
1995	90,723	48,746	23,928	66,040
1996	26,383	21,654	9,590	39,470
1997	9,029	2,254	836	1,944
1998	172,367	34,048	14,548	214,404
1999	66,985	18,895	10,072	133,931
2000	34,691	25,465	11,860	59,563
2001	8,605	6,892	3,743	19,042
2002	210,570	113,408	55,465	507,957
2003	109,587	31,345	18,483	12,366
2004	86,533	1,323	762	6,904
2005	16,798	3,590	2,326	NA
2006	501,926	107,941	57,783	NA
2007	20,507	9,979	5,905	NA
2008	7,831	1,350	311	NA

9 **Late Shuswap** ||| = 1/10 of max for each variable

Year	Run	Spawners	Effective Females	Recruits
Max	15,110,393	5,532,263	2,845,464	15,869,336
Avg	2,199,677	647,524	321,206	2,161,609
Min	2,659	164	83	1,388
1948	NA	10,356	8,502	28,330
1949	NA	3,606	2,011	40,793
1950	NA	1,271,381	583,045	9,944,058
1951	NA	143,498	82,097	529,582
1952	NA	7,317	4,211	17,932
1953	623,812	3,472	1,623	31,027
1954	9,325,573	2,026,693	1,067,603	15,869,336
1955	564,055	63,859	44,632	865,520
1956	18,289	3,321	2,103	7,974
1957	746,422	2,809	1,651	3,163
1958	15,110,393	3,297,045	1,644,152	2,213,808
1959	909,161	134,826	89,270	382,302
1960	8,114	1,907	1,322	2,549
1961	127,110	1,150	854	8,147
1962	2,086,042	1,144,115	651,863	2,925,312
1963	386,642	158,468	80,244	3,131,346
1964	2,659	604	345	19,626
1965	97,559	2,087	1,332	24,808
1966	2,820,125	1,280,308	660,849	4,051,932
1967	3,144,289	844,896	402,412	3,184,223
1968	22,588	3,686	2,713	21,961
1969	125,541	5,985	3,166	29,860
1970	3,982,320	1,524,303	785,282	5,580,907
1971	3,143,039	289,908	158,976	702,125
1972	32,300	4,192	2,155	44,505
1973	202,978	3,808	2,467	67,868
1974	5,397,611	1,150,772	619,123	7,050,422
1975	715,459	167,381	85,544	1,026,264
1976	42,506	4,780	3,072	14,170
1977	211,326	12,510	6,027	93,645
1978	6,891,681	1,897,353	1,014,761	9,657,108
1979	1,039,295	299,547	162,142	1,499,666
1980	14,747	2,498	1,816	23,307
1981	212,923	10,314	5,959	9,470
1982	9,366,352	3,060,235	1,568,605	9,464,846
1983	1,655,793	211,365	100,256	1,980,917
1984	38,141	4,346	2,409	33,174
1985	89,787	1,468	806	13,723
1986	9,223,742	2,345,230	1,068,479	10,934,052
1987	2,125,988	617,343	319,734	3,903,932
1988	48,992	5,011	3,558	8,220
1989	72,317	563	380	13,135
1990	10,638,002	3,717,673	1,745,709	7,770,211
1991	4,086,523	1,255,852	616,033	866,189
1992	62,092	12,996	6,640	19,909
1993	36,347	1,395	765	15,366
1994	7,603,407	1,409,211	686,190	2,610,200
1995	991,547	428,875	210,969	771,591
1996	31,054	12,466	5,492	61,532
1997	24,420	1,072	597	34,711
1998	2,590,229	1,389,271	680,650	7,248,023
1999	770,717	343,540	138,247	698,913
2000	51,951	855	164	1,388
2001	149,532	4,861	2,141	8,890
2002	7,142,670	5,532,263	2,845,464	7,509,787
2003	697,945	381,278	189,793	138,420
2004	22,768	2,994	2,234	1,558
2005	75,289	21,113	11,792	NA
2006	7,394,430	2,897,709	1,170,725	NA
2007	175,092	61,043	32,296	NA
2008	12,198	164	83	NA

10 **Birkenhead** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	1,645,000	335,630	197,896	1,815,929
Avg	384,265	80,757	43,804	382,014
Min	54,042	11,905	5,510	13,338

Year	Run	Spawners	Effective Females	Recruits
1948	NA	83,787	54,755	207,185
1949	NA	70,504	43,328	306,824
1950	NA	64,440	41,370	241,164
1951	NA	21,296	13,590	215,197
1952	NA	47,041	24,744	243,943
1953	277,921	42,491	16,287	155,190
1954	241,810	18,213	8,635	174,476
1955	163,996	14,553	8,185	274,765
1956	267,364	49,754	27,156	277,412
1957	163,859	14,536	7,068	73,969
1958	209,572	15,166	5,510	128,540
1959	273,459	26,159	11,388	267,850
1960	229,571	36,838	19,198	168,764
1961	110,107	31,681	10,550	128,515
1962	131,644	26,369	14,311	102,483
1963	255,230	48,893	20,769	455,767
1964	188,770	48,908	27,978	365,682
1965	109,135	16,230	9,769	163,688
1966	200,785	20,116	13,462	316,227
1967	337,100	39,876	17,580	491,588
1968	332,046	57,947	31,042	285,105
1969	267,383	37,382	14,324	791,608
1970	238,082	30,656	19,252	736,053
1971	491,308	24,629	16,143	368,545
1972	359,172	54,516	26,202	519,125
1973	616,194	56,653	28,374	216,524
1974	880,175	119,637	85,495	722,909
1975	354,038	61,538	23,315	120,109
1976	528,870	77,305	50,023	616,213
1977	247,970	23,845	12,799	425,661
1978	466,395	94,782	48,158	664,732
1979	351,482	60,988	35,482	414,741
1980	524,681	78,613	32,786	163,172
1981	439,405	49,023	27,175	266,159
1982	627,225	119,738	72,353	1,815,929
1983	413,274	44,029	21,113	806,674
1984	246,496	40,245	23,227	467,656
1985	190,989	11,905	5,758	244,631
1986	1,645,000	335,630	197,896	1,211,967
1987	926,526	164,849	89,432	988,553
1988	525,069	166,591	75,535	923,851
1989	262,065	29,334	15,739	1,147,929
1990	983,804	166,773	97,112	238,613
1991	1,047,153	293,626	152,083	120,668
1992	522,057	185,908	93,443	98,306
1993	1,638,660	244,954	151,096	573,466
1994	375,783	39,234	22,315	67,413
1995	87,005	39,871	18,430	170,525
1996	121,470	56,112	27,848	78,931
1997	228,234	50,202	23,275	30,582
1998	406,934	295,669	173,045	618,373
1999	186,244	48,916	26,268	83,528
2000	63,091	13,842	8,333	101,965
2001	62,556	44,450	28,361	191,674
2002	225,740	189,445	107,481	633,756
2003	452,736	309,878	152,651	13,338
2004	99,983	37,617	17,516	76,602
2005	149,258	53,546	27,116	NA
2006	583,865	266,459	137,364	NA
2007	136,045	93,480	54,290	NA
2008	54,042	19,500	6,784	NA

11 **Cultus** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	277,696	47,779	29,903	277,284
Avg	39,679	10,675	5,916	40,360
Min	108	52	17	80

Year	Run	Spawners	Effective Females	Recruits
1948	NA	12,746	6,671	39,076
1949	NA	9,055	5,617	39,151
1950	NA	29,928	18,582	105,287
1951	NA	12,677	9,034	174,068
1952	NA	17,833	11,331	44,424
1953	42,368	11,543	4,939	63,669
1954	105,162	22,036	10,496	65,195
1955	166,202	25,922	16,743	277,284
1956	38,023	13,718	8,486	37,505
1957	75,214	20,375	12,260	28,083
1958	64,096	13,324	7,031	50,913
1959	277,696	47,779	29,903	52,194
1960	36,444	17,640	9,449	23,503
1961	31,338	13,396	6,567	6,148
1962	47,647	26,997	16,384	36,007
1963	52,211	20,303	10,524	138,448
1964	24,249	11,067	5,798	70,603
1965	6,892	2,455	1,515	20,986
1966	39,308	16,919	8,630	45,065
1967	132,823	33,198	17,209	110,501
1968	72,233	25,314	13,889	42,454
1969	25,707	5,942	2,970	6,477
1970	47,795	13,941	7,622	45,857
1971	97,142	9,128	4,638	50,701
1972	49,978	10,366	5,410	30,360
1973	5,941	641	302	713
1974	47,470	8,984	4,999	29,718
1975	48,202	11,349	6,856	115,787
1976	30,377	4,435	2,693	6,129
1977	1,119	82	38	1,571
1978	35,140	5,076	2,947	73,948
1979	109,671	32,031	18,950	109,906
1980	6,490	1,657	900	4,825
1981	6,294	256	134	1,544
1982	70,773	16,725	9,599	18,831
1983	106,803	19,944	11,490	96,326
1984	6,845	720	389	9,321
1985	1,848	424	195	2,431
1986	12,842	3,210	2,020	10,488
1987	100,936	32,162	16,220	65,855
1988	10,114	861	455	7,825
1989	2,222	418	220	10,745
1990	10,419	1,860	944	24,767
1991	65,018	20,157	9,850	17,363
1992	7,505	1,203	698	1,880
1993	11,107	1,063	571	160
1994	23,266	4,399	2,524	10,408
1995	19,089	10,316	4,279	15,414
1996	2,442	2,022	723	4,365
1997	156	88	35	716
1998	10,503	1,959	955	6,025
1999	13,840	12,427	4,800	2,852
2000	5,837	1,227	470	80
2001	698	515	180	212
2002	5,974	4,873	2,375	5,292
2003	2,885	1,939	662	728
2004	108	52	17	NA
2005	402	112	57	NA
2006	5,015	3,509	1,305	NA
2007	934	538	210	NA
2008	1,192	338	145	NA

12 **Portage** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	202,593	31,343	15,201	210,984
Avg	46,723	6,448	3,346	42,423
Min	742	9	5	47

Year	Run	Spawners	Effective Females	Recruits
1953	NA	50	24	394
1954	NA	3,369	1,729	38,700
1955	NA	41	20	4,392
1956	NA	NA	NA	NA
1957	NA	40	20	47
1958	35,962	4,791	2,749	25,645
1959	NA	572	286	5,565
1960	NA	NA	NA	NA
1961	NA	23	12	2,723
1962	24,872	11,935	6,326	72,180
1963	NA	2,011	1,116	58,437
1964	NA	9	5	624
1965	NA	981	589	3,463
1966	72,325	31,343	15,201	31,339
1967	56,440	4,025	1,983	4,286
1968	742	86	51	1,046
1969	3,651	963	491	34,582
1970	30,871	3,873	2,139	58,068
1971	4,308	281	155	18,043
1972	4,999	190	98	15,283
1973	32,060	3,963	1,688	91,287
1974	58,801	8,475	4,843	42,611
1975	17,939	3,175	1,631	15,753
1976	23,928	1,042	753	7,590
1977	82,341	7,610	3,923	39,989
1978	41,513	9,978	3,963	111,703
1979	15,089	3,575	2,023	52,692
1980	8,100	1,800	996	12,225
1981	39,750	5,855	2,951	20,069
1982	100,971	23,867	11,734	210,984
1983	63,045	7,747	4,909	37,358
1984	12,420	1,710	941	50,565
1985	17,289	1,765	960	25,840
1986	202,593	14,291	6,212	71,594
1987	49,008	6,820	3,766	63,044
1988	25,630	1,068	797	21,096
1989	49,583	7,900	5,067	199,353
1990	69,041	18,336	8,415	50,970
1991	65,213	12,053	7,292	15,891
1992	17,361	2,706	1,378	17,136
1993	190,877	19,760	9,829	174,902
1994	63,474	9,270	3,890	127,670
1995	17,588	7,875	4,319	40,314
1996	14,118	3,422	1,759	86,511
1997	171,626	9,766	5,056	41,499
1998	130,209	25,179	11,873	18,053
1999	40,228	6,264	2,079	9,078
2000	86,582	1,269	671	12,829
2001	43,064	3,150	1,851	18,610
2002	18,931	14,953	8,001	48,191
2003	8,824	4,940	3,179	5,210
2004	13,572	1,287	778	5,695
2005	18,593	12,082	8,261	NA
2006	48,183	18,882	10,971	NA
2007	4,835	1,699	849	NA
2008	6,002	97	63	NA

13 **Weaver Creek** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	1,338,092	294,083	115,031	1,505,995
Avg	371,305	49,062	23,197	364,686
Min	59,471	2,756	616	42,717

Year	Run	Spawners	Effective Females	Recruits
1966	NA	19,489	9,860	76,161
1967	NA	22,581	10,619	88,405
1968	NA	3,799	2,202	155,396
1969	NA	58,727	30,604	412,913
1970	NA	10,435	5,004	384,039
1971	82,203	4,990	2,656	155,284
1972	154,227	25,738	15,027	350,142
1973	389,606	48,541	24,885	274,667
1974	420,933	64,093	28,099	284,880
1975	151,690	29,736	16,033	169,860
1976	340,808	49,932	28,243	304,434
1977	274,831	52,627	28,510	235,763
1978	268,428	75,171	42,315	1,366,185
1979	200,964	45,026	25,702	141,028
1980	275,796	73,830	43,285	364,714
1981	250,979	42,002	22,627	270,292
1982	1,201,868	294,083	115,031	1,505,995
1983	302,470	39,341	27,380	239,991
1984	346,248	59,602	30,435	635,778
1985	245,733	37,019	22,773	69,300
1986	1,338,092	110,738	41,837	42,717
1987	448,634	59,968	30,106	220,718
1988	594,647	49,258	27,623	513,778
1989	101,711	17,167	10,620	765,938
1990	59,471	16,365	8,524	634,660
1991	198,747	38,121	18,710	65,545
1992	365,168	58,686	28,480	753,217
1993	873,383	84,456	34,019	500,654
1994	672,610	64,956	35,516	715,932
1995	77,637	33,125	10,905	266,443
1996	640,946	72,070	26,849	383,413
1997	509,510	25,504	10,724	215,997
1998	766,084	57,091	29,811	566,885
1999	239,693	34,634	13,106	246,929
2000	446,928	6,613	2,732	114,132
2001	225,093	19,915	8,035	196,083
2002	524,062	101,033	36,269	242,830
2003	248,940	49,488	24,681	188,799
2004	168,587	25,379	13,967	102,858
2005	155,708	48,516	23,597	NA
2006	277,878	39,781	13,618	NA
2007	149,581	37,300	15,825	NA
2008	119,683	2,756	616	NA

14 **Fennel Creek** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	69,236	32,279	15,223	78,650
Avg	26,125	7,098	3,895	25,888
Min	1,003	9	5	586

Year	Run	Spawners	Effective Females	Recruits
1967	NA	916	294	15,201
1968	NA	954	577	15,037
1969	NA	52	22	881
1970	NA	9	5	740
1971	NA	1,293	306	16,707
1972	14,846	1,931	1,030	29,007
1973	1,058	205	83	1,106
1974	1,003	140	70	586
1975	15,603	4,005	2,181	62,451
1976	29,190	4,090	2,373	22,761
1977	1,764	355	174	10,484
1978	1,105	107	46	2,390
1979	58,955	15,565	8,046	18,386
1980	23,293	8,437	4,413	36,205
1981	10,031	2,076	1,069	3,947
1982	5,296	1,132	656	11,140
1983	9,144	4,977	2,596	39,122
1984	43,562	11,021	6,291	49,442
1985	4,680	1,598	696	33,819
1986	10,433	6,024	3,324	35,411
1987	38,191	16,633	9,211	78,650
1988	45,929	26,927	13,098	50,650
1989	30,062	3,988	2,813	19,804
1990	43,296	11,862	6,702	22,803
1991	68,149	20,554	11,944	14,854
1992	56,756	9,139	5,959	50,629
1993	20,431	7,546	4,928	42,656
1994	20,406	5,919	3,507	13,865
1995	18,960	11,245	5,986	37,010
1996	46,989	32,279	15,223	13,827
1997	36,539	9,000	4,326	6,261
1998	18,848	8,741	4,966	13,140
1999	40,391	5,697	3,333	43,525
2000	15,045	10,155	4,623	60,597
2001	8,113	5,721	3,302	11,861
2002	11,829	7,198	4,847	76,212
2003	34,407	9,087	5,226	13,693
2004	69,236	2,718	1,568	8,898
2005	13,930	4,220	2,760	NA
2006	69,185	11,117	8,038	NA
2007	19,719	11,212	6,783	NA
2008	10,262	2,270	210	NA

15 **Scotch Creek** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	675,243	144,199	72,732	693,222
Avg	84,587	19,829	9,173	81,275
Min	3,141	107	62	1,532

Year	Run	Spawners	Effective Females	Recruits
1980	NA	107	62	1,532
1981	NA	18,952	6,887	25,367
1982	NA	4,709	2,544	109,597
1983	NA	239	133	2,632
1984	NA	409	265	2,625
1985	25,488	3,385	1,422	44,012
1986	103,900	26,624	11,299	257,059
1987	7,899	2,089	1,149	30,444
1988	4,334	1,060	723	3,320
1989	42,541	7,236	3,928	16,728
1990	250,960	83,388	34,459	316,280
1991	26,781	9,954	4,540	25,716
1992	13,660	2,156	1,385	2,454
1993	16,415	8,359	3,259	11,886
1994	311,164	73,180	26,711	184,451
1995	26,899	14,772	7,811	14,176
1996	5,832	4,609	2,230	4,148
1997	12,372	3,085	1,440	2,253
1998	181,999	35,981	17,024	193,690
1999	14,507	4,093	2,060	26,423
2000	5,333	3,765	1,754	41,212
2001	3,141	2,449	1,336	17,024
2002	191,273	101,269	50,374	693,222
2003	17,993	5,089	2,478	1,681
2004	51,213	783	432	3,933
2005	19,891	4,163	2,686	NA
2006	675,243	144,199	72,732	NA
2007	17,117	8,272	4,758	NA
2008	4,140	654	138	NA

16 **Gates** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	315,105	99,470	17,840	319,543
Avg	54,259	13,496	4,393	55,275
Min	4,217	70	14	412

Year	Run	Spawners	Effective Females	Recruits
1968	NA	10,113	3,835	82,665
1969	NA	777	359	4,766
1970	NA	78	14	412
1971	NA	426	115	12,647
1972	NA	8,323	3,128	132,613
1973	4,217	795	351	14,685
1974	5,248	70	37	2,972
1975	11,901	1,982	1,246	19,756
1976	129,455	17,133	8,820	73,230
1977	11,328	2,582	1,174	21,324
1978	9,148	258	129	1,647
1979	18,924	3,828	1,648	18,266
1980	68,525	25,088	11,032	79,631
1981	20,047	4,670	1,908	18,129
1982	6,288	930	439	9,701
1983	17,608	7,384	3,055	28,098
1984	77,380	28,899	9,072	137,919
1985	19,424	4,578	2,031	131,962
1986	10,321	3,572	1,879	27,349
1987	28,806	9,417	4,105	27,833
1988	121,761	44,913	17,840	319,543
1989	142,321	16,963	9,794	53,094
1990	32,839	5,374	3,304	15,949
1991	32,755	9,040	4,618	21,685
1992	315,105	41,747	9,224	195,433
1993	43,840	17,952	9,089	67,524
1994	23,281	3,360	1,706	34,364
1995	32,130	7,181	4,533	23,459
1996	177,767	99,470	14,150	198,058
1997	63,368	6,498	1,877	13,409
1998	35,566	7,248	2,442	4,812
1999	33,872	4,135	1,765	42,642
2000	190,293	88,647	16,571	92,002
2001	20,535	12,921	4,008	50,246
2002	7,523	2,173	1,144	13,001
2003	38,916	9,811	5,036	4,761
2004	89,834	9,606	5,484	49,579
2005	48,716	15,150	8,850	NA
2006	17,999	2,858	1,456	NA
2007	4,915	2,555	1,079	NA
2008	41,380	14,838	1,754	NA

17 **Nadina** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	451,557	194,381	65,444	546,597
Avg	81,361	21,858	9,044	81,525
Min	3,824	1,625	846	3,186

Year	Run	Spawners	Effective Females	Recruits
1973	NA	16,720	9,638	73,354
1974	NA	3,730	2,074	20,212
1975	NA	15,309	8,359	158,876
1976	NA	1,625	846	7,274
1977	NA	16,858	9,260	132,049
1978	26,098	2,584	1,527	31,247
1979	152,834	55,681	20,415	101,373
1980	13,148	3,017	1,518	21,372
1981	125,386	18,912	10,924	76,800
1982	34,976	2,349	1,423	6,775
1983	86,683	26,876	15,419	149,731
1984	33,498	7,070	3,501	24,917
1985	78,545	13,807	7,722	46,853
1986	8,977	3,545	2,048	20,838
1987	139,891	37,624	15,150	191,036
1988	31,813	8,744	4,304	57,739
1989	45,734	4,940	2,653	20,016
1990	21,538	6,033	3,404	15,734
1991	175,659	61,074	33,360	56,339
1992	68,657	7,728	2,355	104,713
1993	24,667	9,595	4,797	56,702
1994	19,657	2,008	1,076	18,358
1995	47,970	23,998	8,403	65,517
1996	63,955	38,654	18,093	546,597
1997	101,188	9,499	2,681	3,186
1998	15,180	3,705	1,983	4,879
1999	73,967	10,338	5,026	11,388
2000	451,557	194,381	65,444	259,537
2001	97,489	54,824	17,875	96,125
2002	4,655	1,925	1,031	6,180
2003	12,345	3,163	1,678	3,705
2004	233,547	22,603	13,773	219,368
2005	74,010	21,834	12,140	NA
2006	53,863	8,655	4,487	NA
2007	3,824	1,741	1,006	NA
2008	200,870	65,754	10,174	NA

18 **Upper Pitt River** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	203,986	131,481	72,407	217,474
Avg	73,150	28,249	13,772	72,902
Min	8,622	3,560	2,088	9,117

Year	Run	Spawners	Effective Females	Recruits
1948	NA	55,380	20,340	122,720
1949	NA	9,290	4,449	20,778
1950	NA	40,061	13,312	146,337
1951	NA	37,837	17,922	120,302
1952	NA	48,899	21,904	71,842
1953	102,064	18,673	9,303	25,807
1954	105,924	17,624	8,332	51,094
1955	96,805	17,950	11,221	164,991
1956	118,493	32,094	11,107	68,770
1957	44,620	12,335	5,130	29,207
1958	51,050	10,381	6,658	16,147
1959	91,535	15,731	6,096	61,976
1960	114,761	24,510	12,493	33,277
1961	44,072	11,158	6,525	102,366
1962	38,721	16,580	8,460	57,275
1963	24,957	12,680	5,749	142,935
1964	46,082	13,756	6,313	191,918
1965	53,763	6,966	3,368	38,984
1966	100,163	20,842	10,723	77,701
1967	121,828	10,282	5,236	67,780
1968	102,267	16,988	8,189	105,539
1969	158,842	25,073	11,710	61,083
1970	48,638	6,642	3,098	55,281
1971	77,235	15,452	6,663	217,474
1972	81,841	13,412	6,569	122,915
1973	76,625	11,895	4,744	29,176
1974	74,089	20,581	8,854	135,238
1975	124,762	39,920	21,369	85,230
1976	203,986	36,525	19,467	105,338
1977	56,665	13,852	7,791	34,586
1978	70,731	24,786	14,109	34,854
1979	145,893	37,542	20,307	38,236
1980	34,838	17,101	9,169	16,913
1981	106,816	25,327	13,224	34,272
1982	29,956	8,708	5,086	18,265
1983	27,896	16,852	10,074	62,053
1984	45,180	15,797	8,755	75,696
1985	8,622	3,560	2,088	23,208
1986	36,196	29,177	12,283	40,001
1987	25,747	13,637	5,503	21,968
1988	68,939	37,747	17,876	61,300
1989	63,157	16,037	5,583	16,609
1990	23,421	12,202	5,701	9,117
1991	40,959	22,500	10,867	33,888
1992	17,185	9,129	4,335	100,553
1993	63,675	22,835	9,040	102,923
1994	13,220	9,500	4,365	34,714
1995	9,248	5,500	2,352	52,971
1996	62,069	50,077	19,451	150,961
1997	87,030	35,798	14,996	96,262
1998	91,252	76,888	47,612	133,321
1999	38,855	35,961	19,390	142,614
2000	65,492	42,638	18,584	111,288
2001	141,955	131,481	72,407	54,820
2002	118,367	90,280	39,416	69,160
2003	123,415	78,229	39,927	13,786
2004	159,989	60,942	33,796	41,620
2005	76,754	62,047	33,243	NA
2006	72,421	38,816	21,346	NA
2007	44,547	41,829	19,926	NA
2008	22,809	16,921	6,186	NA

19 **Harrison** ||| = 1/10 of max for each variable

	Run	Spawners	Effective Females	Recruits
Max	421,280	388,605	211,552	386,967
Avg	55,674	22,947	12,077	55,596
Min	2,312	313	172	1,963

Year	Run	Spawners	Effective Females	Recruits
1948	NA	26,162	14,577	43,283
1949	NA	8,000	4,372	37,073
1950	NA	33,044	18,216	78,099
1951	NA	17,145	13,181	122,022
1952	NA	25,794	17,215	23,054
1953	73,919	21,030	7,641	9,784
1954	132,871	28,800	16,869	14,797
1955	36,499	5,595	3,405	141,038
1956	6,865	2,586	1,266	96,858
1957	13,698	3,793	1,820	60,554
1958	68,766	14,701	6,404	59,892
1959	168,094	27,868	17,692	41,545
1960	34,971	17,210	7,076	29,451
1961	90,445	42,773	21,725	13,225
1962	14,932	8,162	4,197	50,812
1963	57,173	22,258	9,803	87,825
1964	4,991	2,202	1,101	51,177
1965	42,684	15,034	7,779	20,432
1966	69,955	32,646	9,295	55,444
1967	81,431	20,548	12,672	50,935
1968	15,484	5,379	2,854	17,838
1969	54,978	14,959	7,559	7,302
1970	34,391	12,666	6,471	39,763
1971	42,468	3,790	1,970	84,459
1972	6,370	1,346	794	1,963
1973	23,962	3,060	1,571	37,681
1974	82,138	16,920	8,709	40,338
1975	24,329	5,987	3,381	128,650
1976	33,066	5,130	2,933	44,728
1977	11,558	2,246	1,374	24,058
1978	57,214	19,717	10,488	41,193
1979	149,185	45,615	20,234	10,895
1980	17,260	5,092	2,262	14,393
1981	14,998	3,193	1,788	17,869
1982	34,647	9,189	4,686	28,956
1983	23,841	4,239	2,132	17,919
1984	13,443	1,267	689	5,265
1985	9,678	5,097	1,825	14,476
1986	32,605	7,265	4,145	9,610
1987	13,622	5,228	2,686	46,184
1988	5,263	1,544	947	4,013
1989	16,393	2,934	1,998	13,564
1990	7,412	4,515	1,888	129,502
1991	44,707	15,000	7,958	38,111
1992	2,312	313	172	3,736
1993	74,831	3,258	2,271	19,096
1994	72,172	9,515	6,087	20,682
1995	34,202	16,618	6,758	49,813
1996	17,864	15,379	8,255	7,560
1997	4,737	1,418	1,084	82,240
1998	21,933	4,496	3,013	64,475
1999	51,334	8,577	5,592	91,504
2000	14,859	4,343	1,745	12,173
2001	90,043	15,309	8,335	386,967
2002	63,163	41,542	24,384	276,837
2003	82,956	8,259	6,043	104,854
2004	57,833	2,106	986	143,000
2005	421,280	388,605	211,552	NA
2006	209,463	168,259	90,943	NA
2007	191,321	128,295	57,444	NA
2008	41,115	6,717	4,411	NA

Appendix 4 : Spawner-recruit summary figures

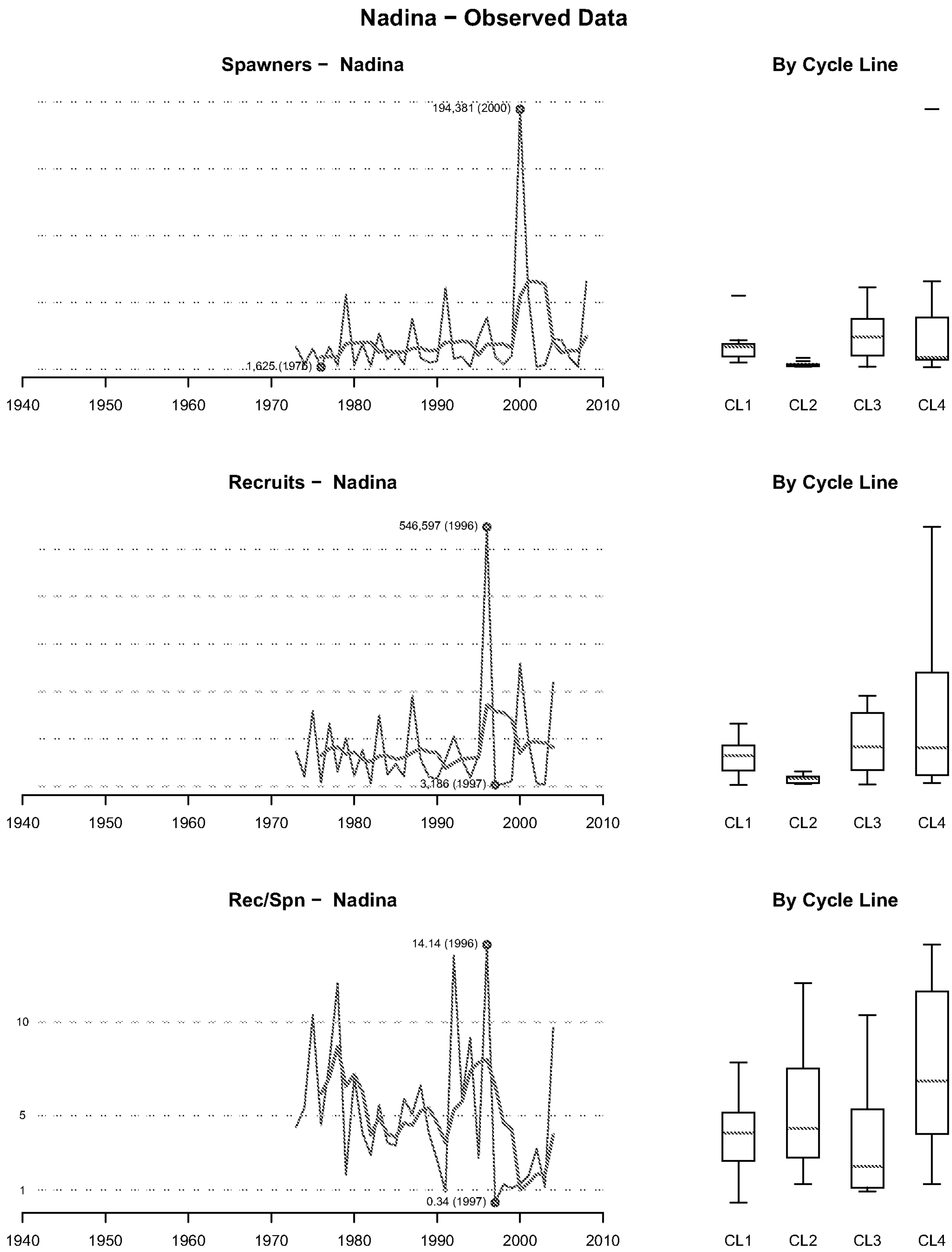


Figure A.1a: Observed Data − Nadina

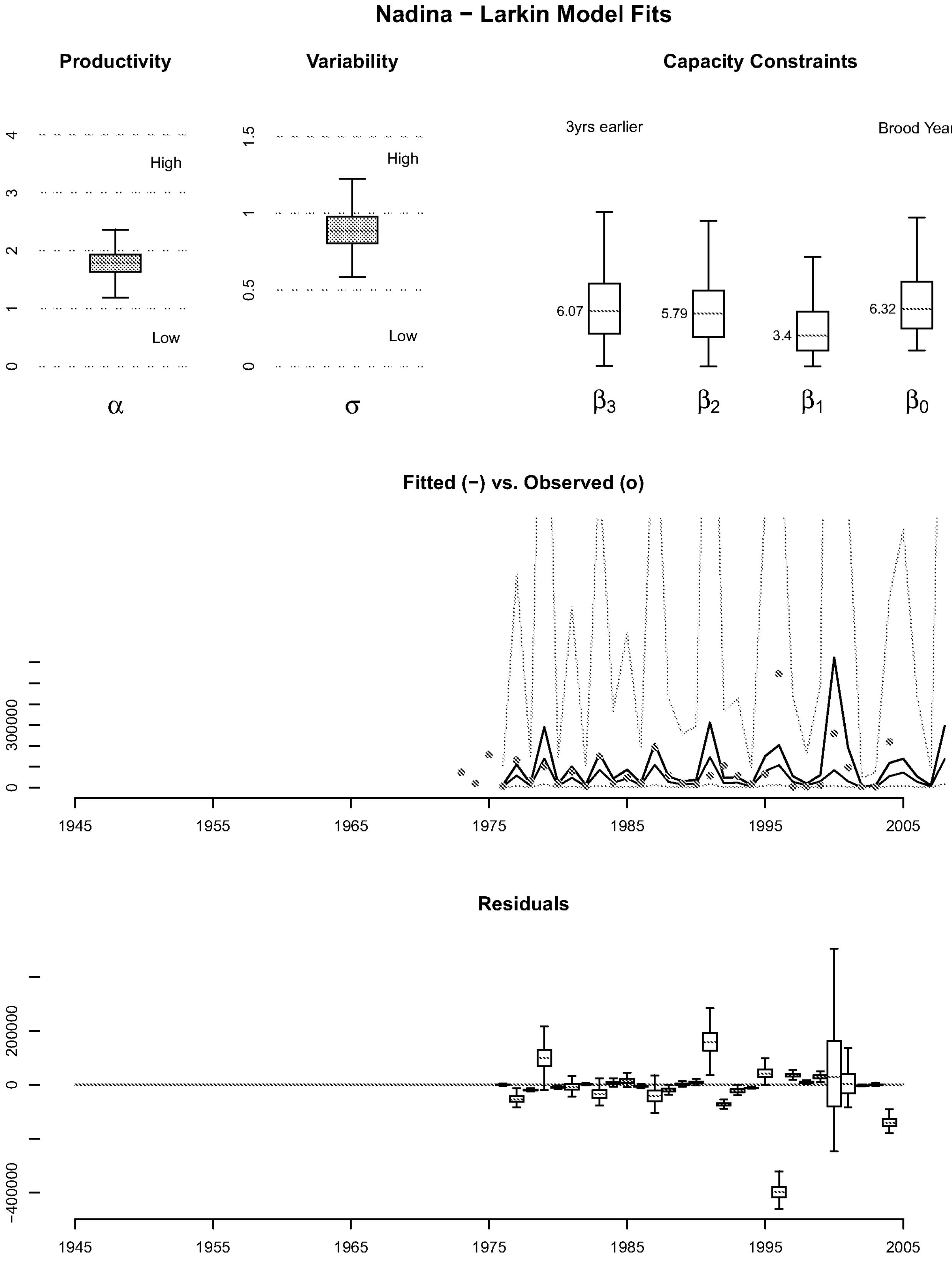


Figure A.1b: Larkin Model Fits − Nadina

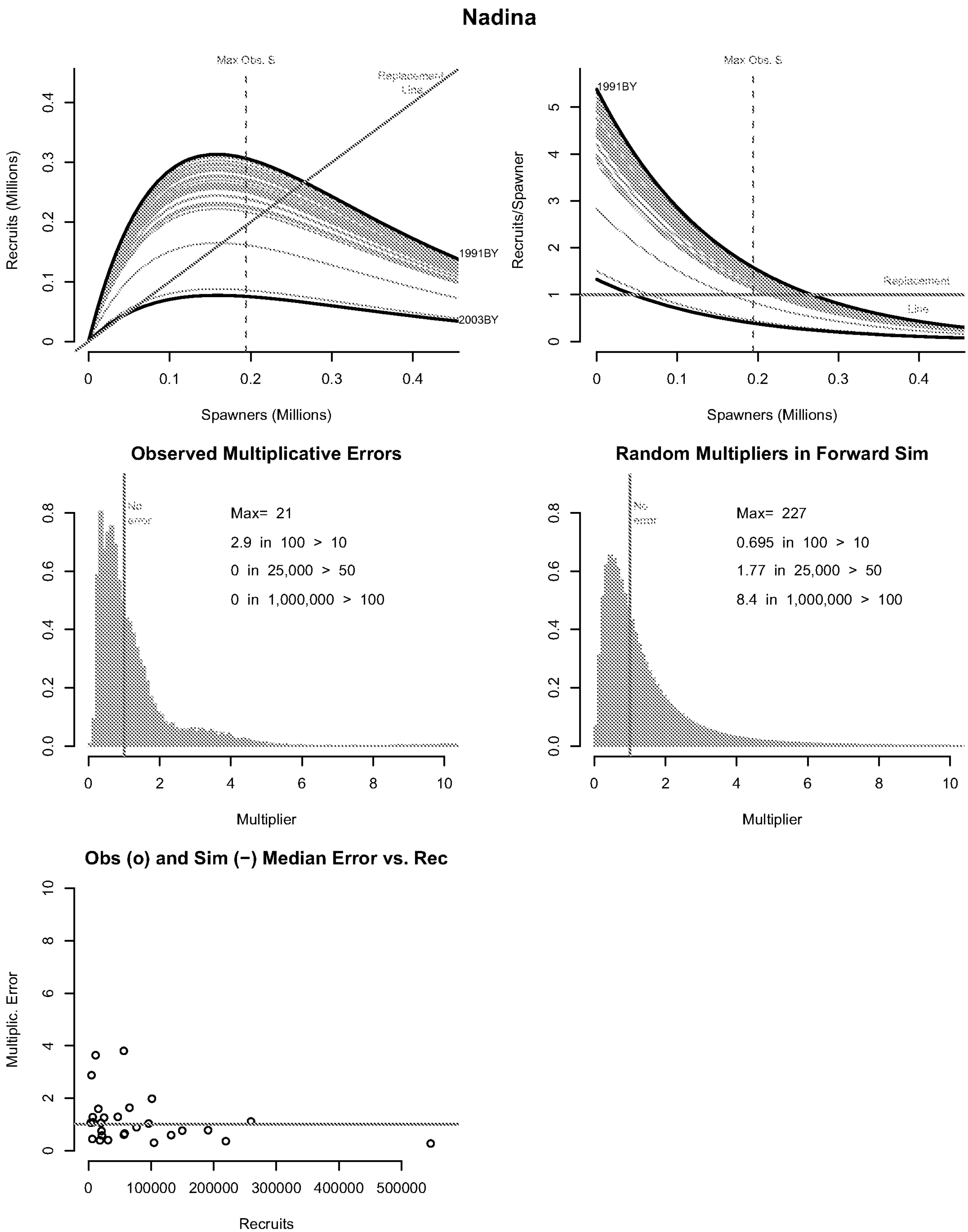


Figure A.1c: Delayed−density effects and error structure − Nadina

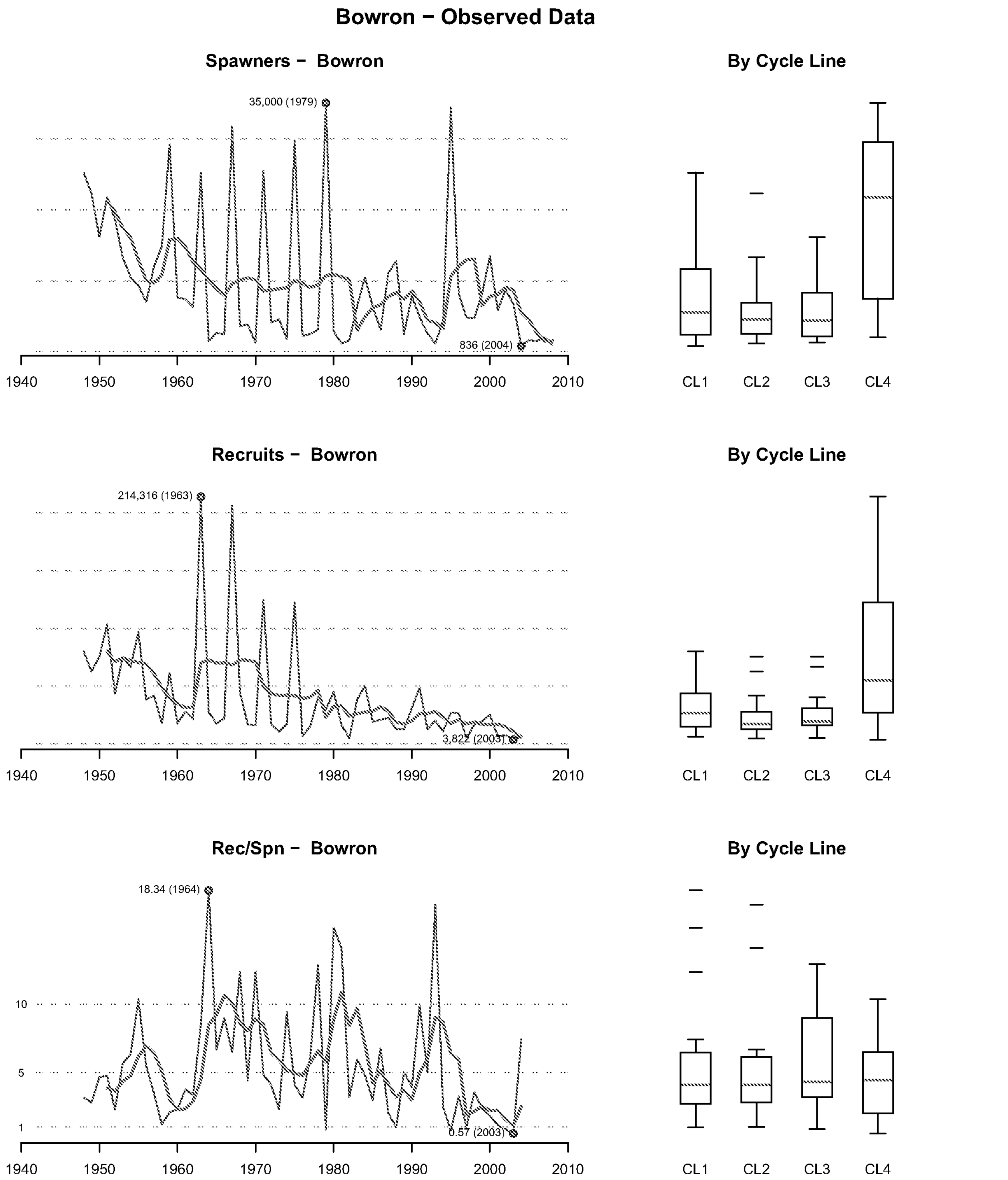


Figure A.2a: Observed Data − Bowron

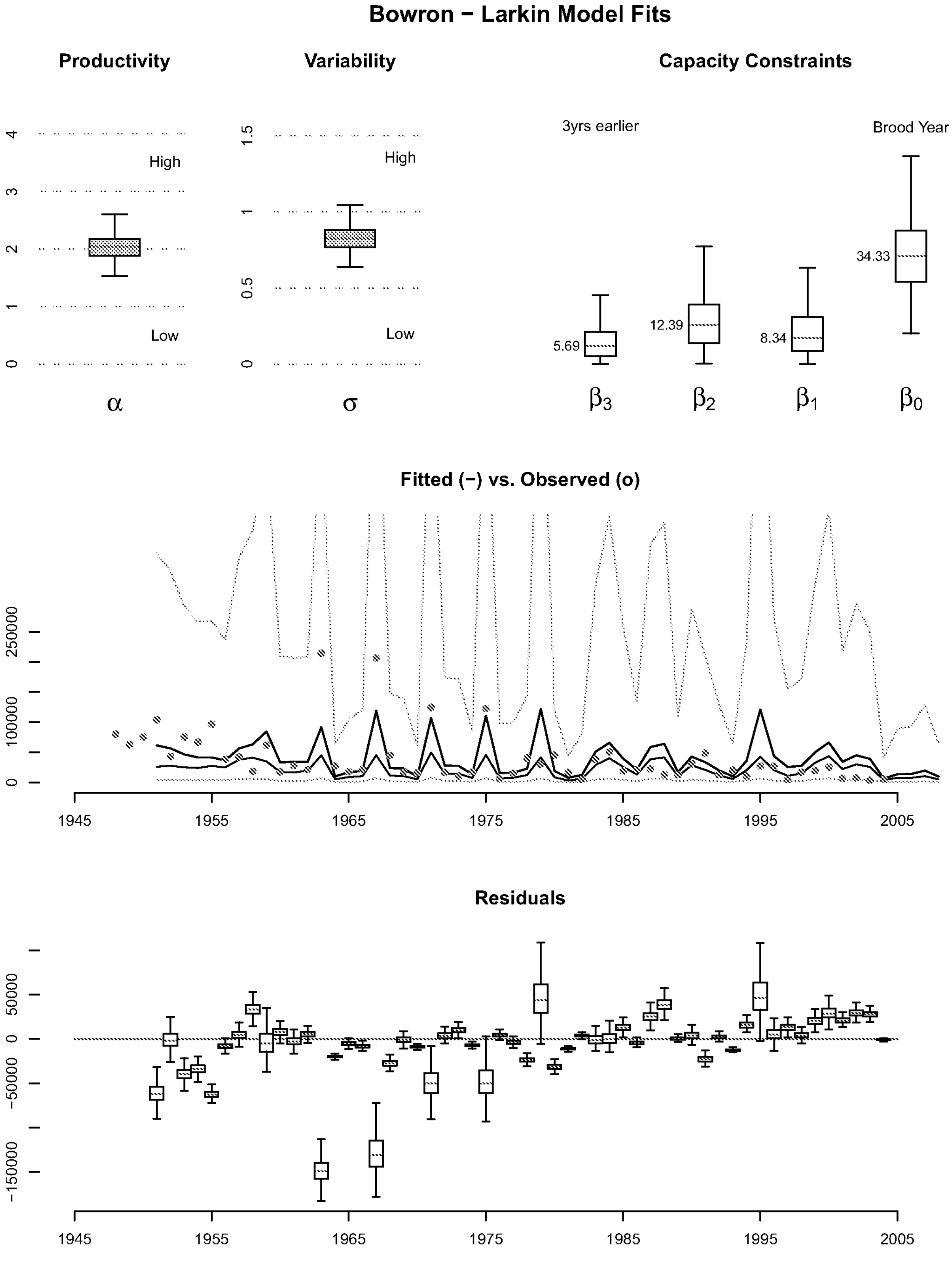


Figure A.2b: Larkin Model Fits − Bowron

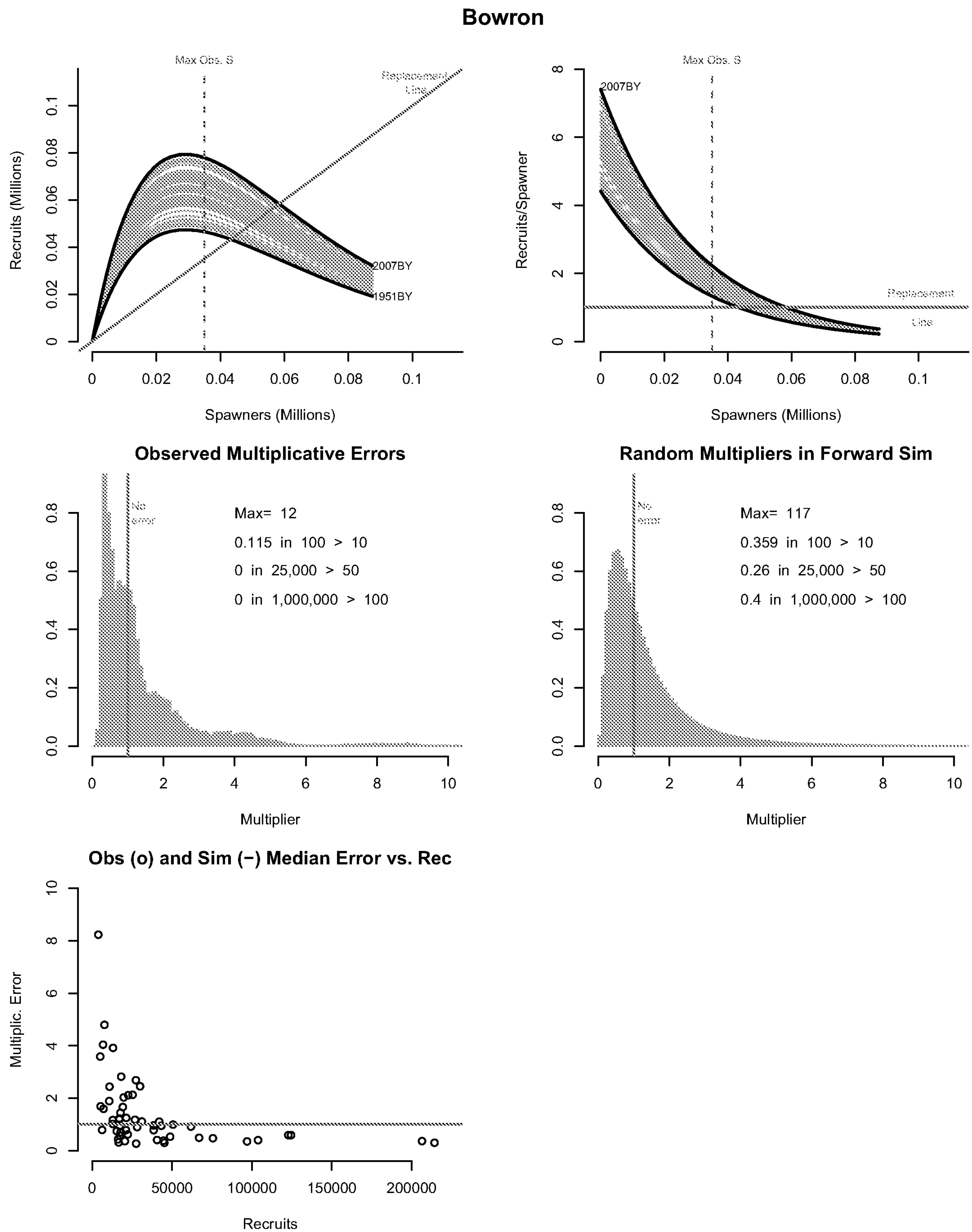


Figure A.2c: Delayed−density effects and error structure − Bowron

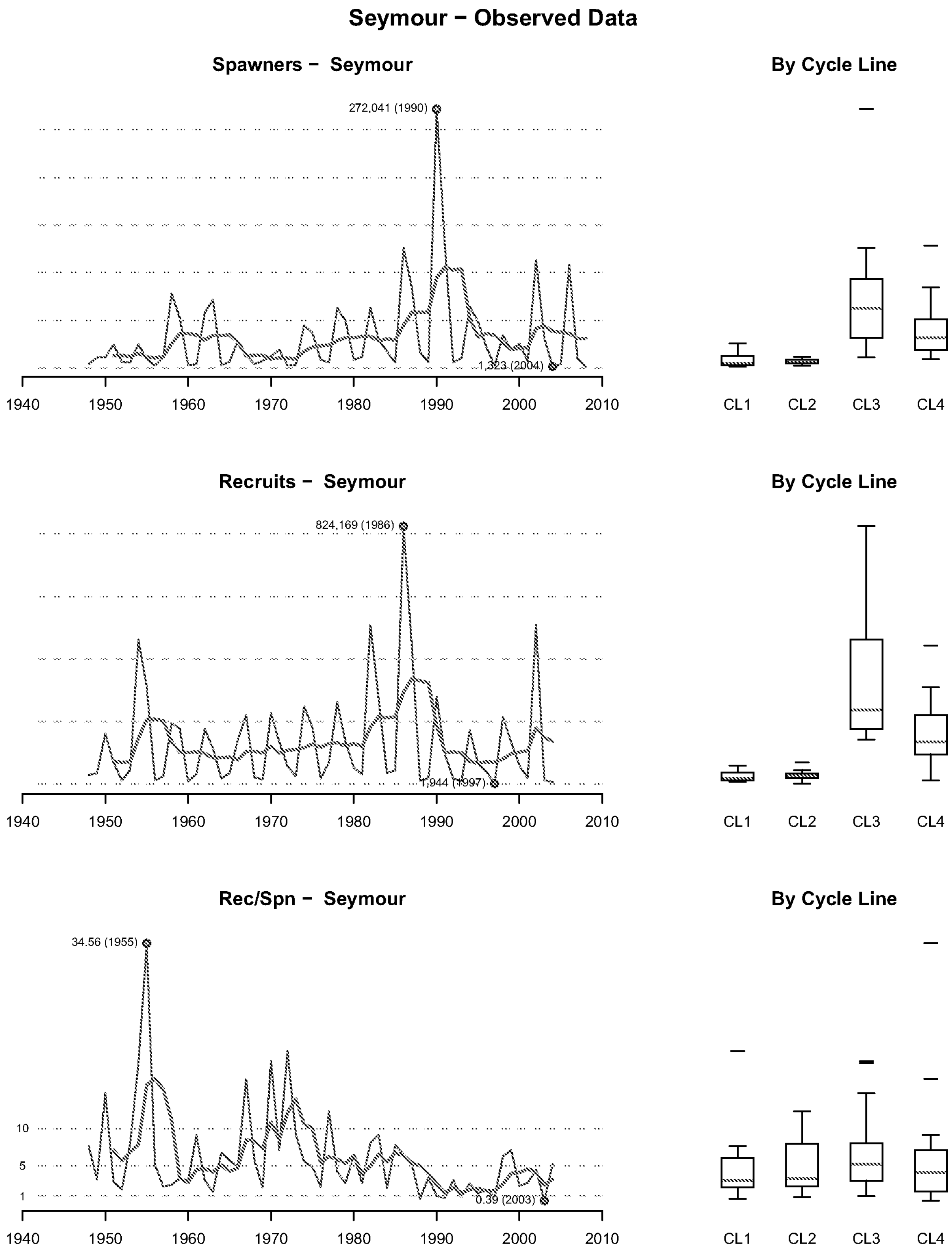


Figure A.3a: Observed Data − Seymour

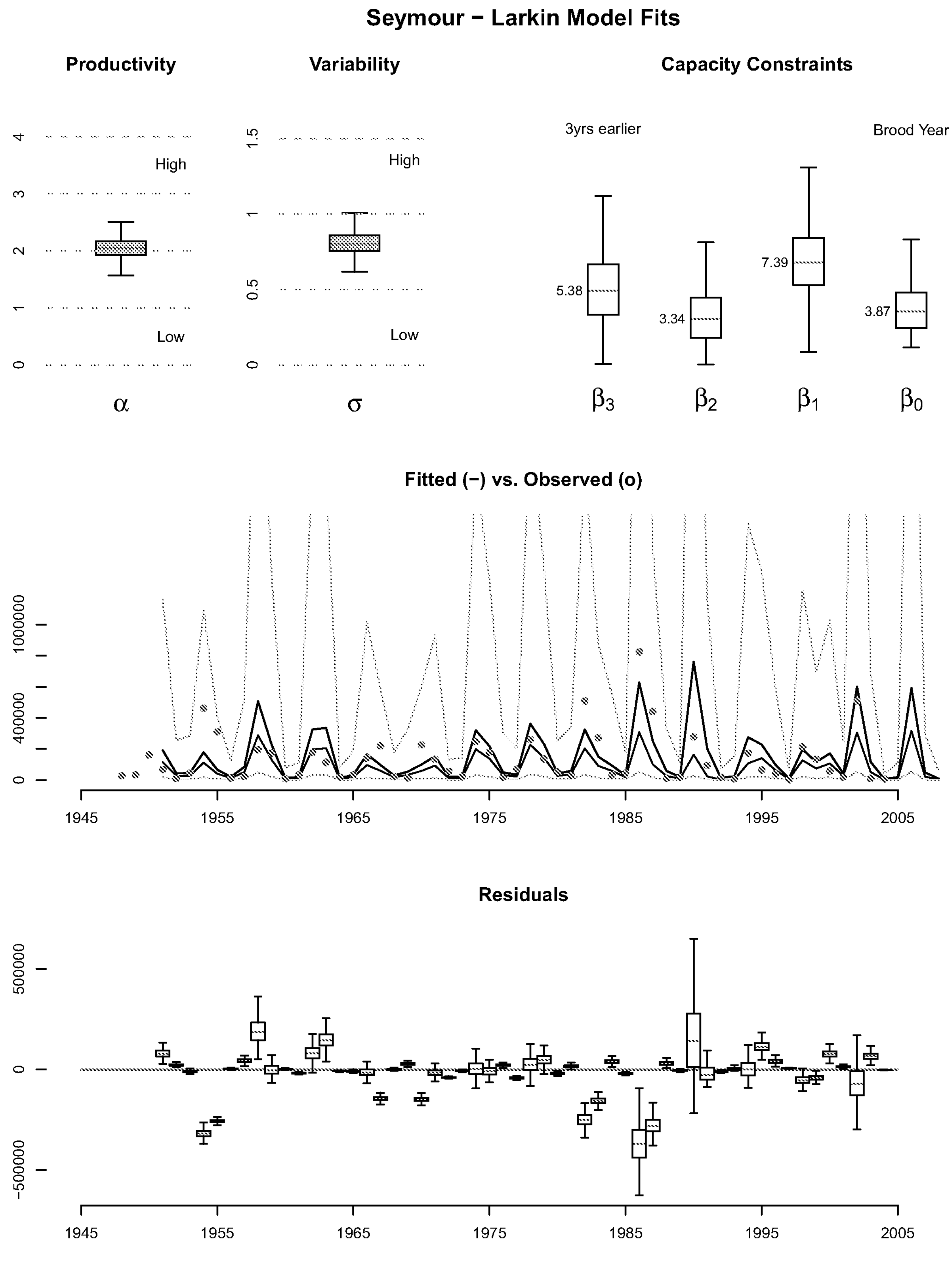


Figure A.3b: Larkin Model Fits − Seymour

Seymour

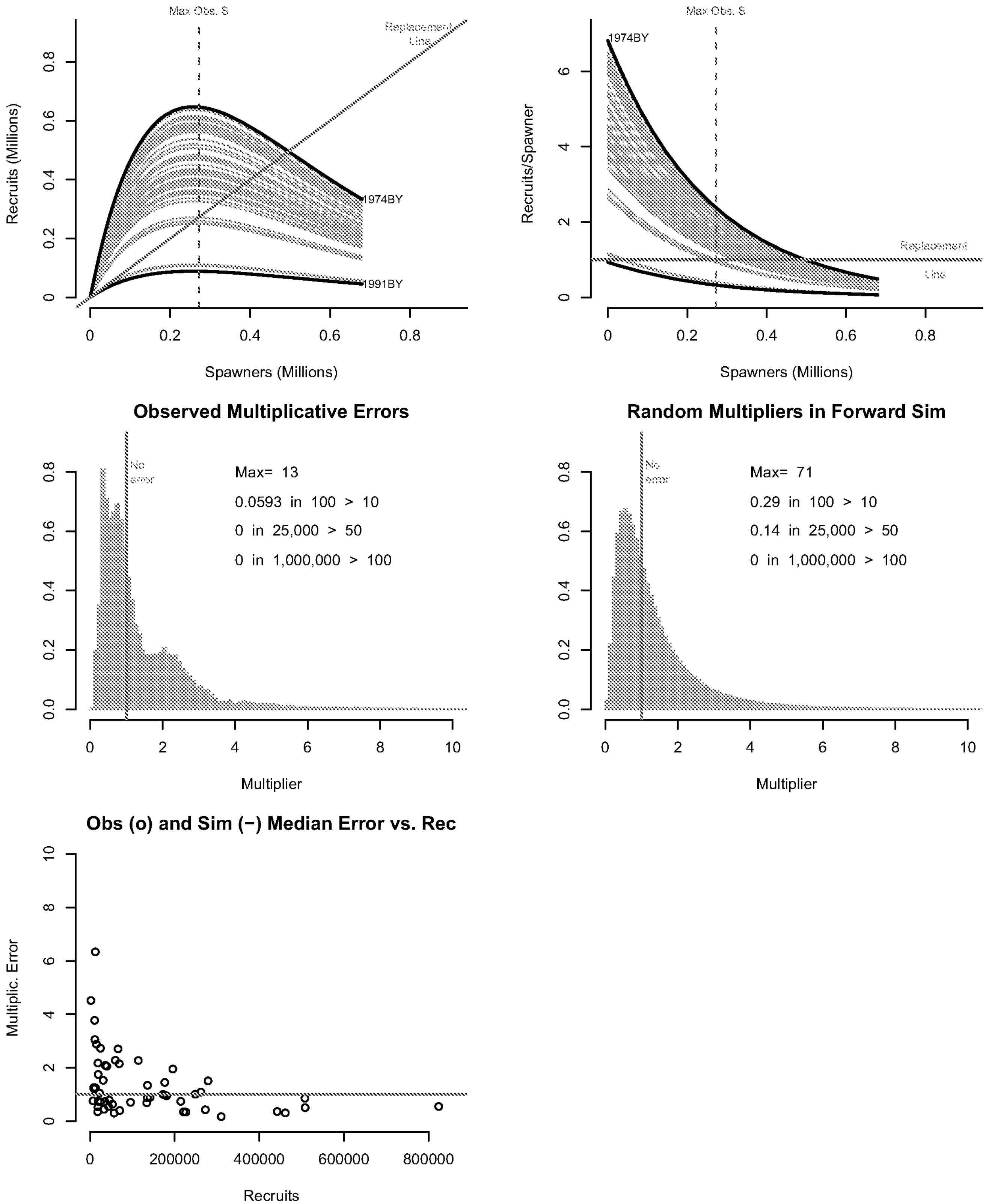


Figure A.3c: Delayed−density effects and error structure − Seymour

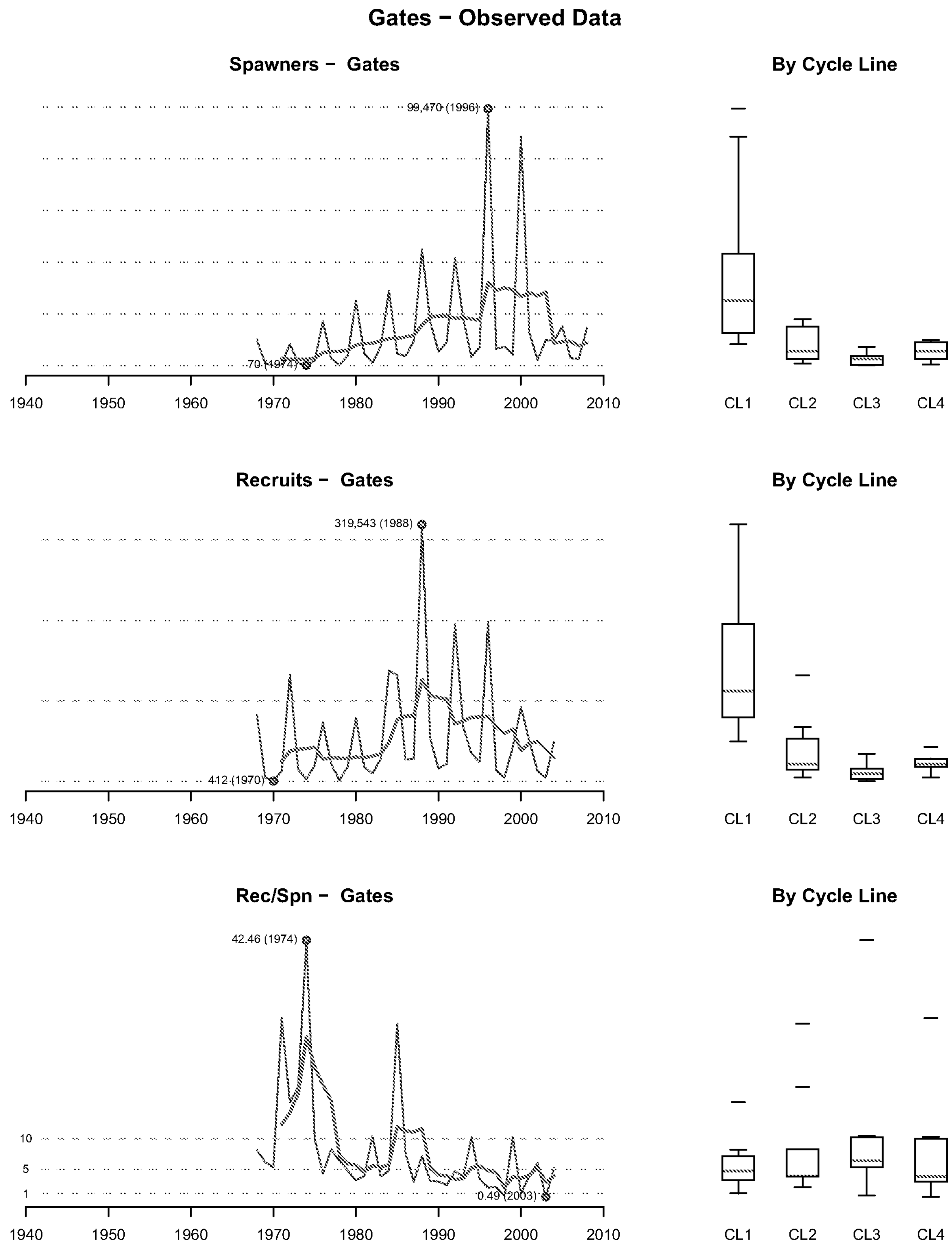


Figure A.4a: Observed Data − Gates

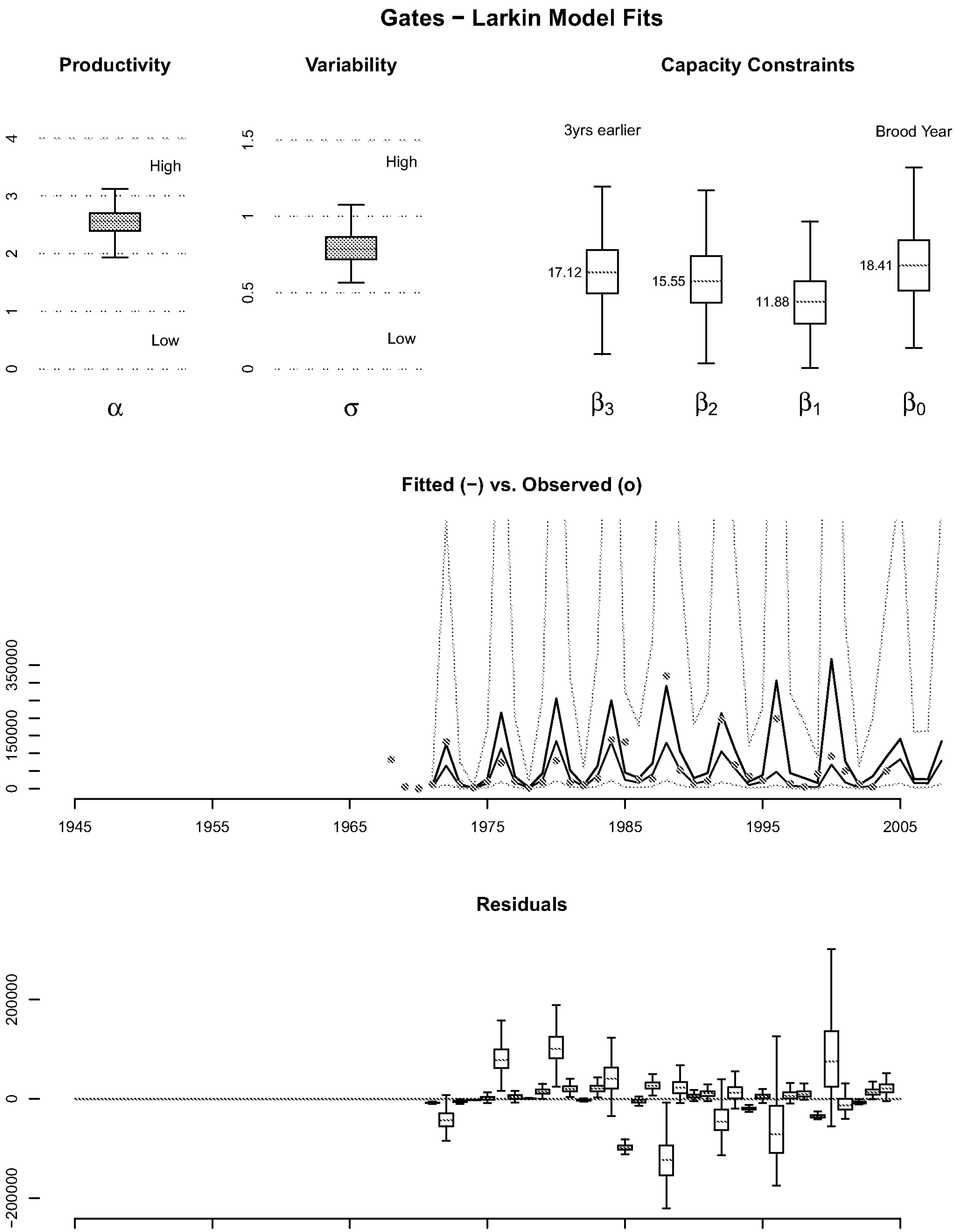


Figure A.4b: Larkin Model Fits − Gates

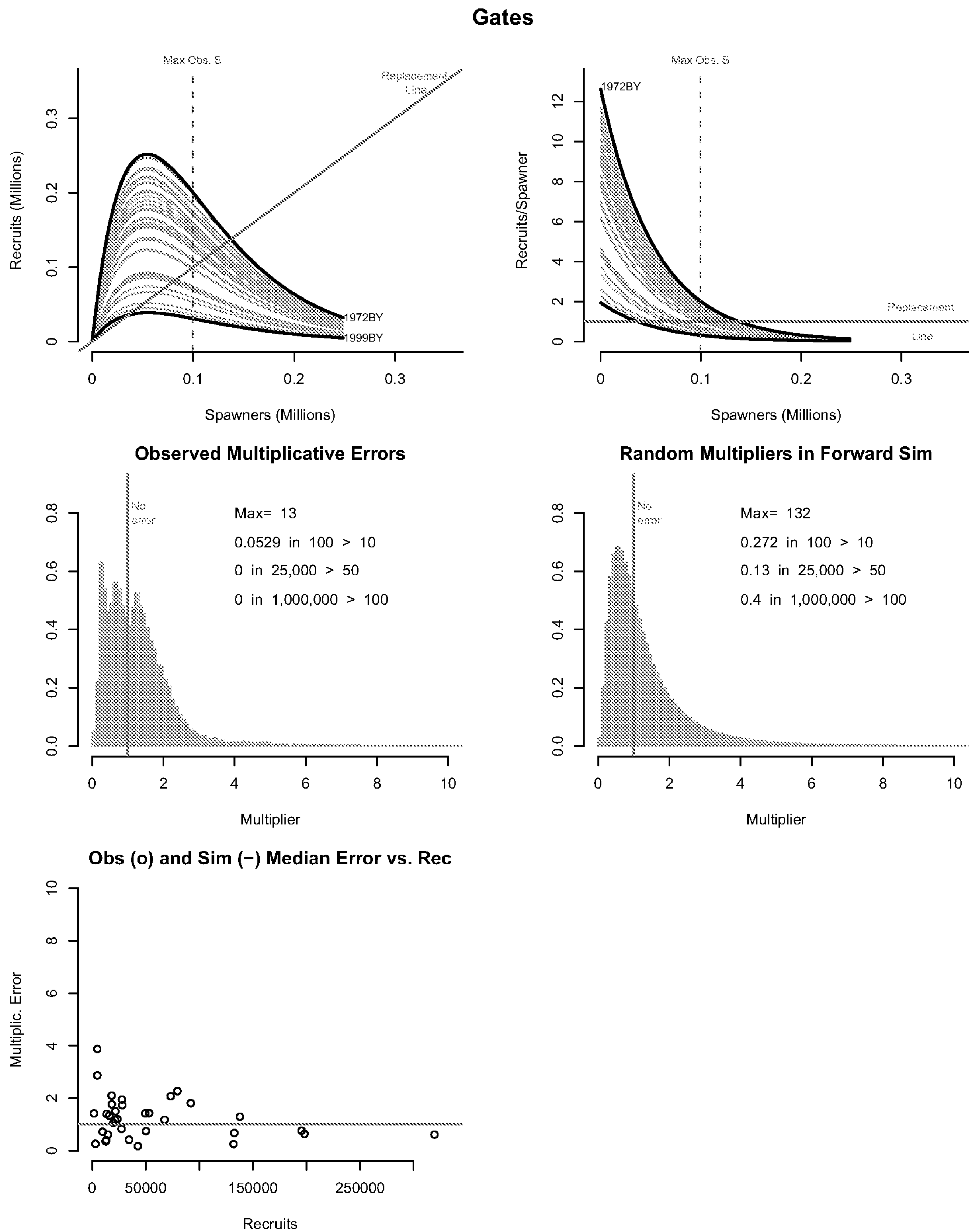


Figure A.4c: Delayed−density effects and error structure − Gates

Upper Pitt River − Observed Data

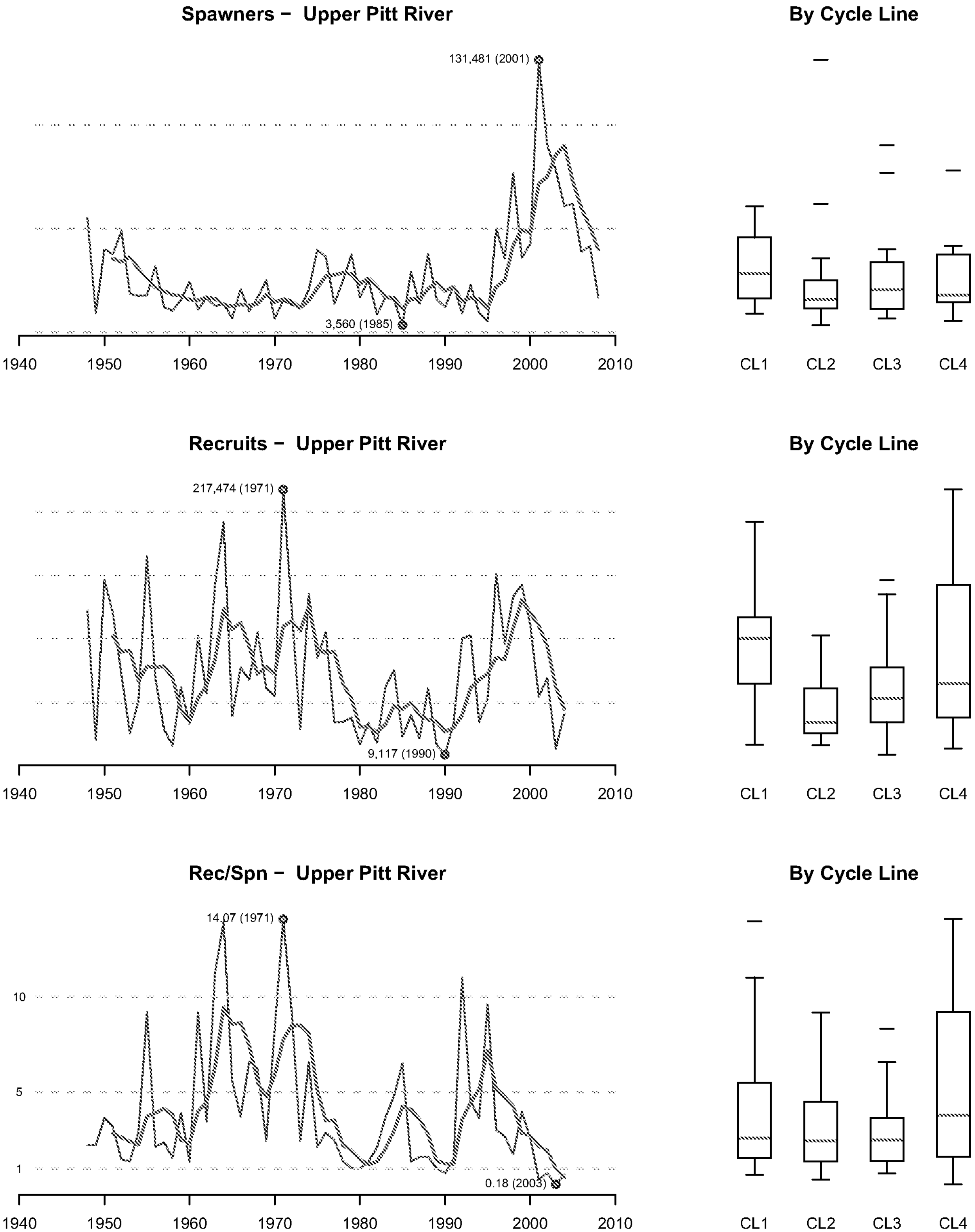


Figure A.5a: Observed Data − Upper Pitt River

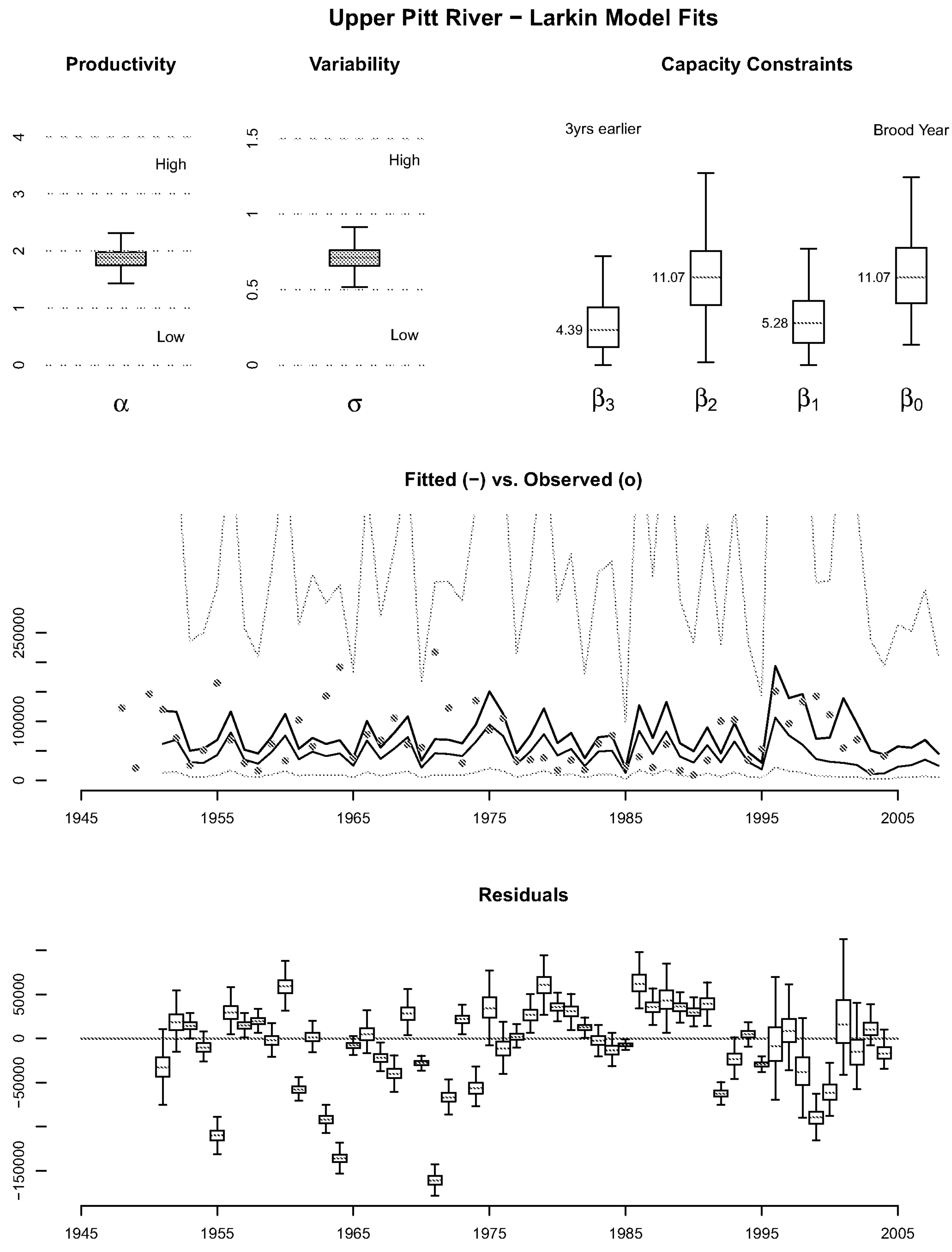


Figure A.5b: Larkin Model Fits − Upper Pitt River

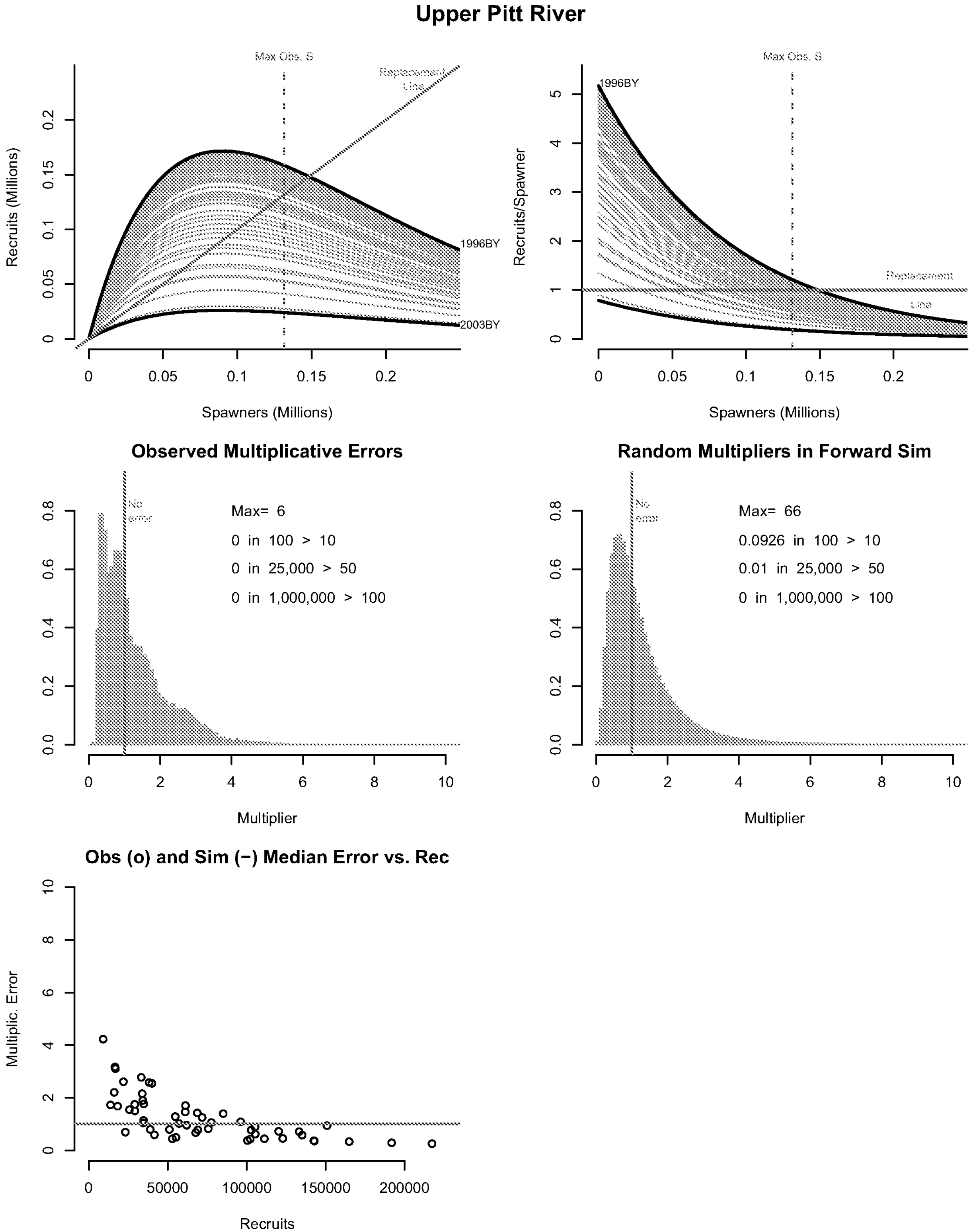


Figure A.5c: Delayed−density effects and error structure − Upper Pitt River

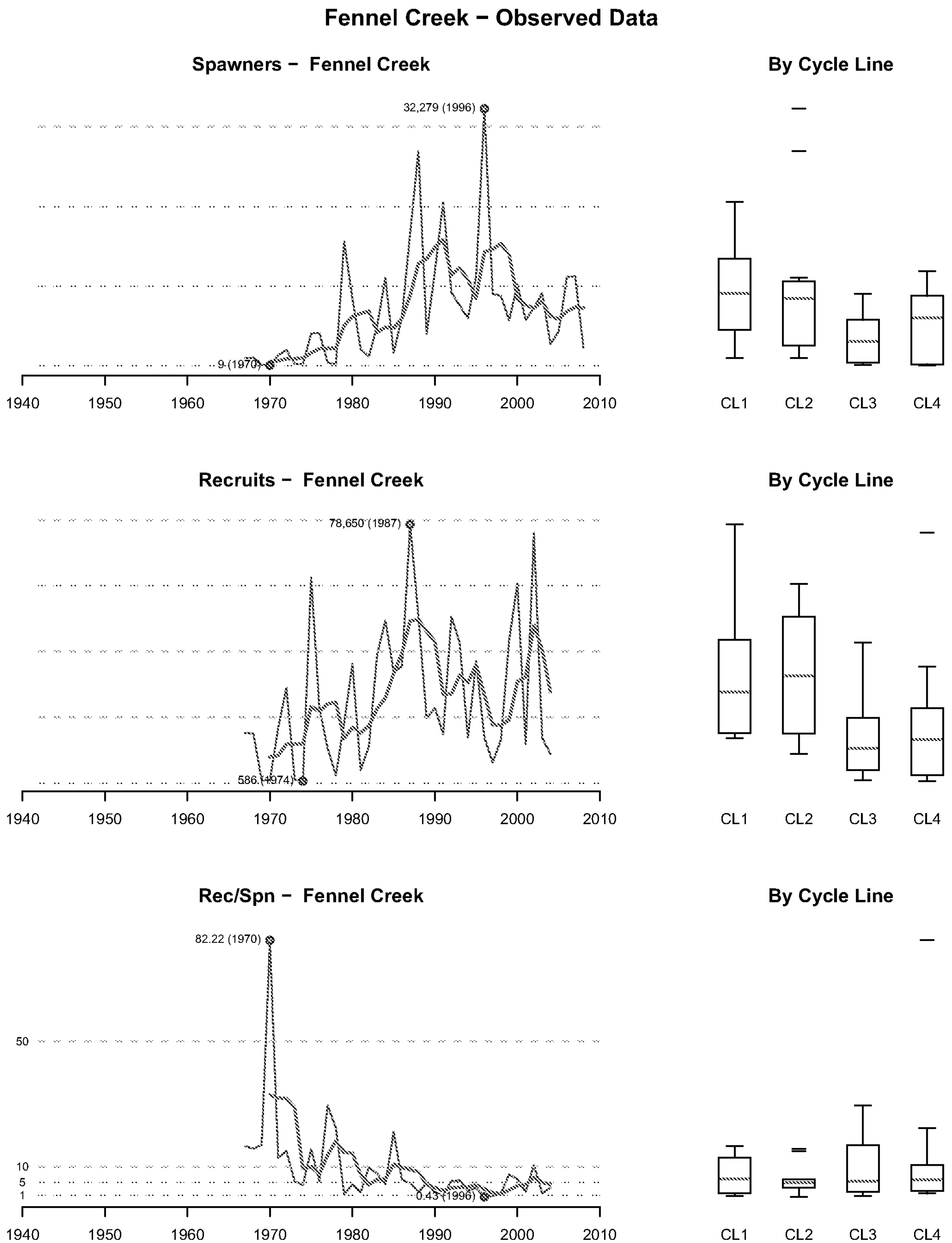


Figure A.6a: Observed Data − Fennel Creek

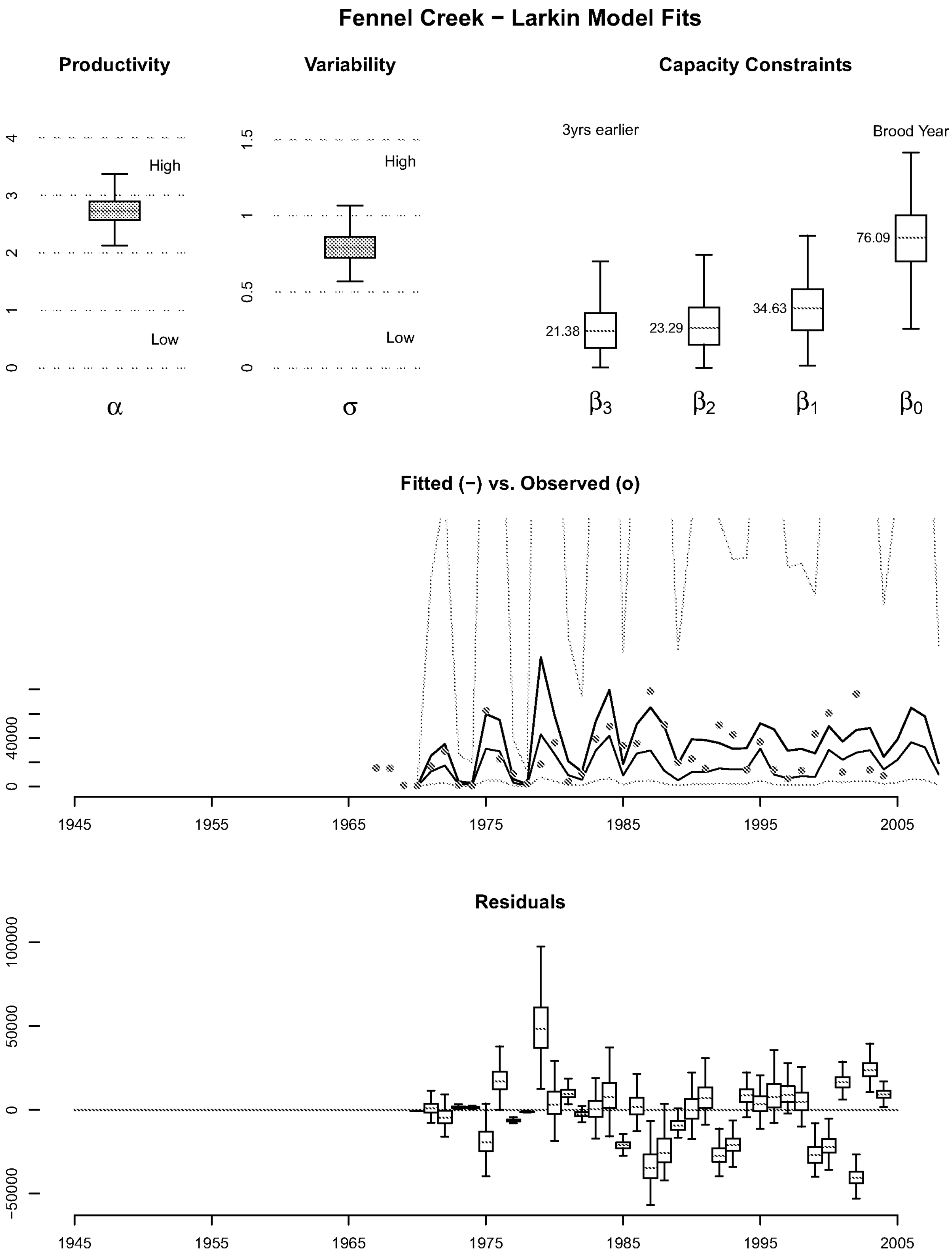


Figure A.6b: Larkin Model Fits − Fennel Creek

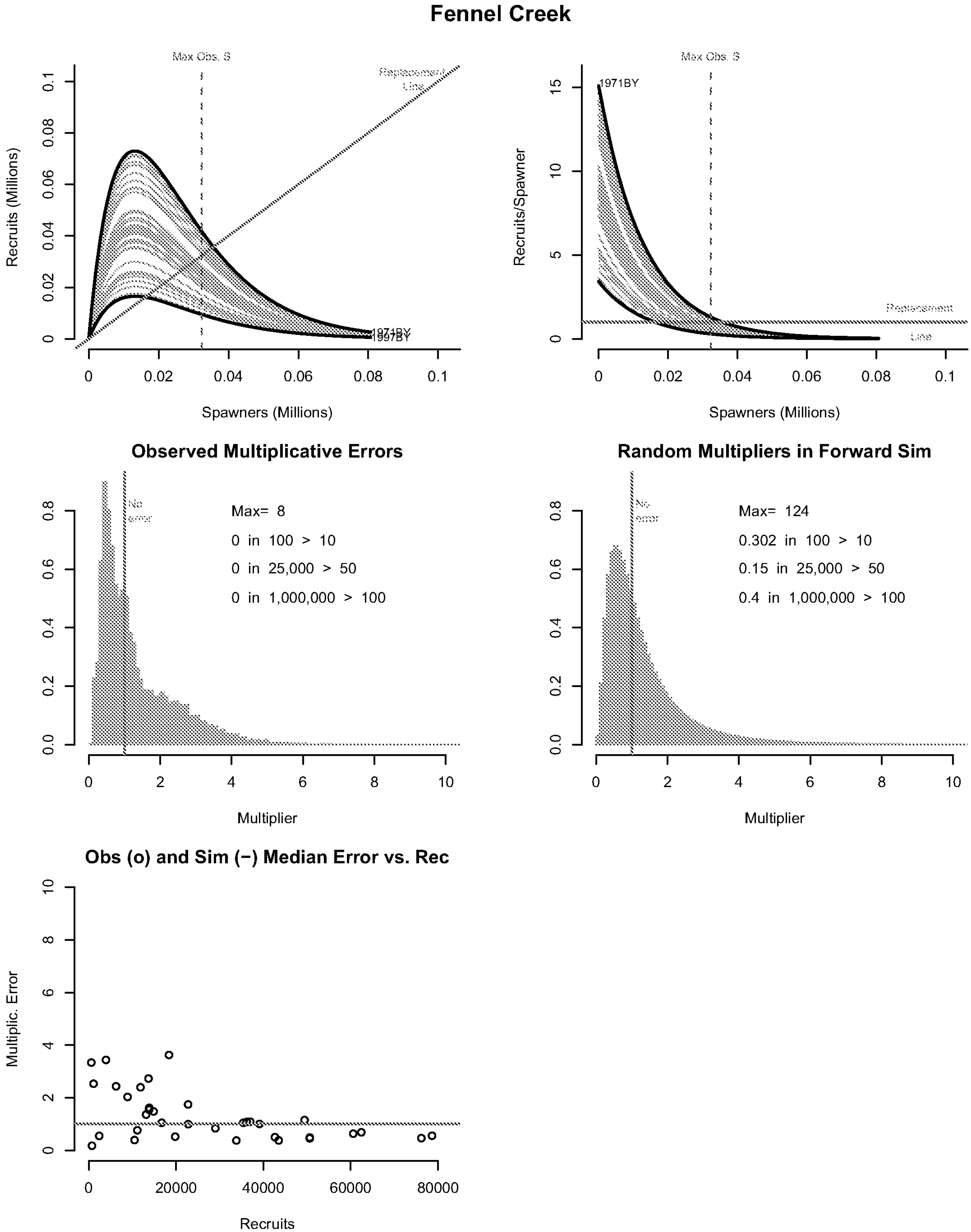


Figure A.6c: Delayed−density effects and error structure − Fennel Creek

Scotch Creek − Observed Data

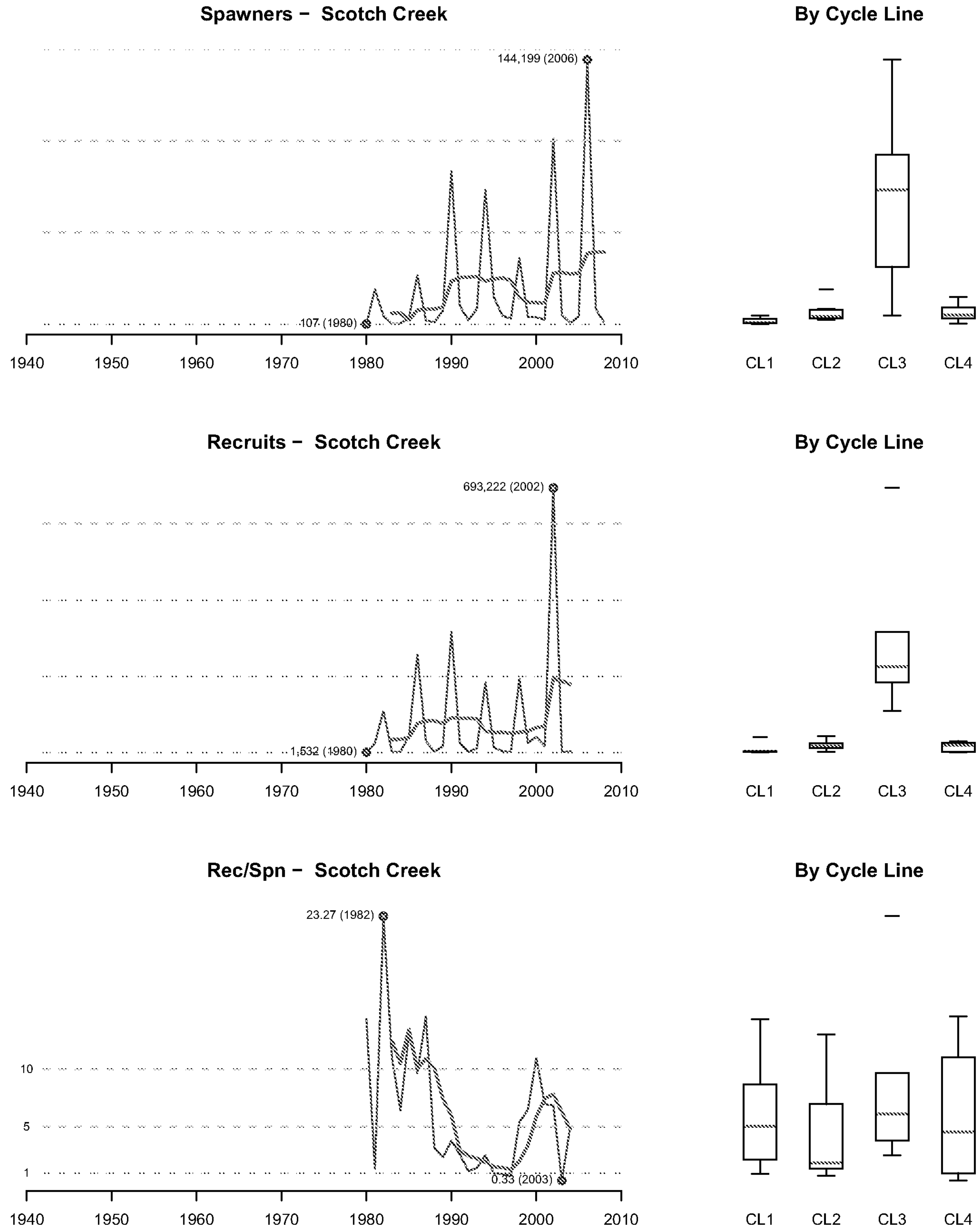


Figure A.7a: Observed Data − Scotch Creek

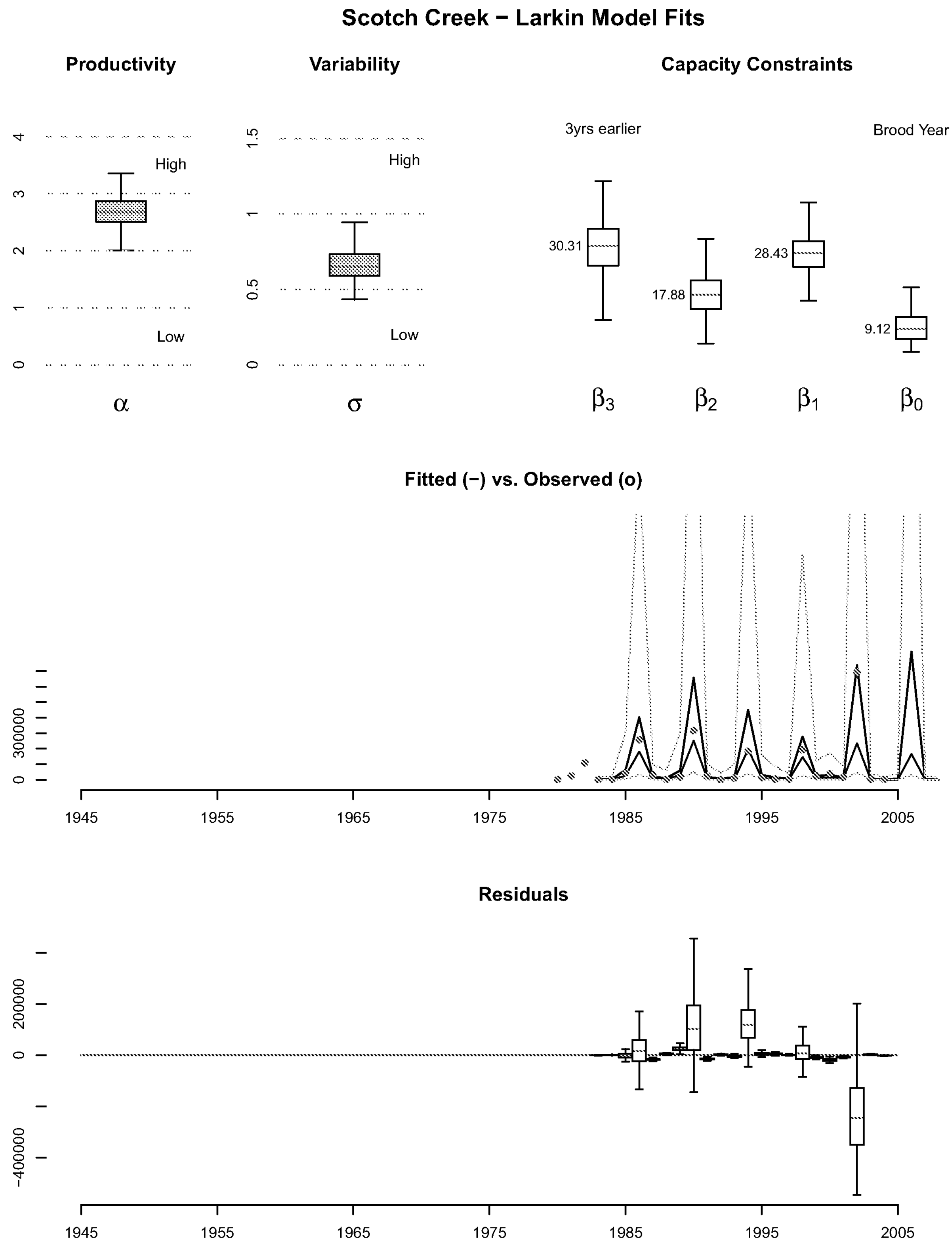


Figure A.7b: Larkin Model Fits − Scotch Creek

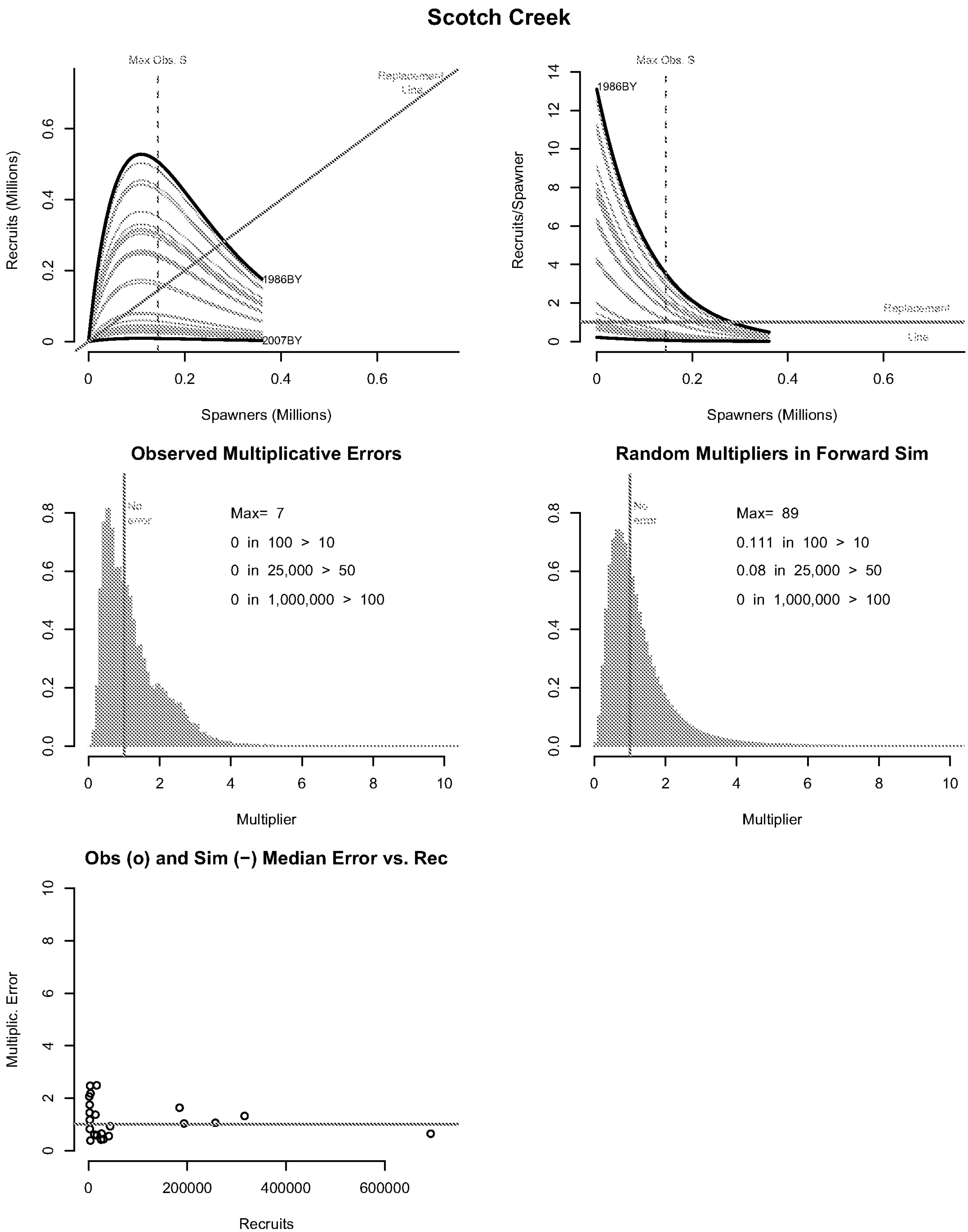


Figure A.7c: Delayed−density effects and error structure − Scotch Creek

Raft − Observed Data

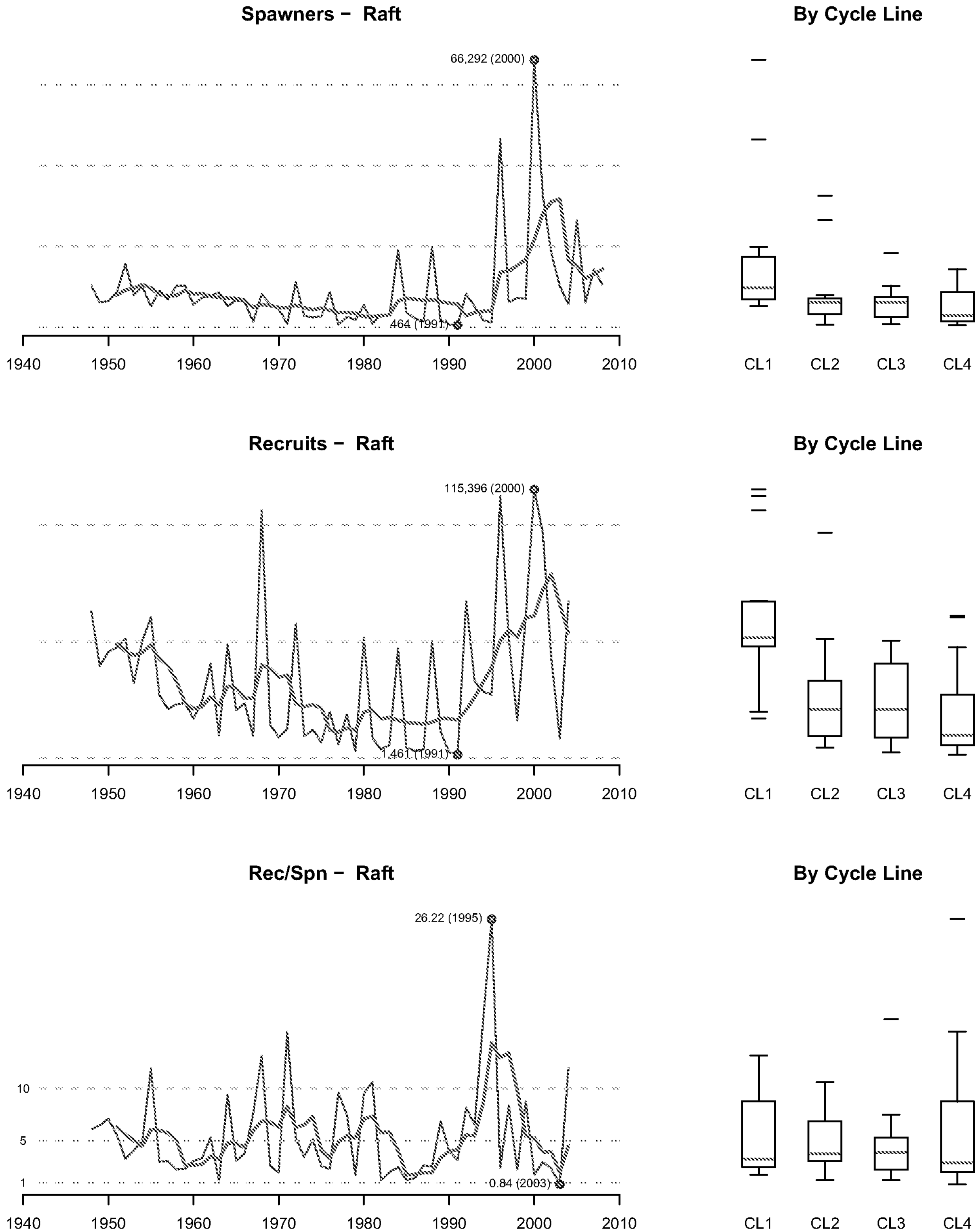


Figure A.8a: Observed Data − Raft

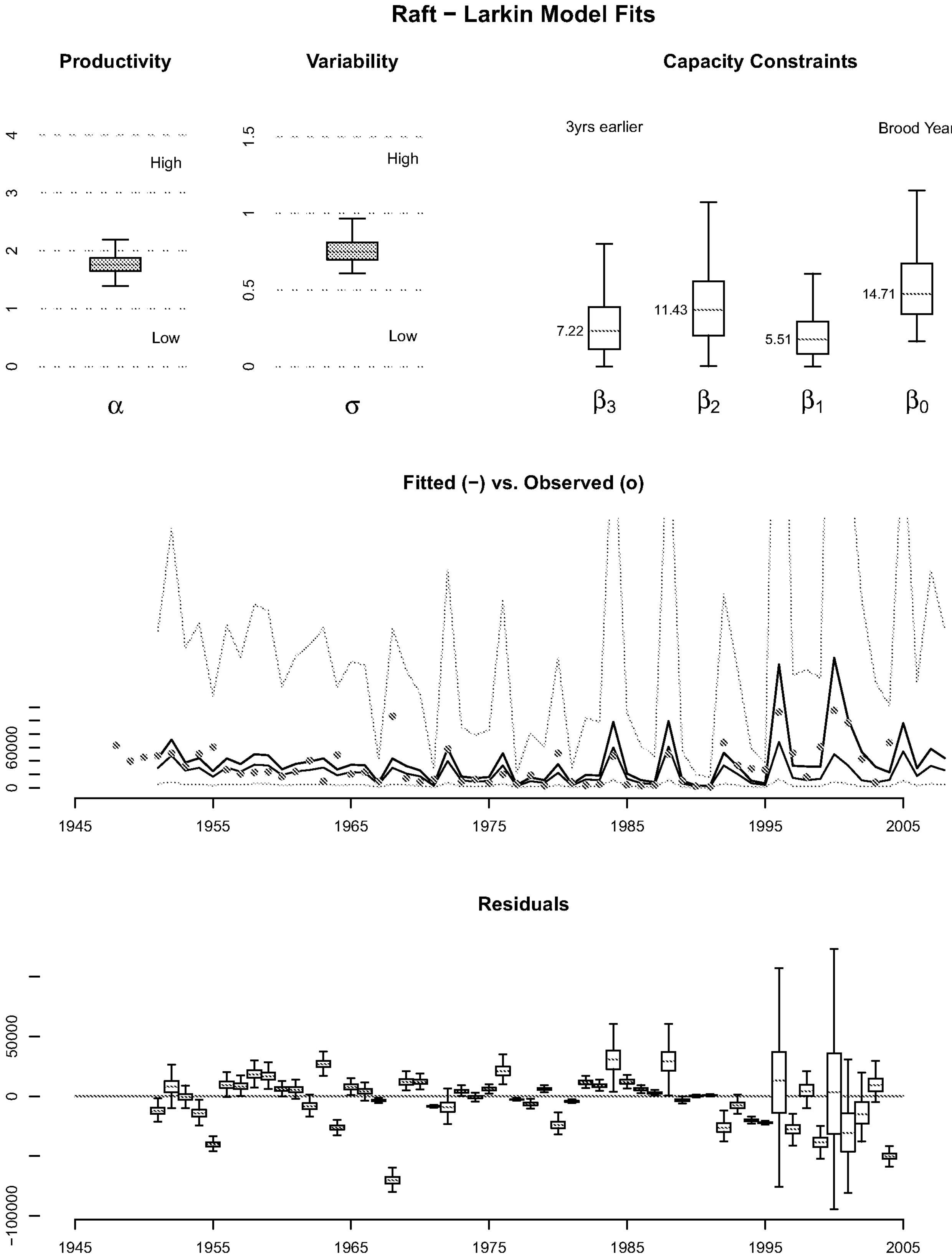


Figure A.8b: Larkin Model Fits − Raft

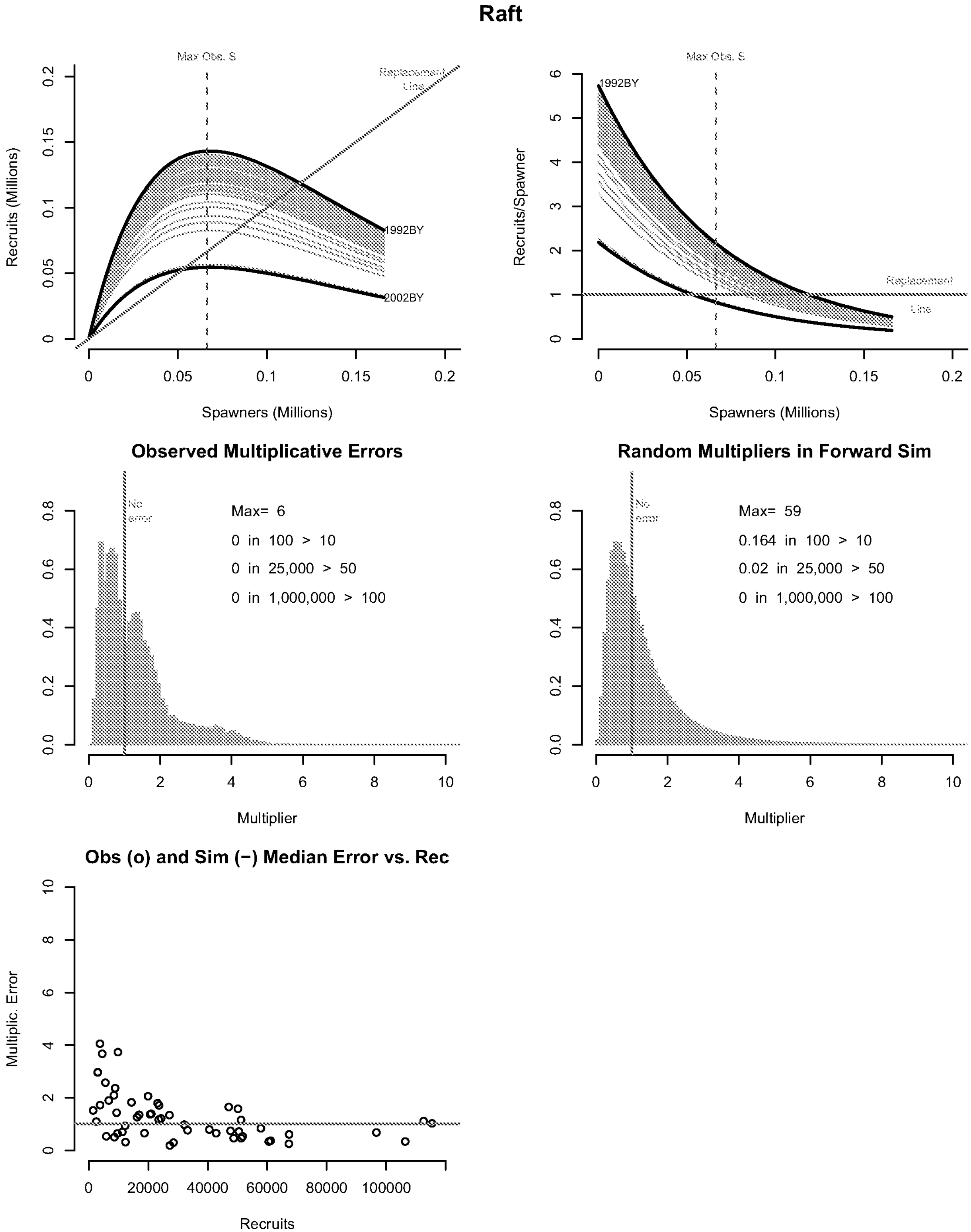


Figure A.8c: Delayed−density effects and error structure − Raft

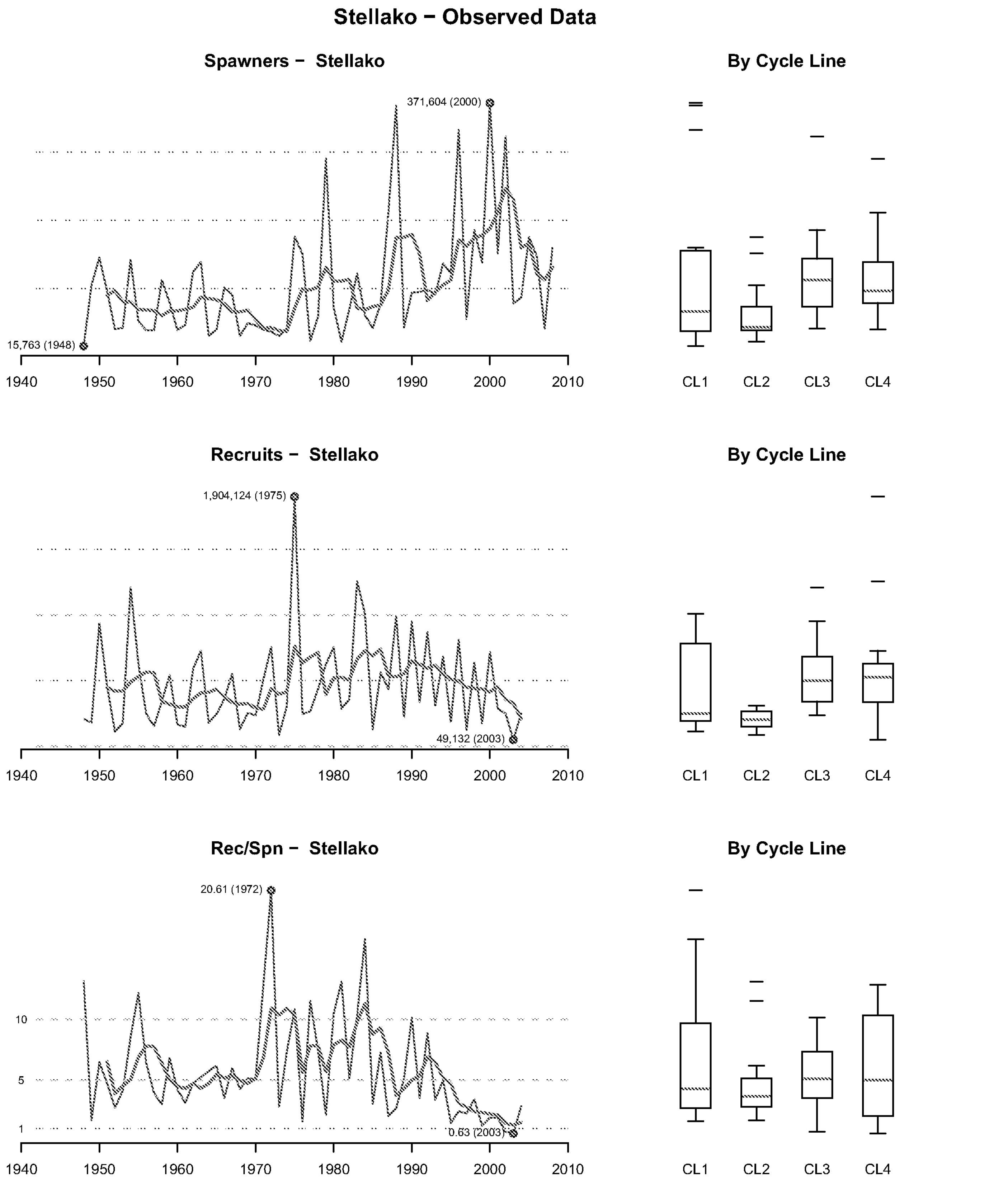


Figure A.9a: Observed Data − Stellako

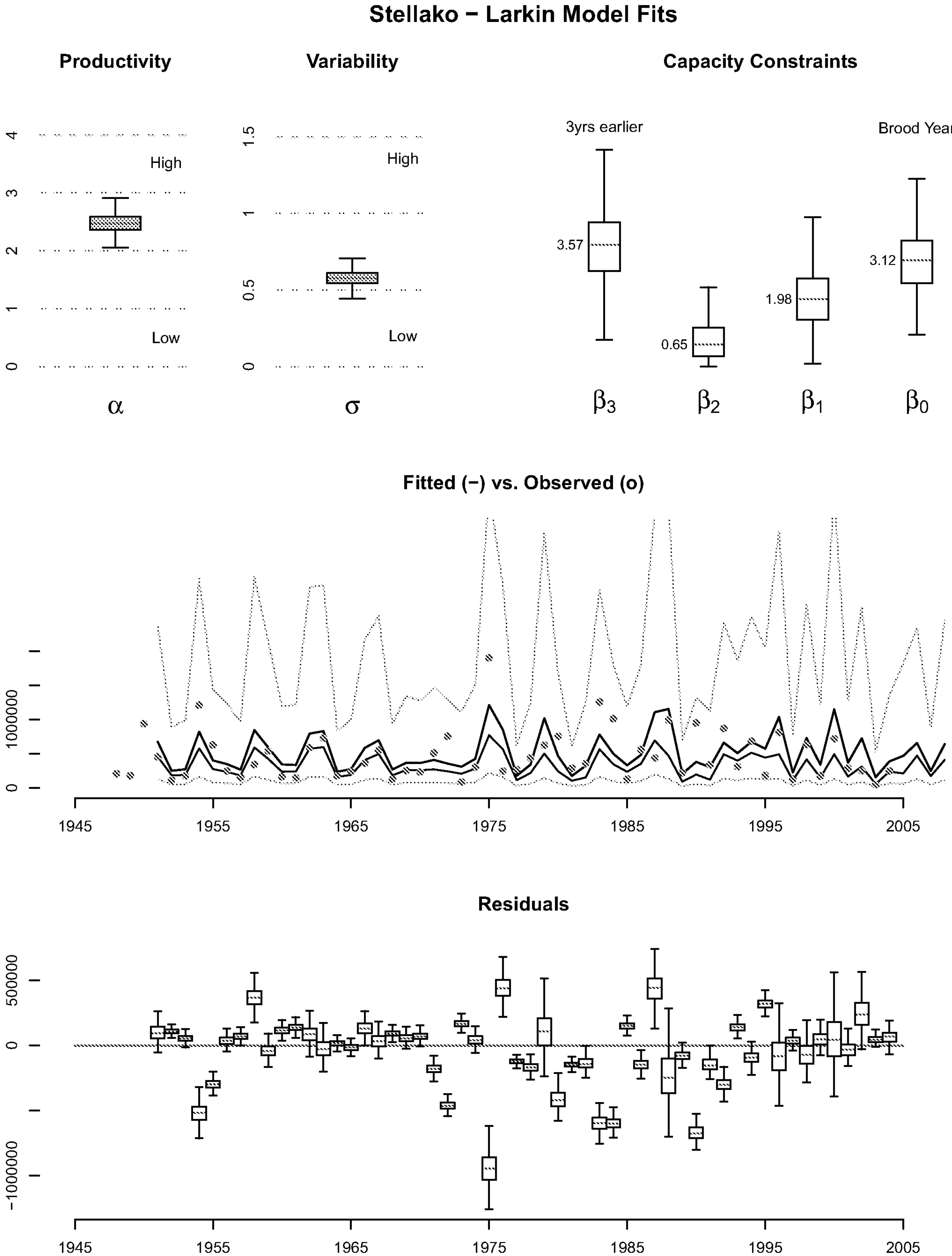


Figure A.9b: Larkin Model Fits − Stellako

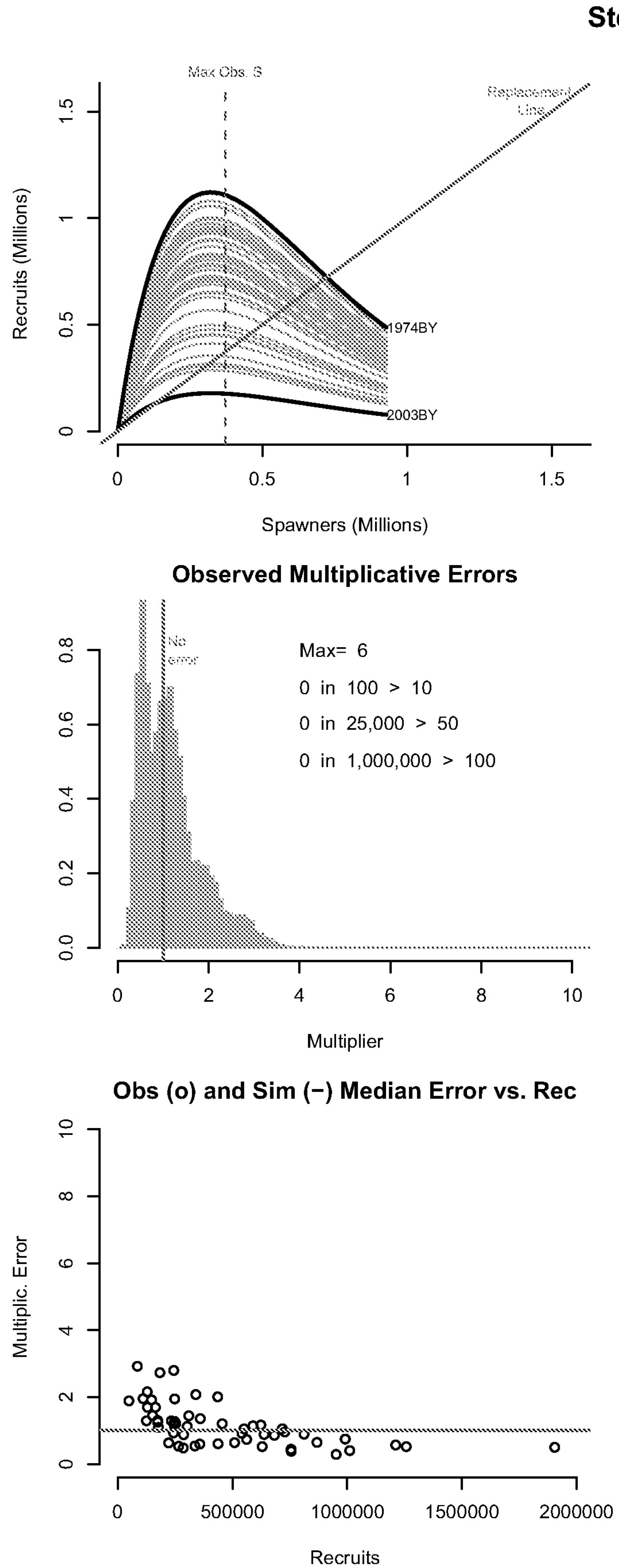


Figure A.9c: Delayed−density effects and error structure − Stellako

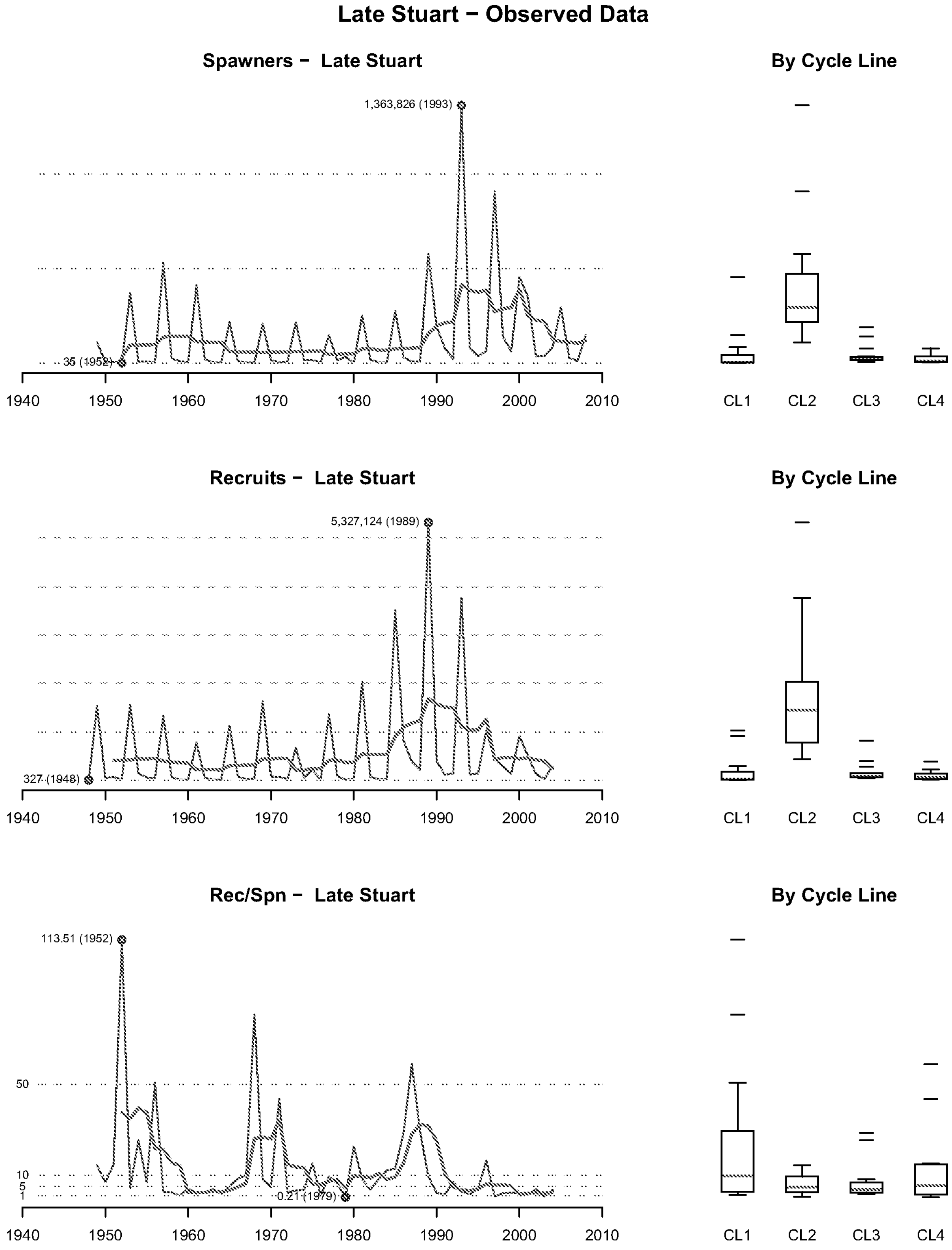


Figure A.10a: Observed Data − Late Stuart

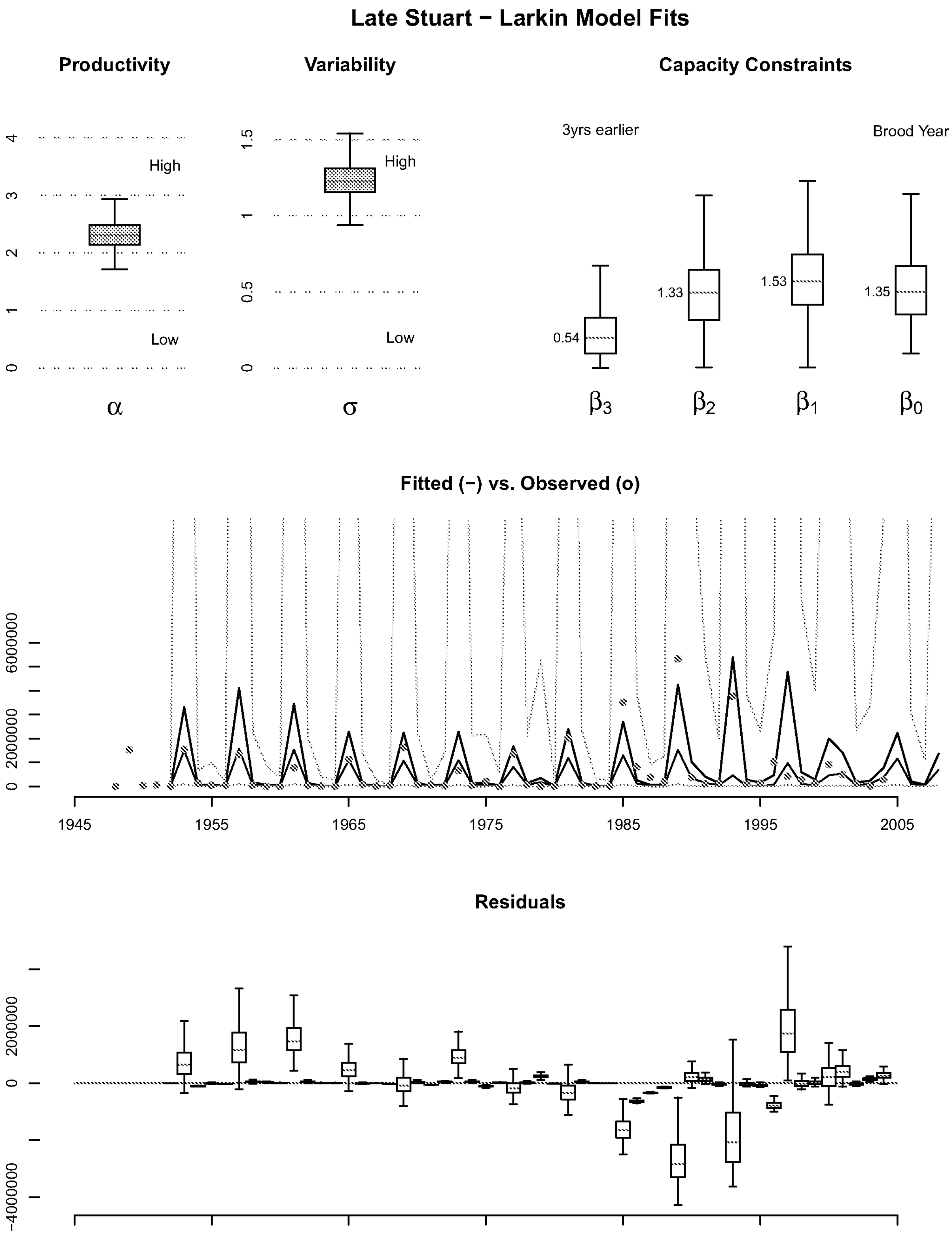


Figure A.10b: Larkin Model Fits − Late Stuart

Late Stuart

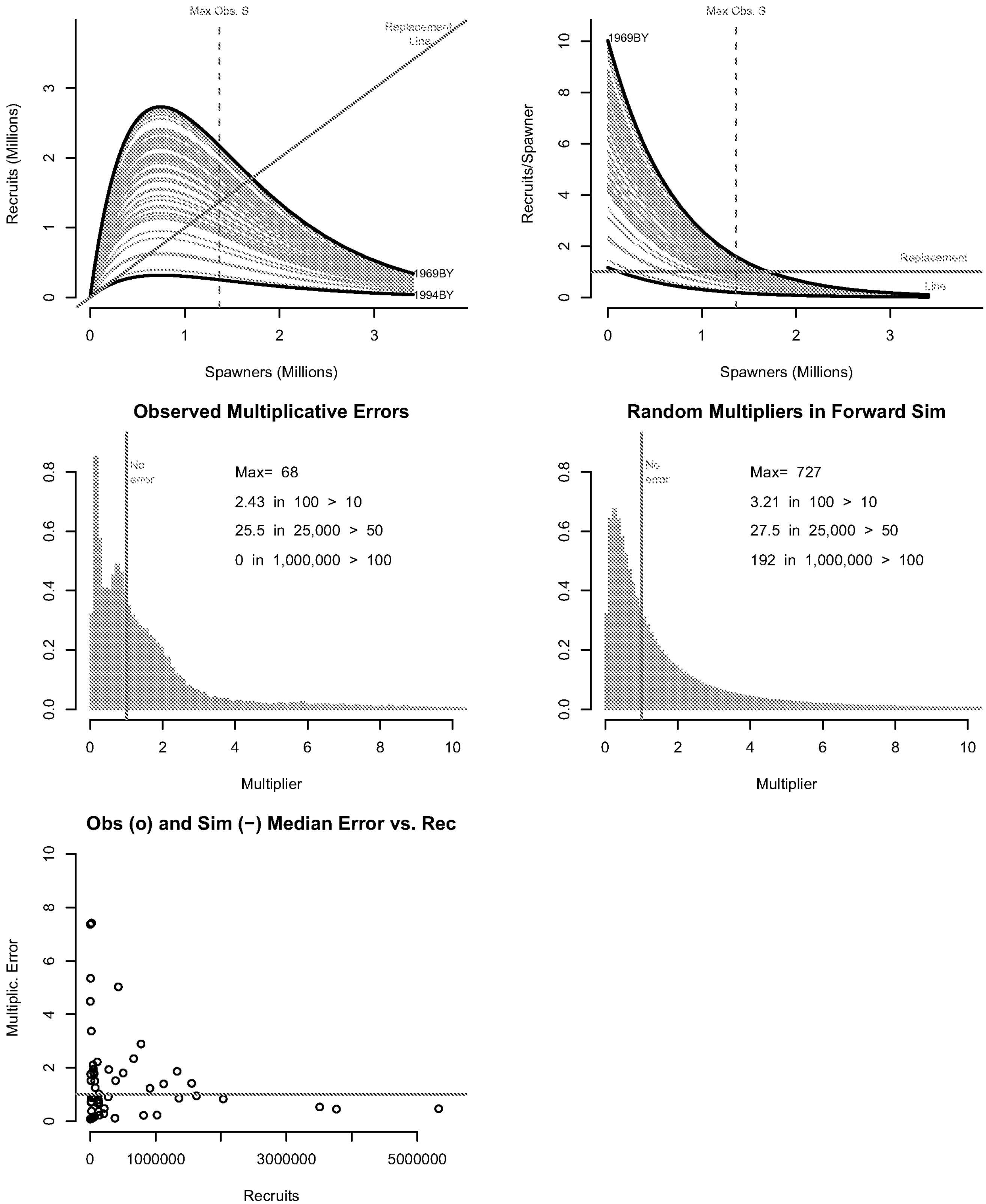


Figure A.10c: Delayed−density effects and error structure − Late Stuart

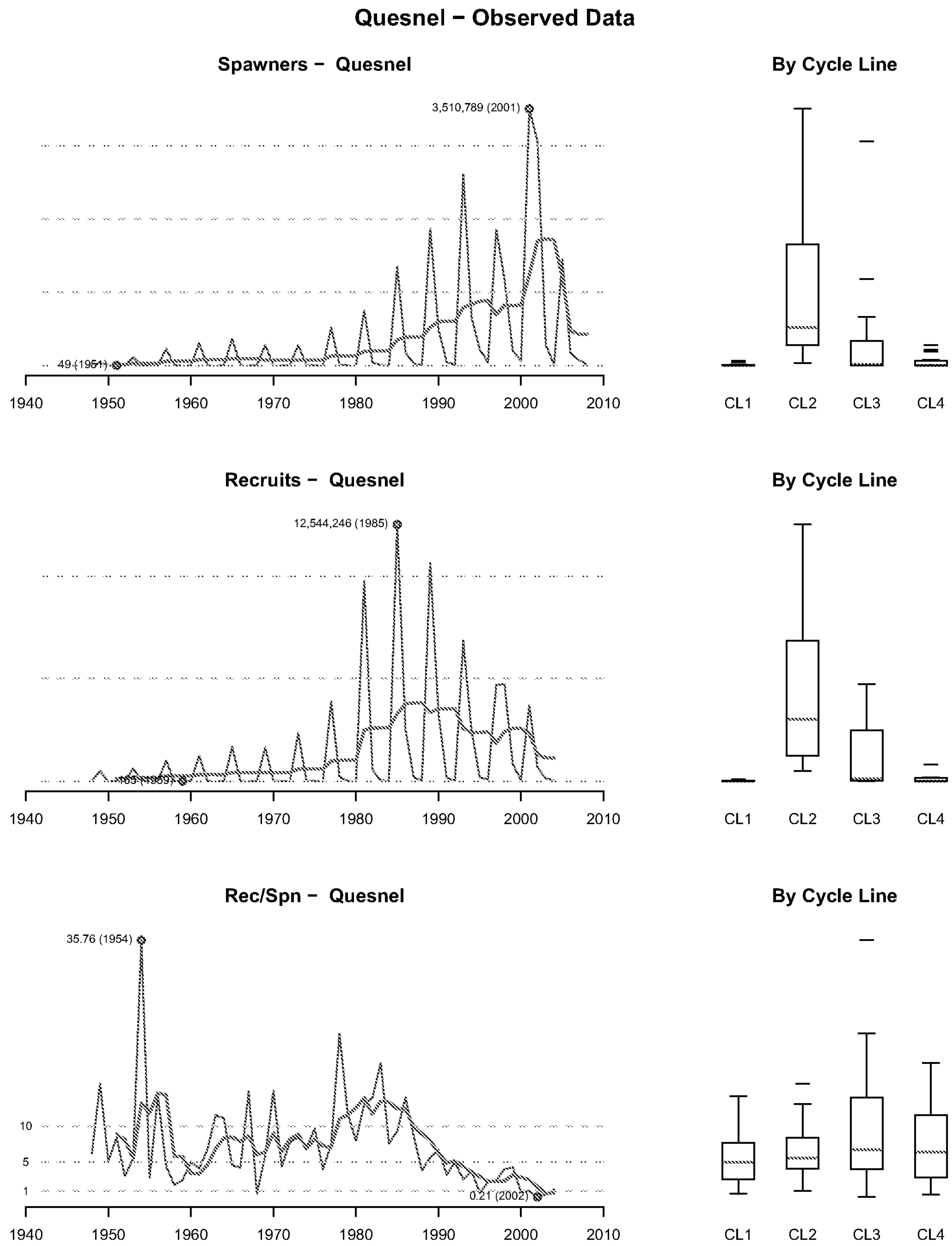


Figure A.11a: Observed Data − Quesnel

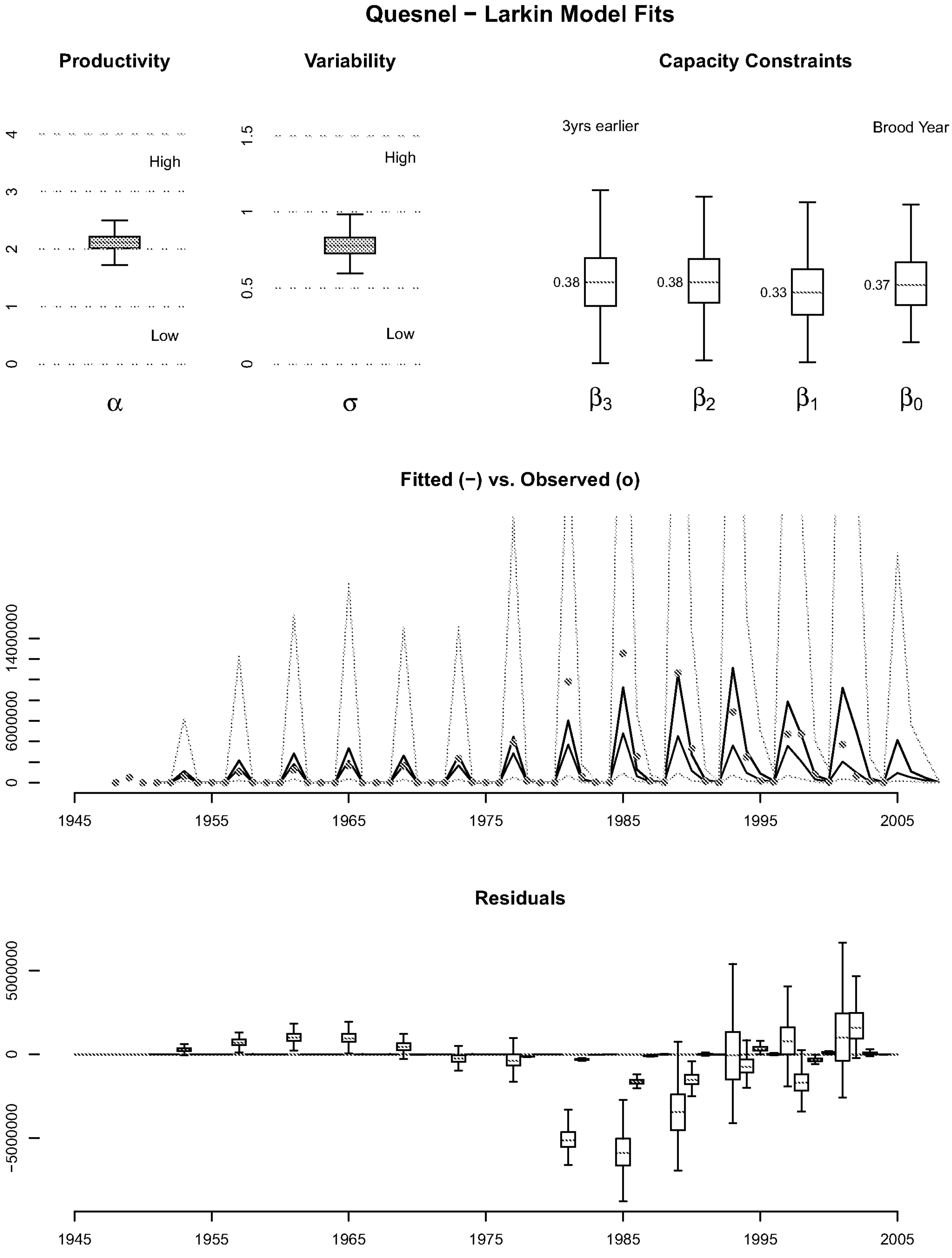


Figure A.11b: Larkin Model Fits − Quesnel

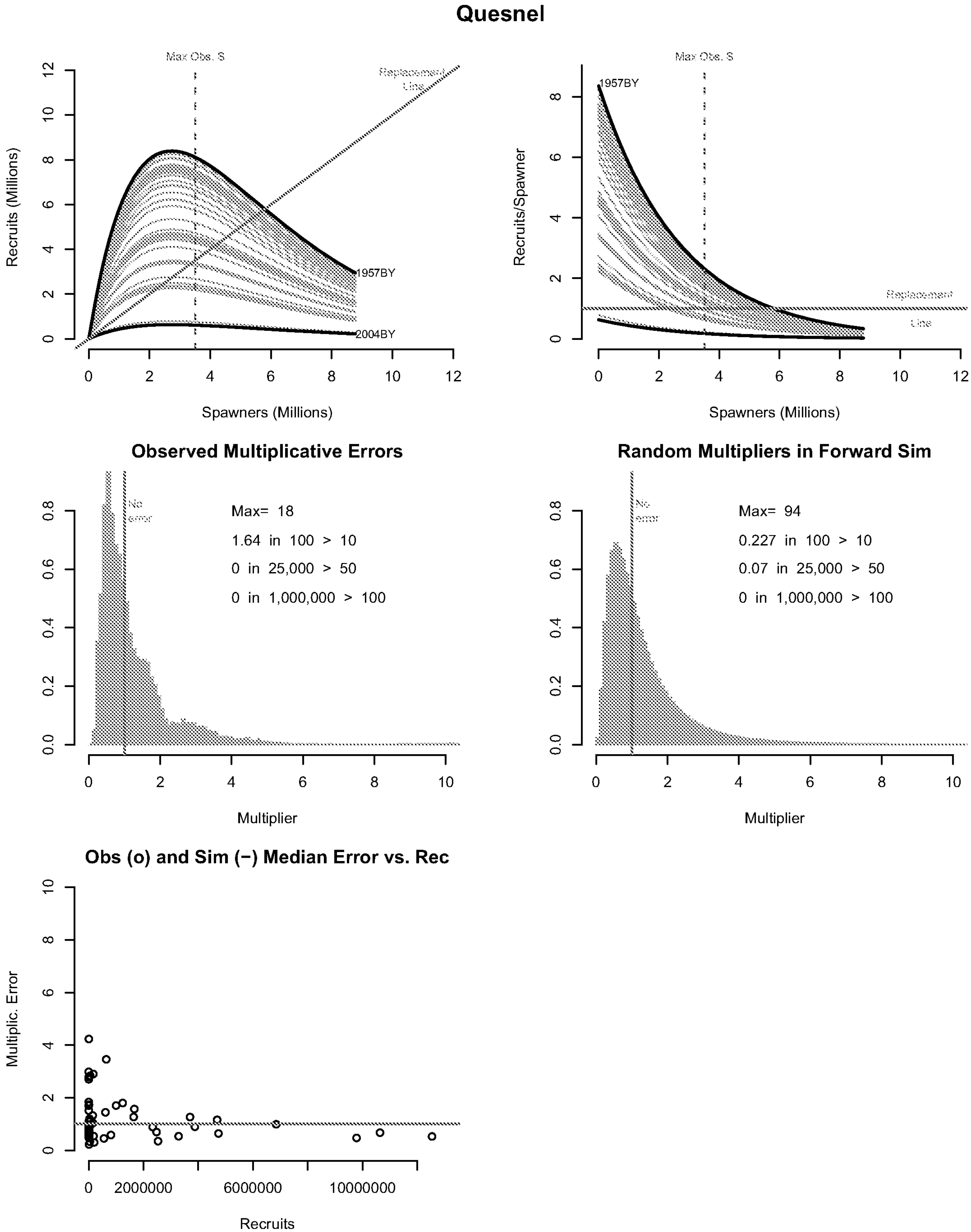


Figure A.11c: Delayed−density effects and error structure − Quesnel

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Chilko − Observed Data

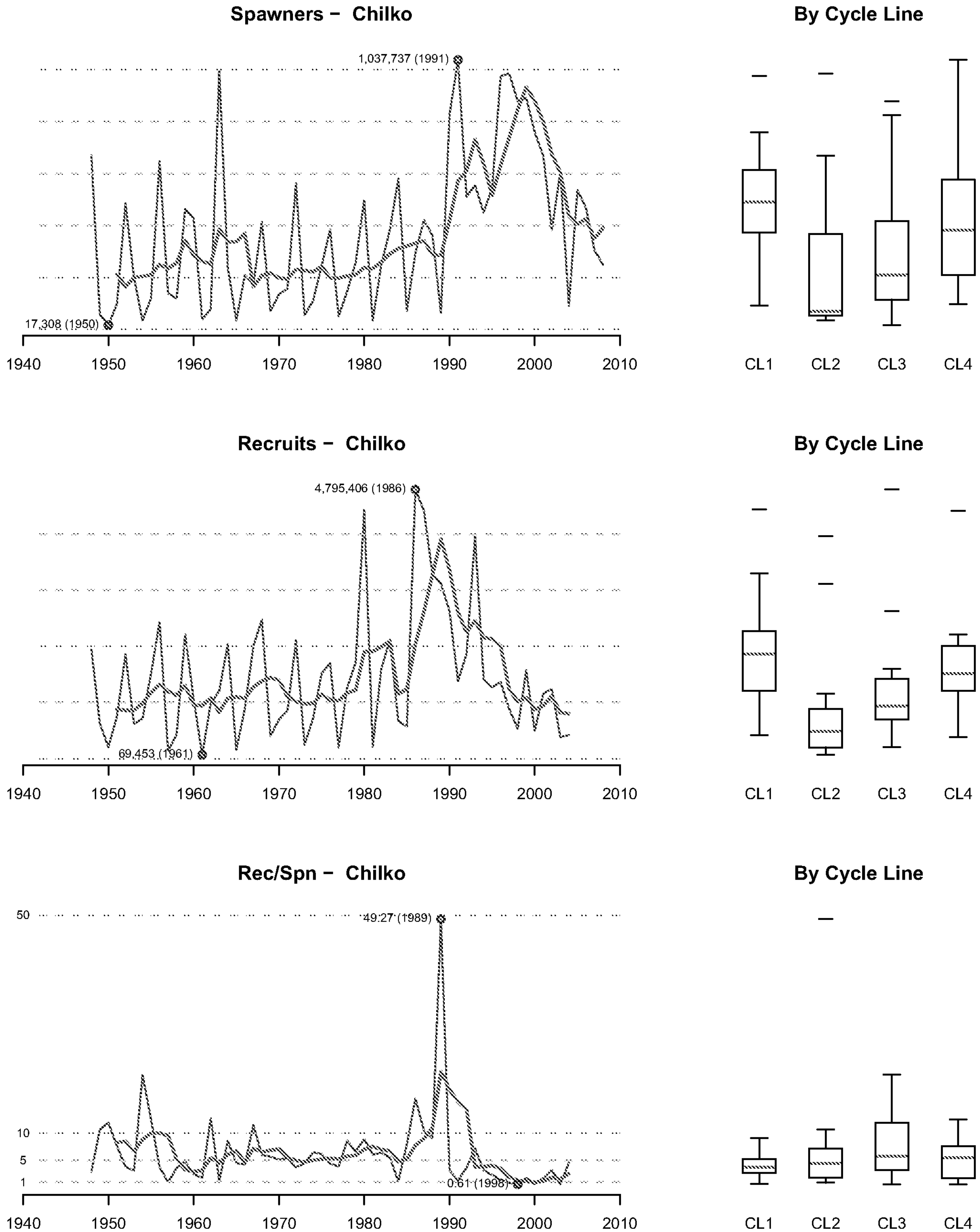


Figure A.12a: Observed Data − Chilko

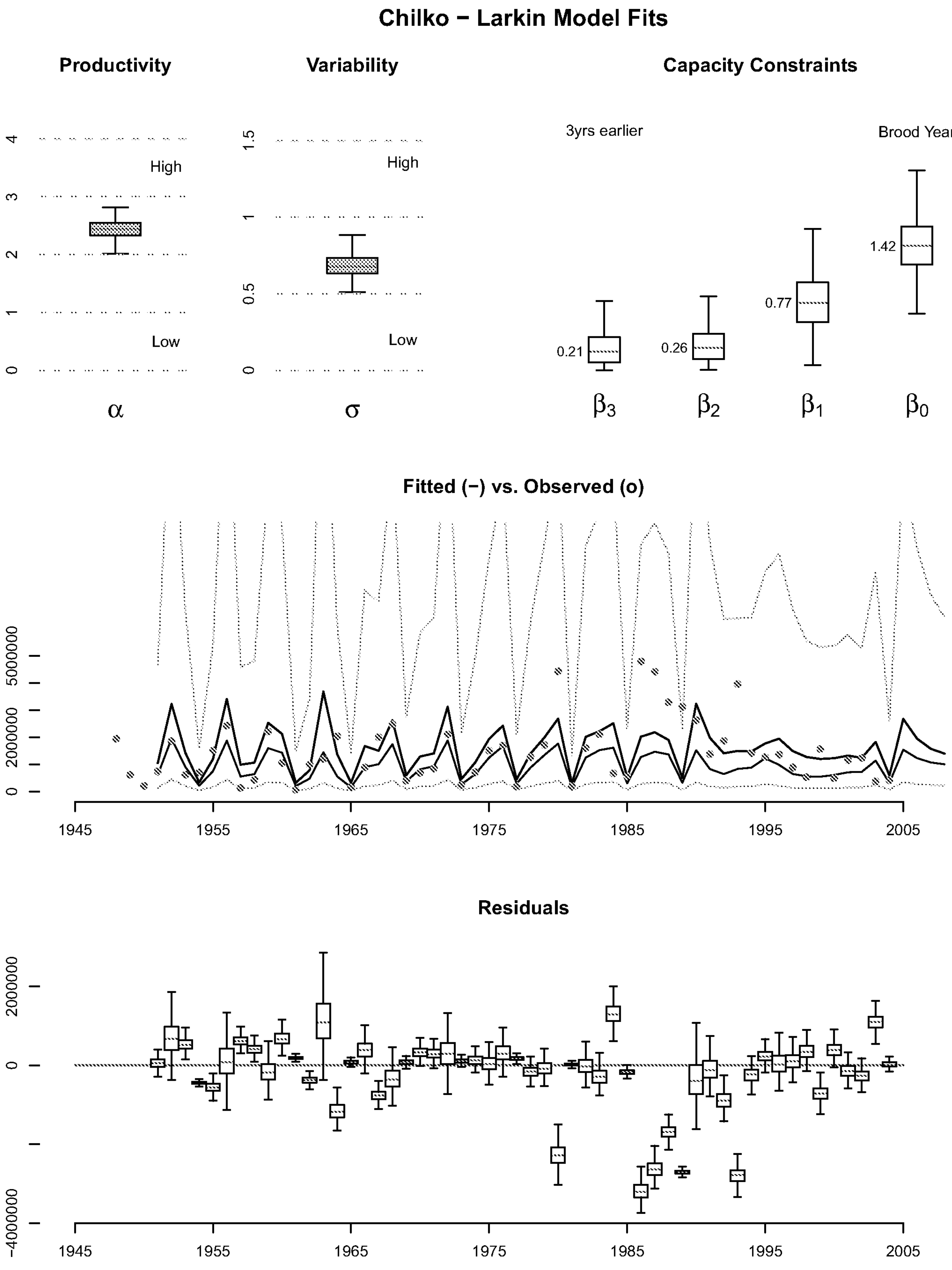


Figure A.12b: Larkin Model Fits − Chilko

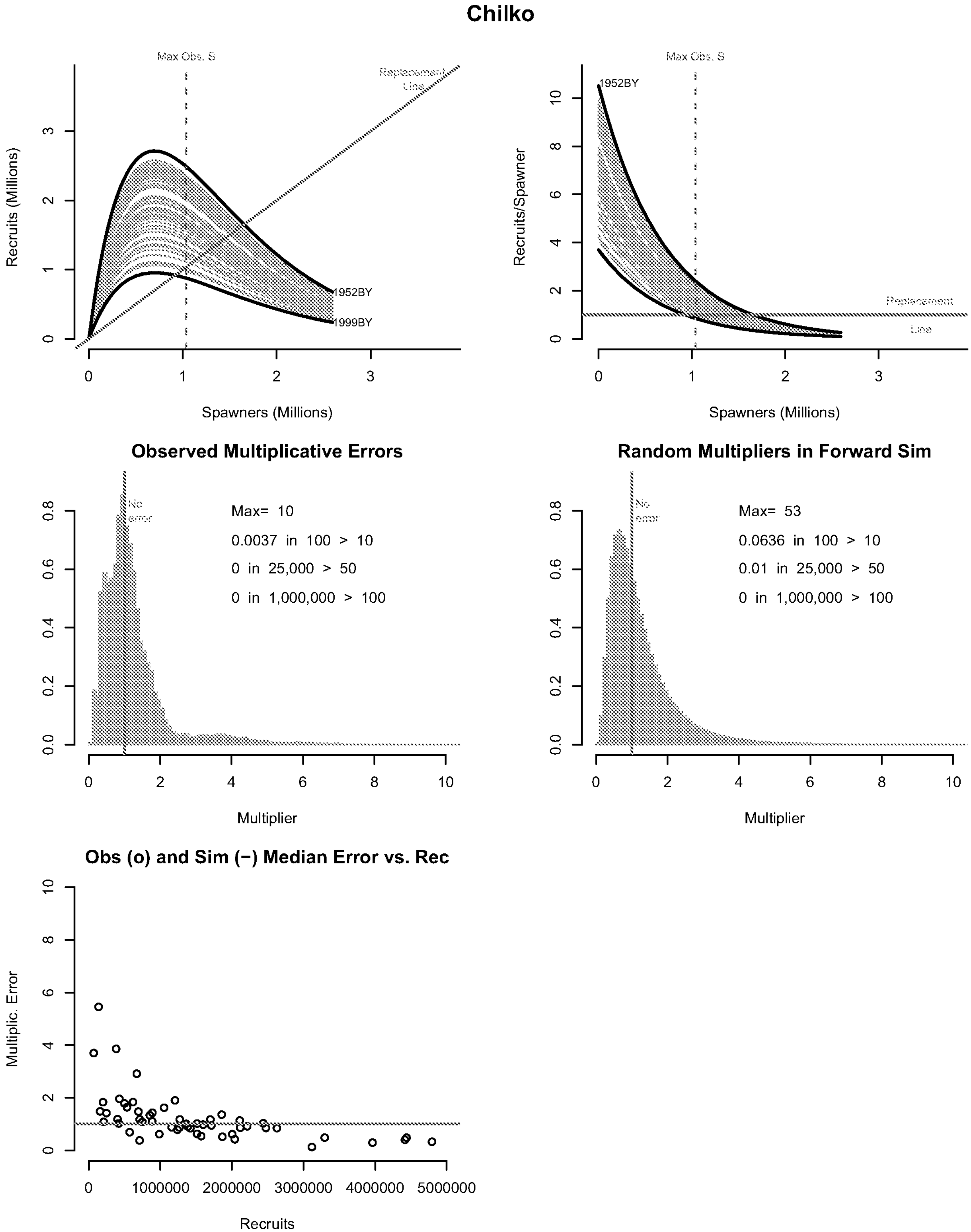


Figure A.12c: Delayed−density effects and error structure − Chilko

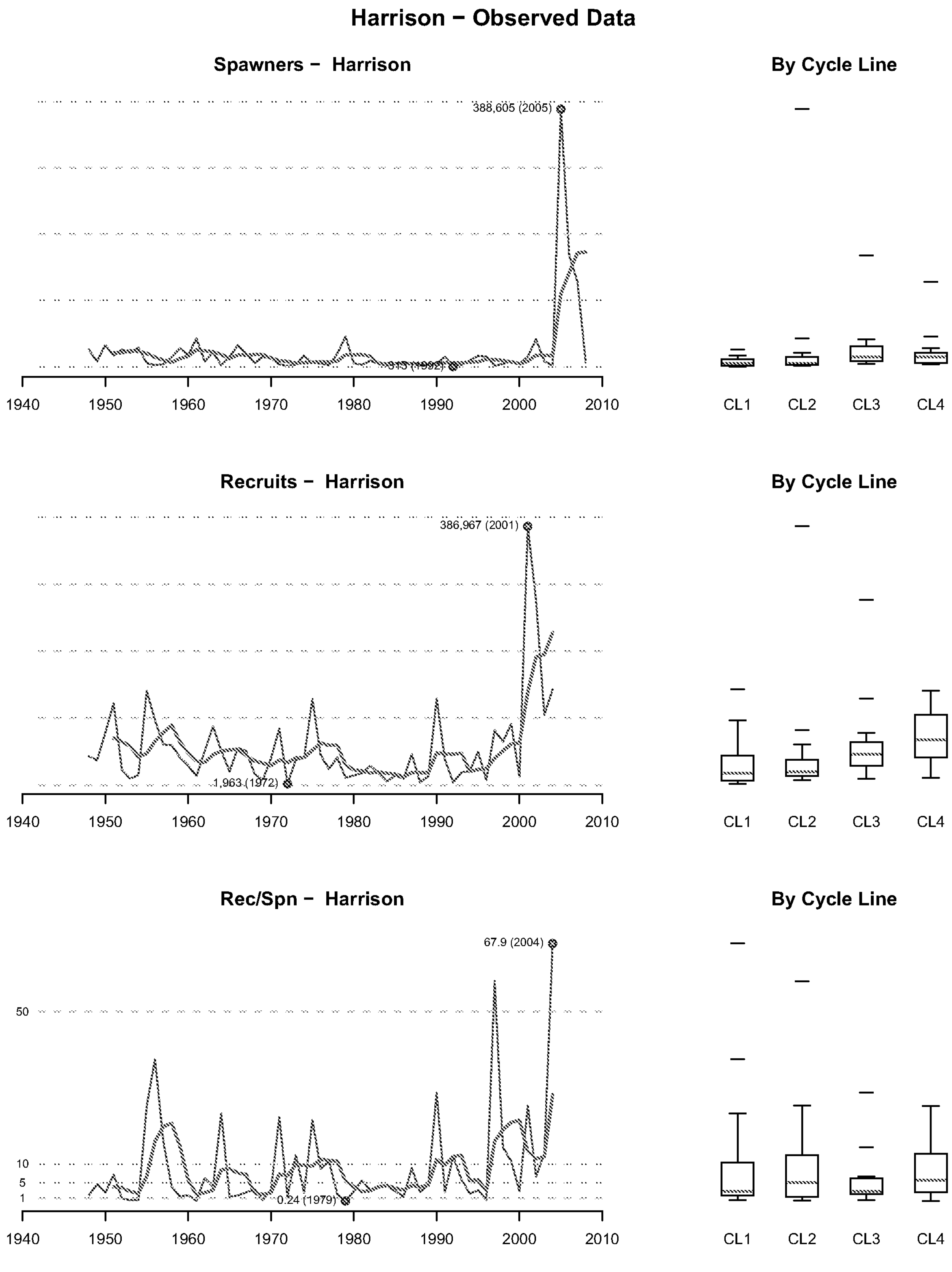


Figure A.13a: Observed Data − Harrison

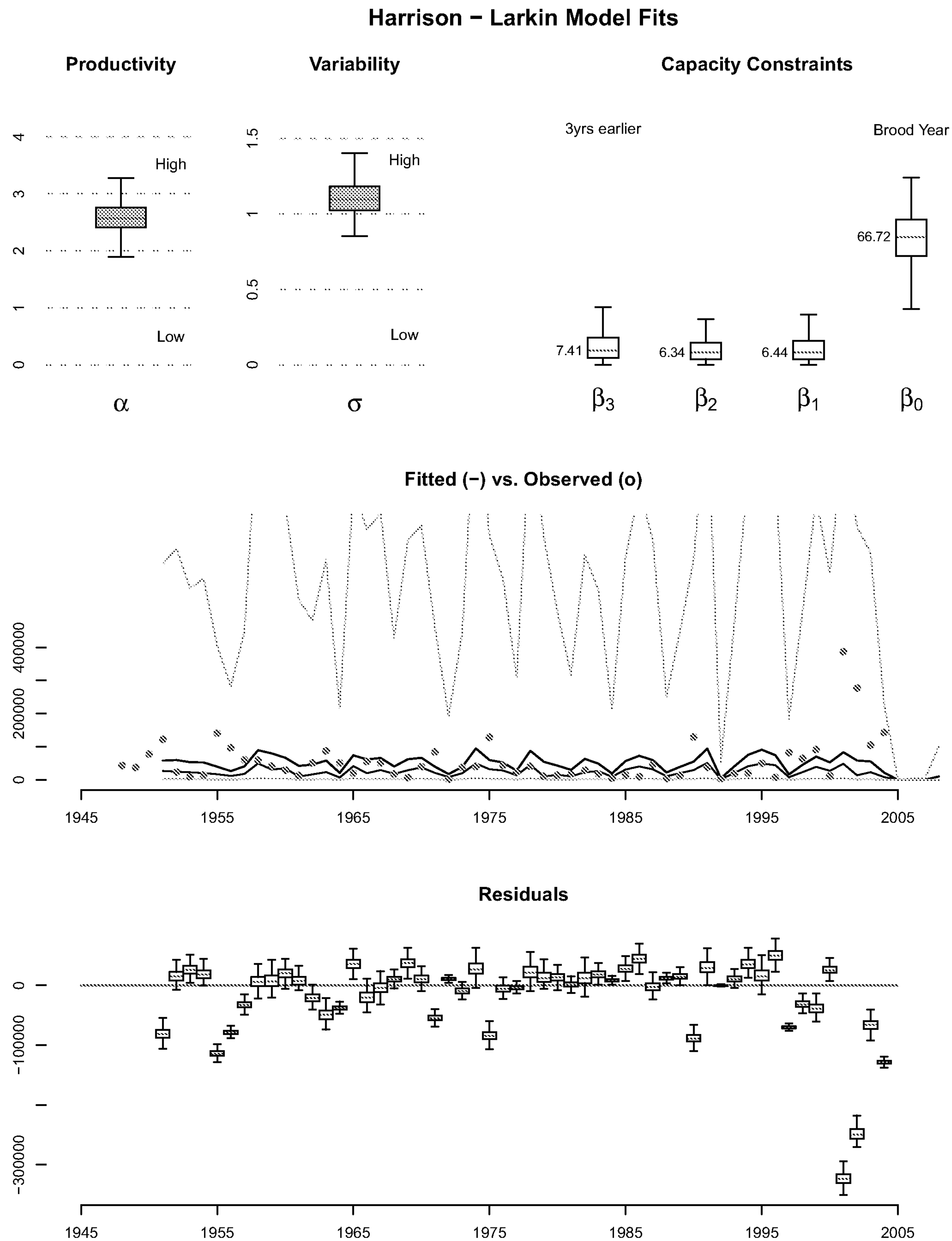


Figure A.13b: Larkin Model Fits − Harrison

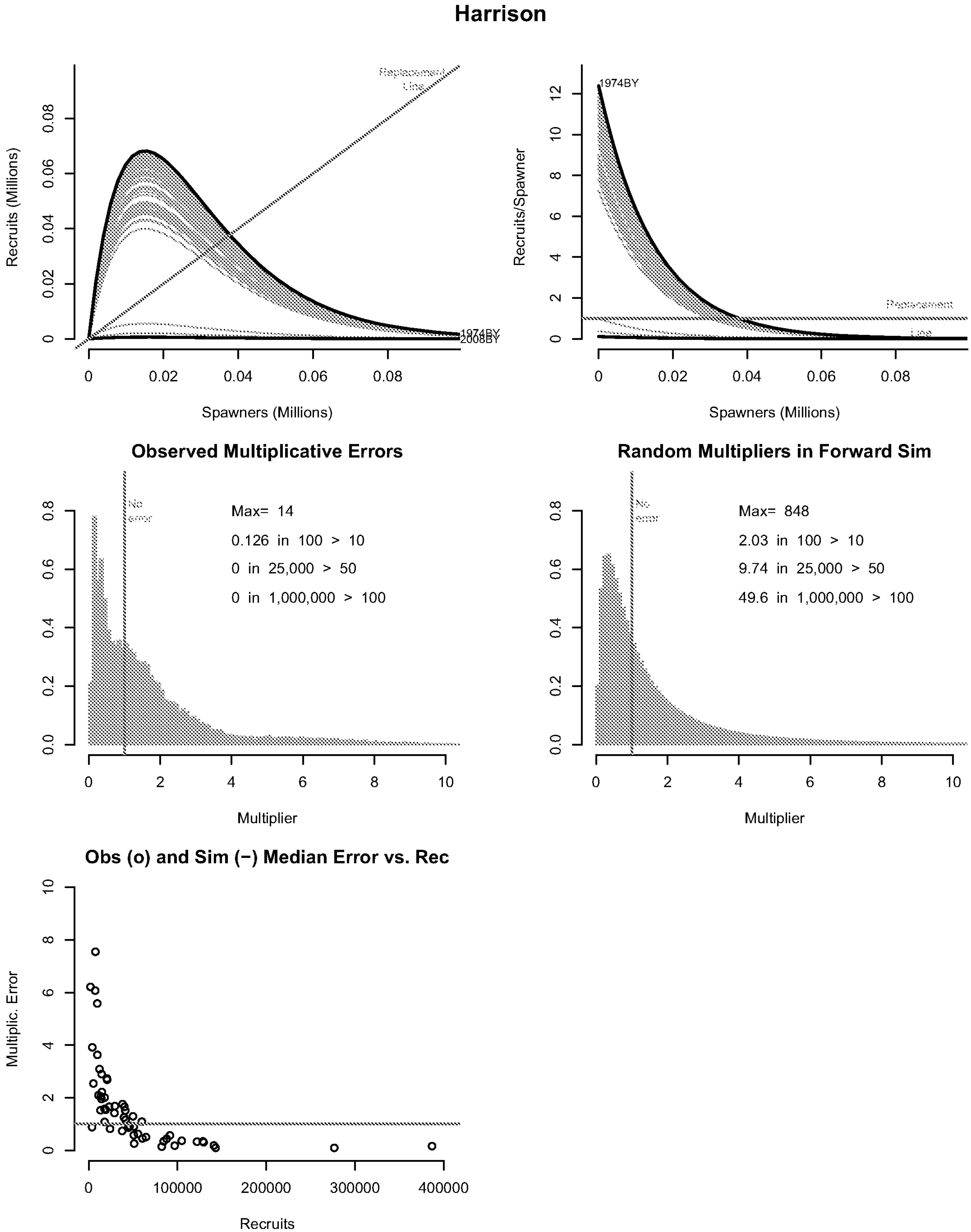


Figure A.13c: Delayed−density effects and error structure − Harrison

Portage − Observed Data

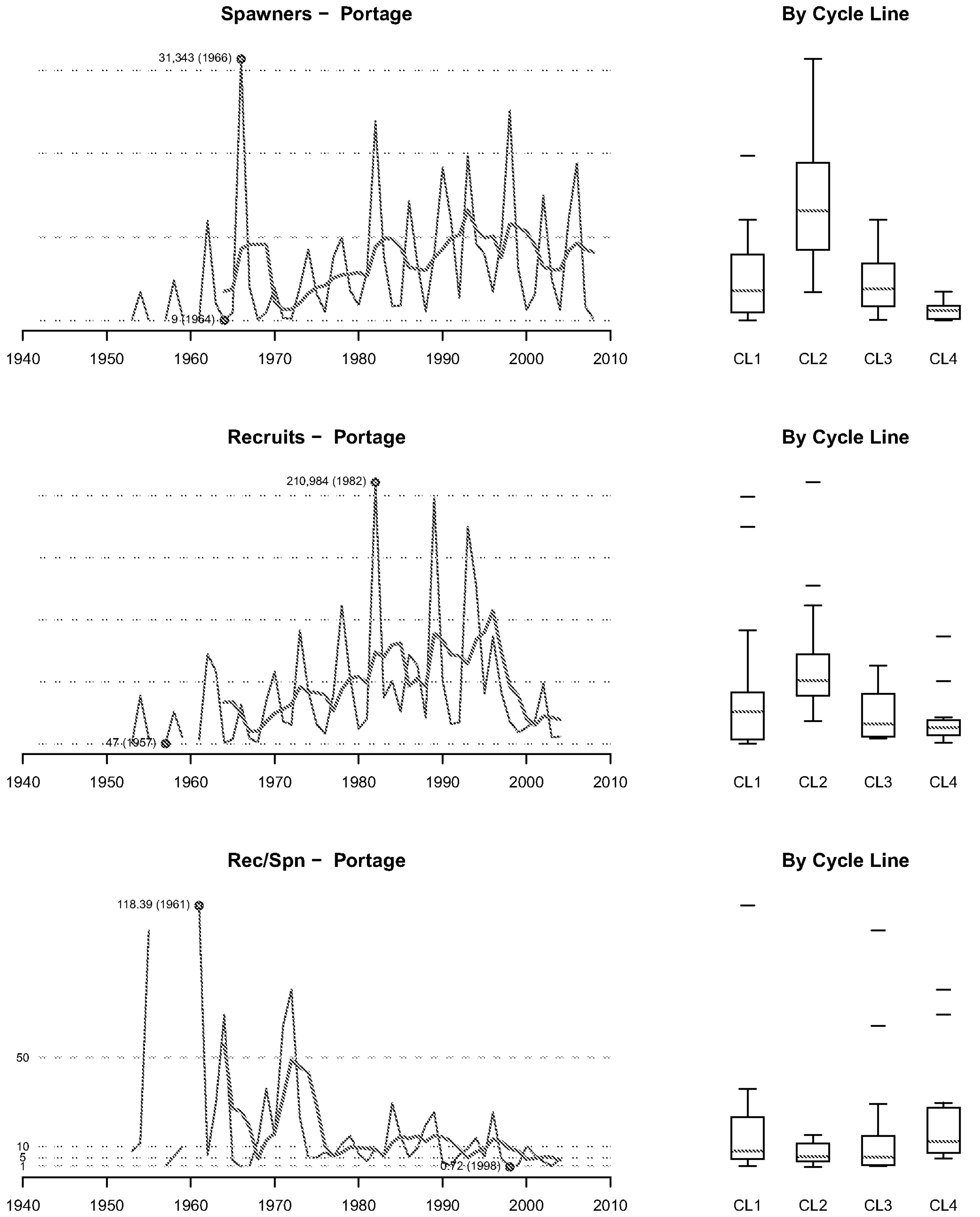


Figure A.14a: Observed Data − Portage

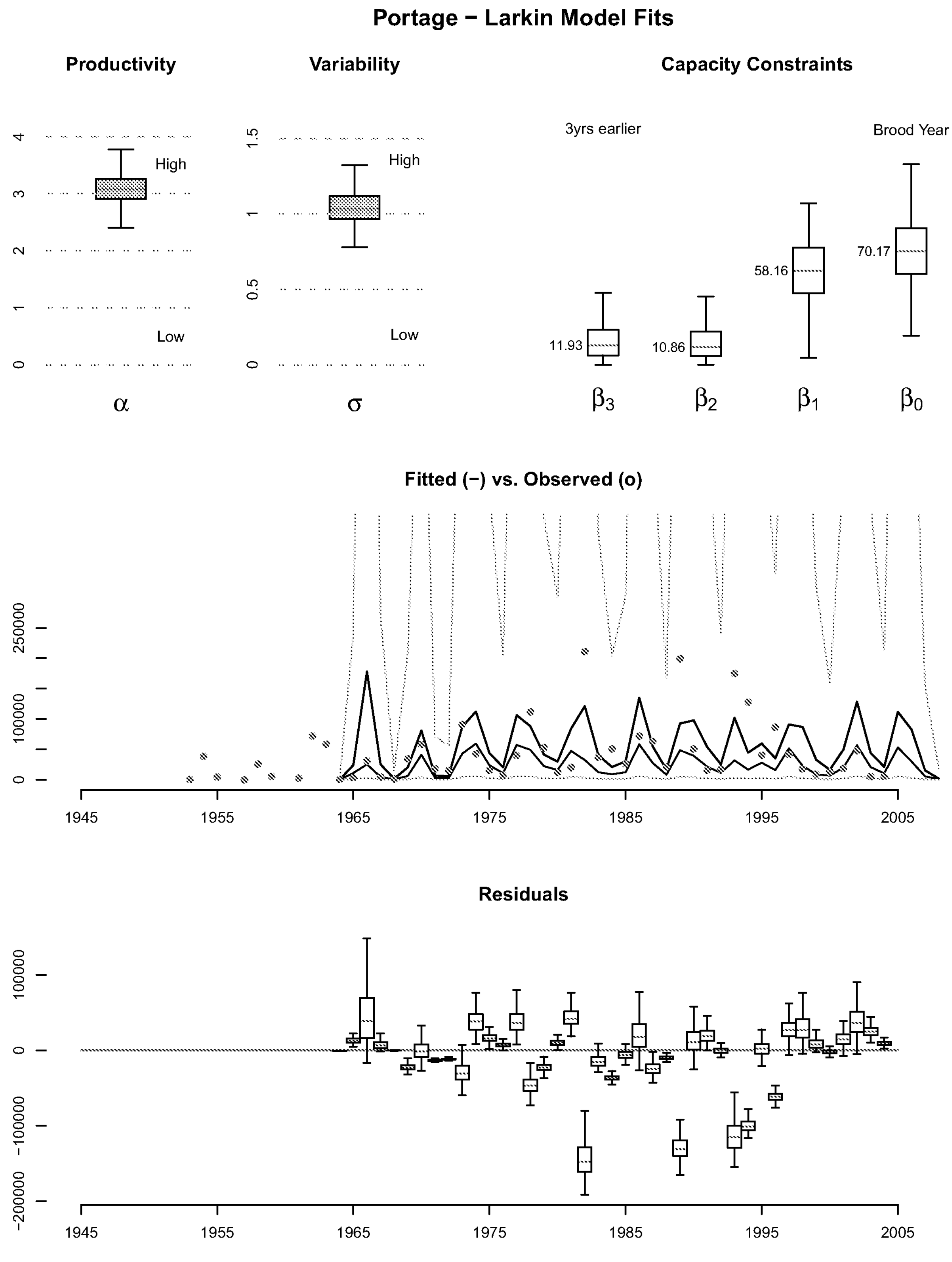


Figure A.14b: Larkin Model Fits − Portage

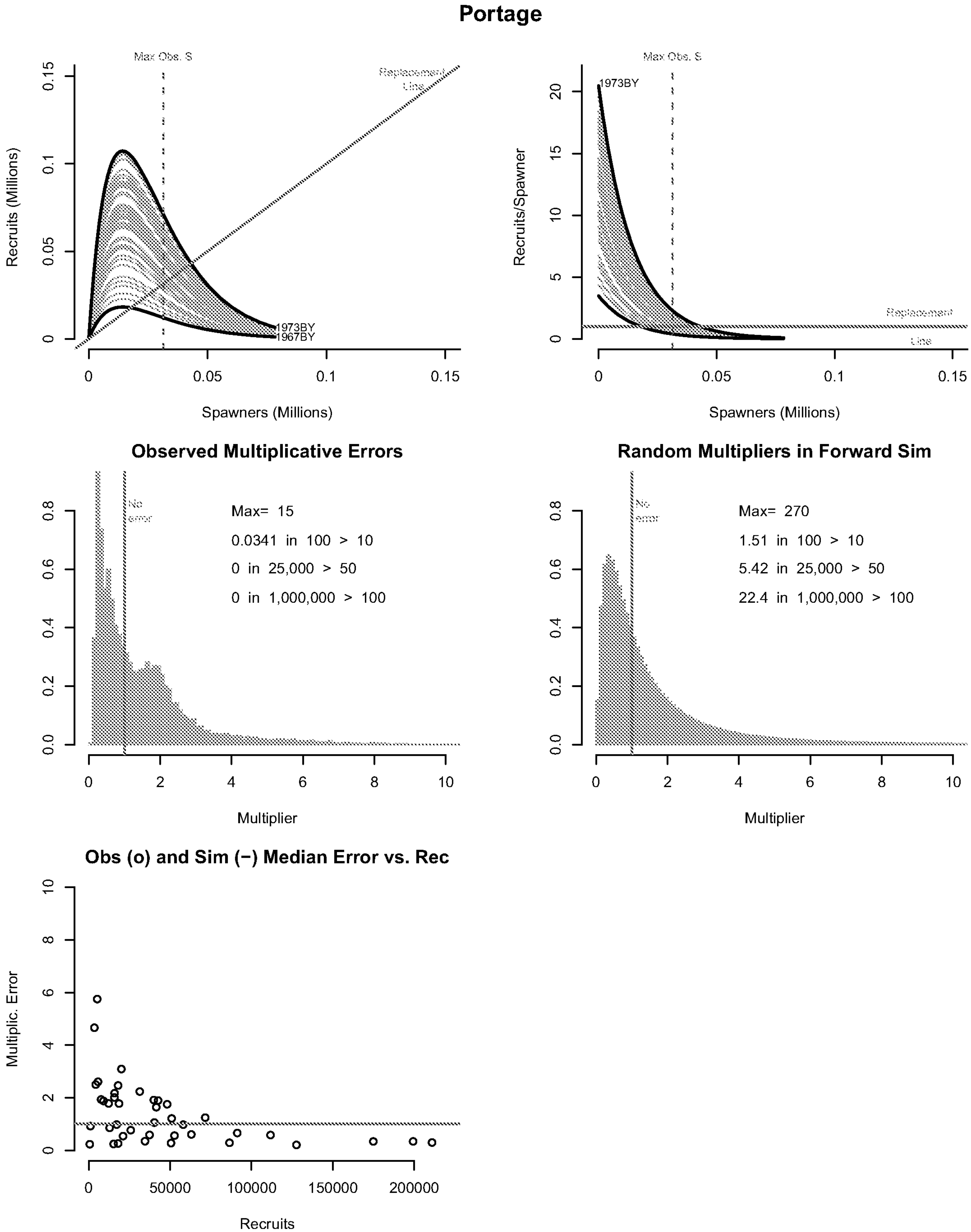


Figure A.14c: Delayed−density effects and error structure − Portage

Late Shuswap − Observed Data

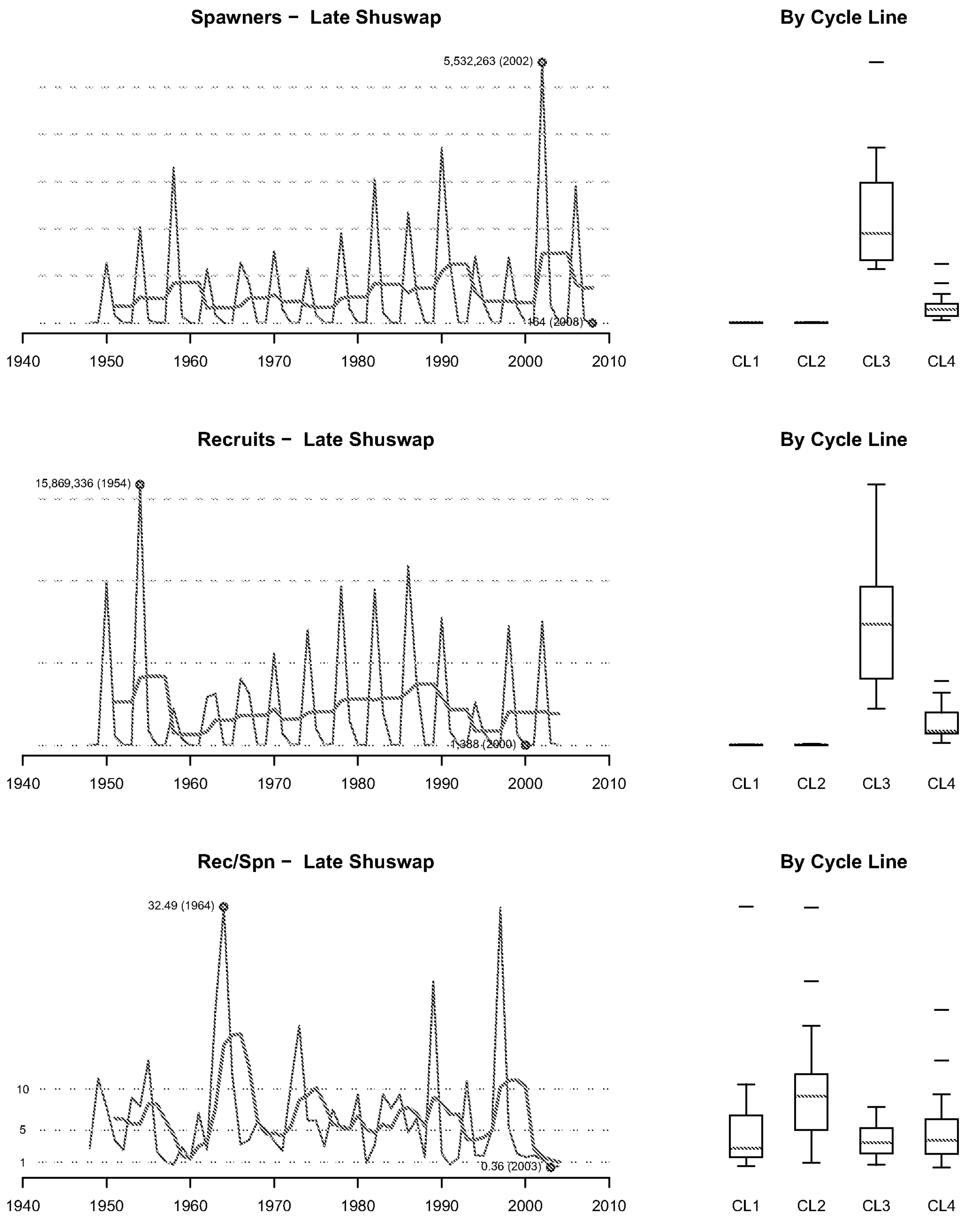


Figure A.15a: Observed Data − Late Shuswap

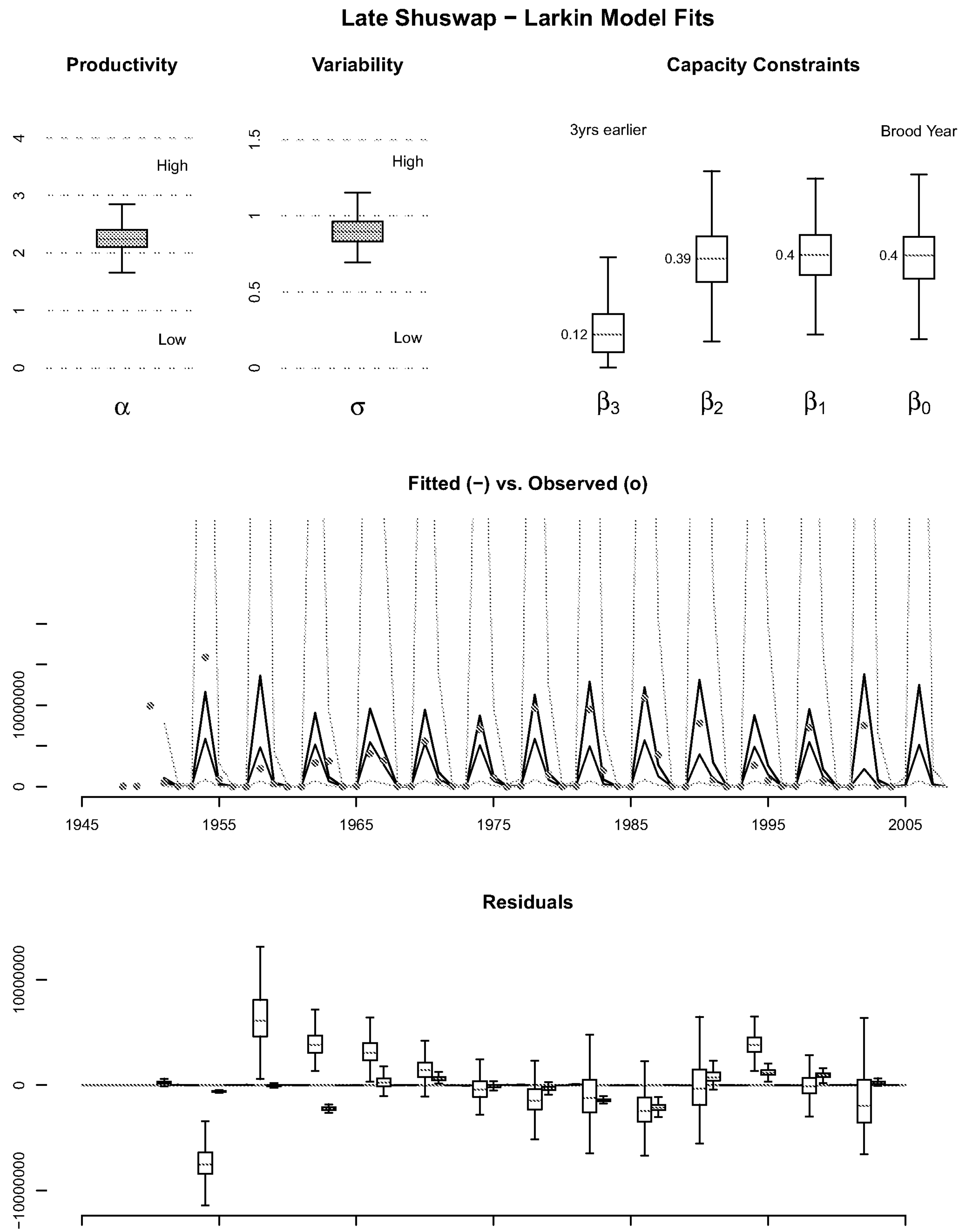


Figure A.15b: Larkin Model Fits − Late Shuswap

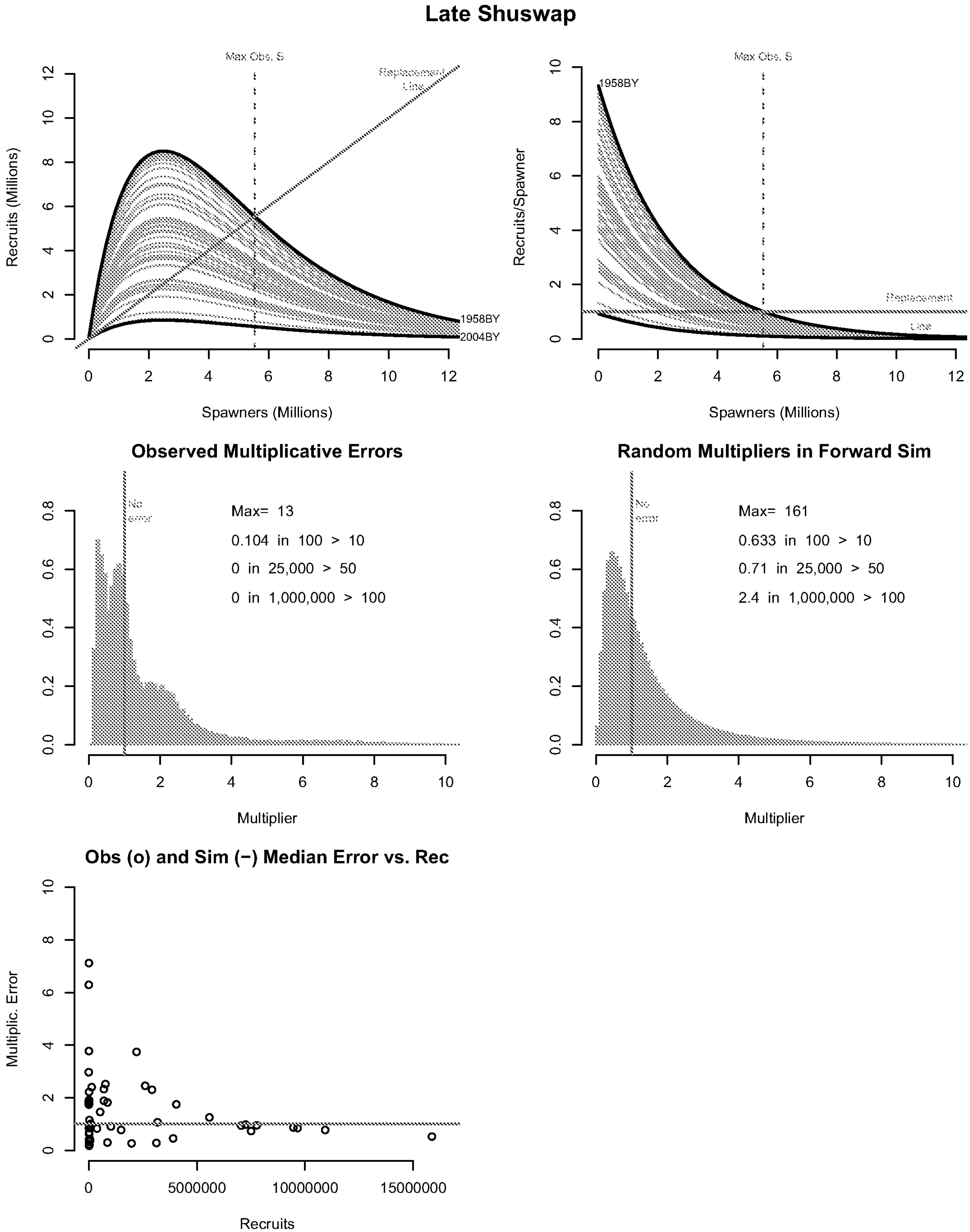


Figure A.15c: Delayed−density effects and error structure − Late Shuswap

Birkenhead − Observed Data

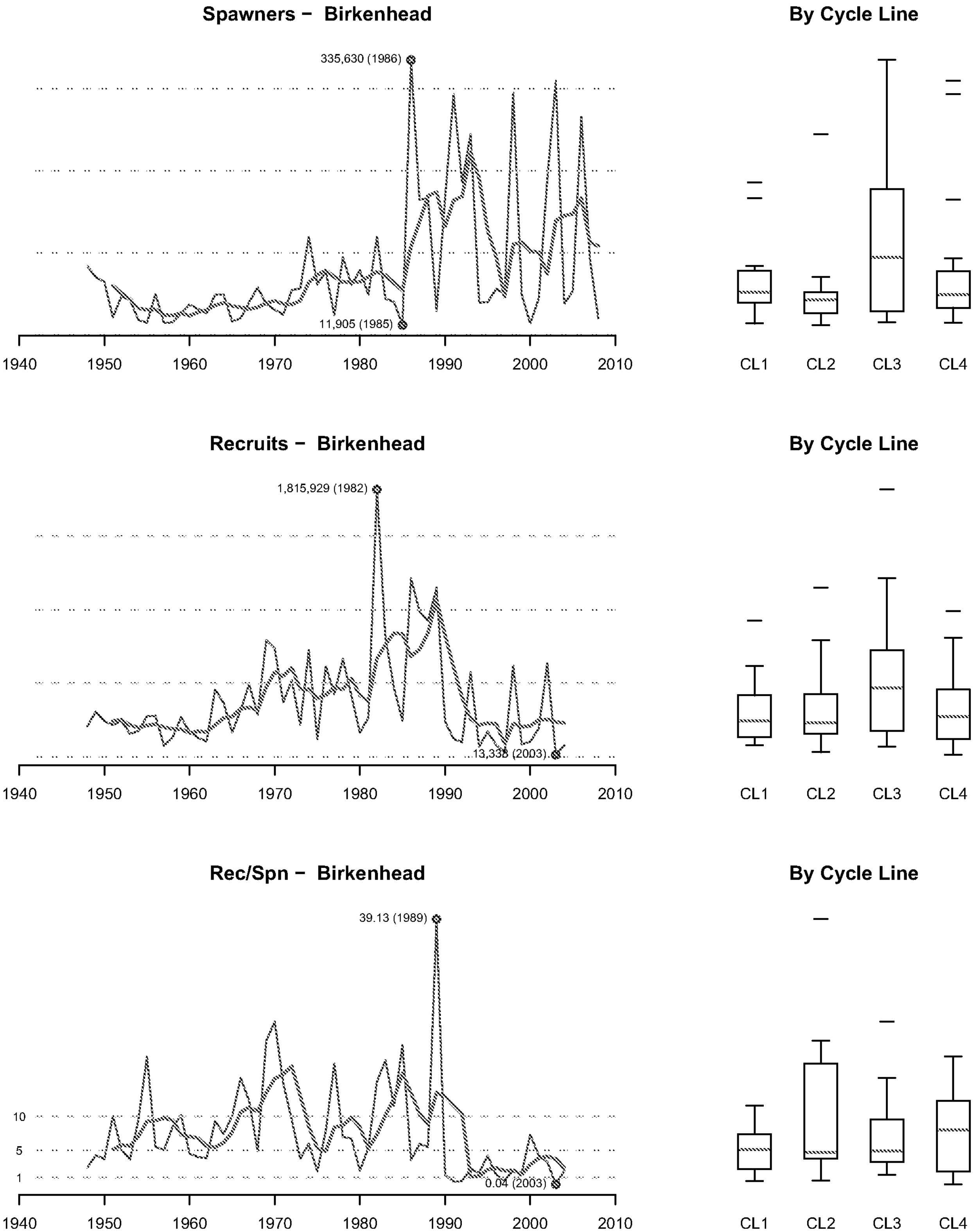


Figure A.16a: Observed Data − Birkenhead

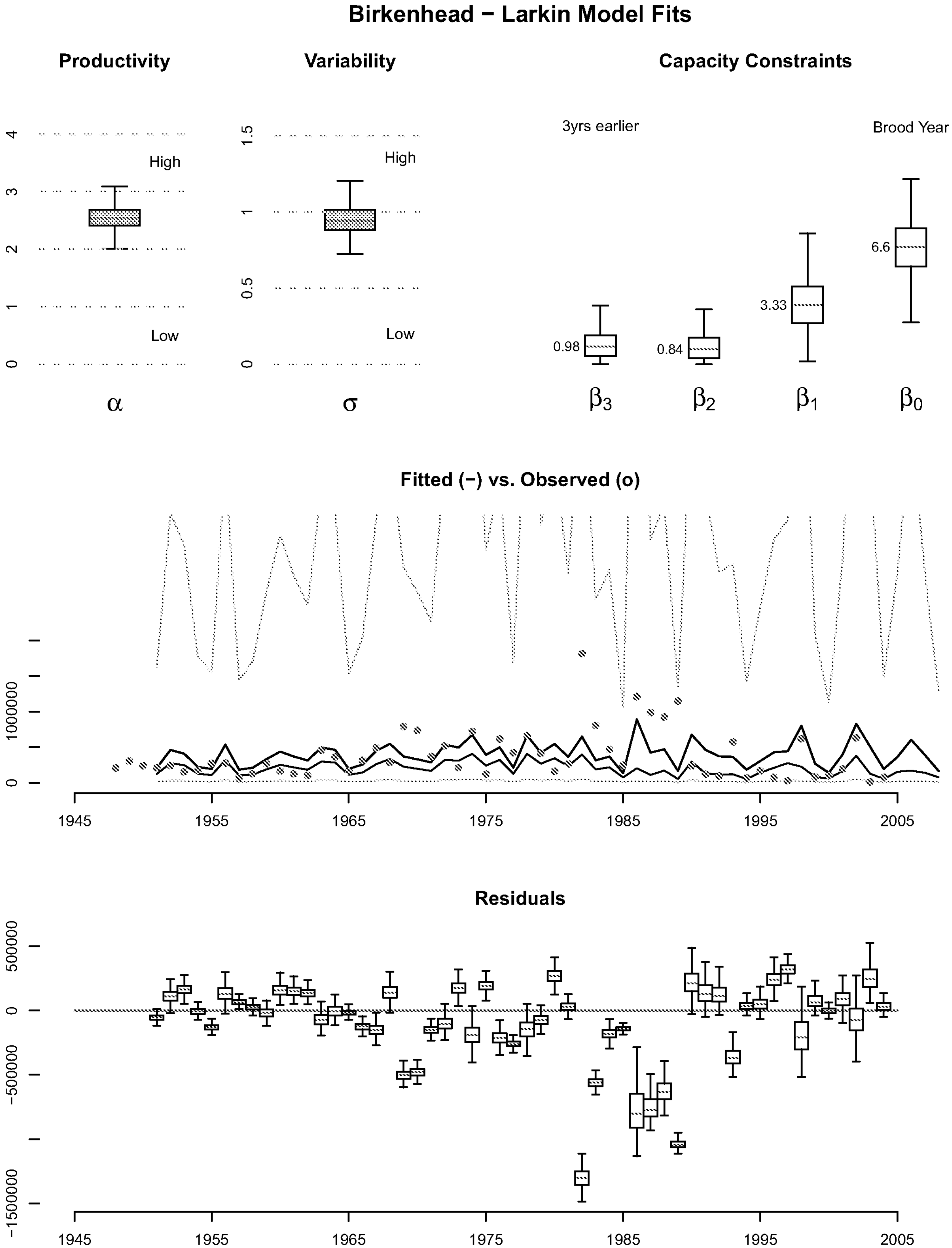


Figure A.16b: Larkin Model Fits − Birkenhead

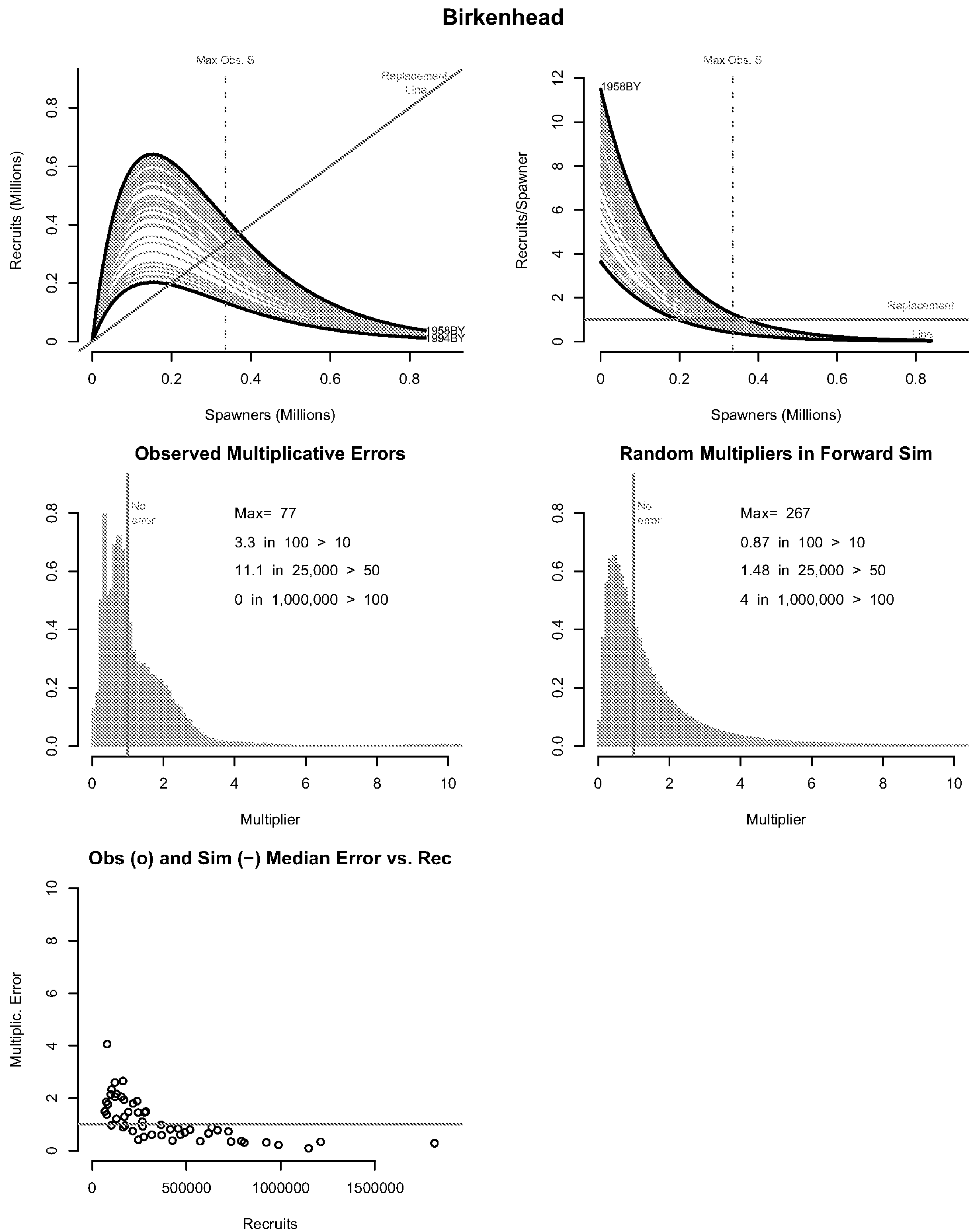


Figure A.16c: Delayed−density effects and error structure − Birkenhead

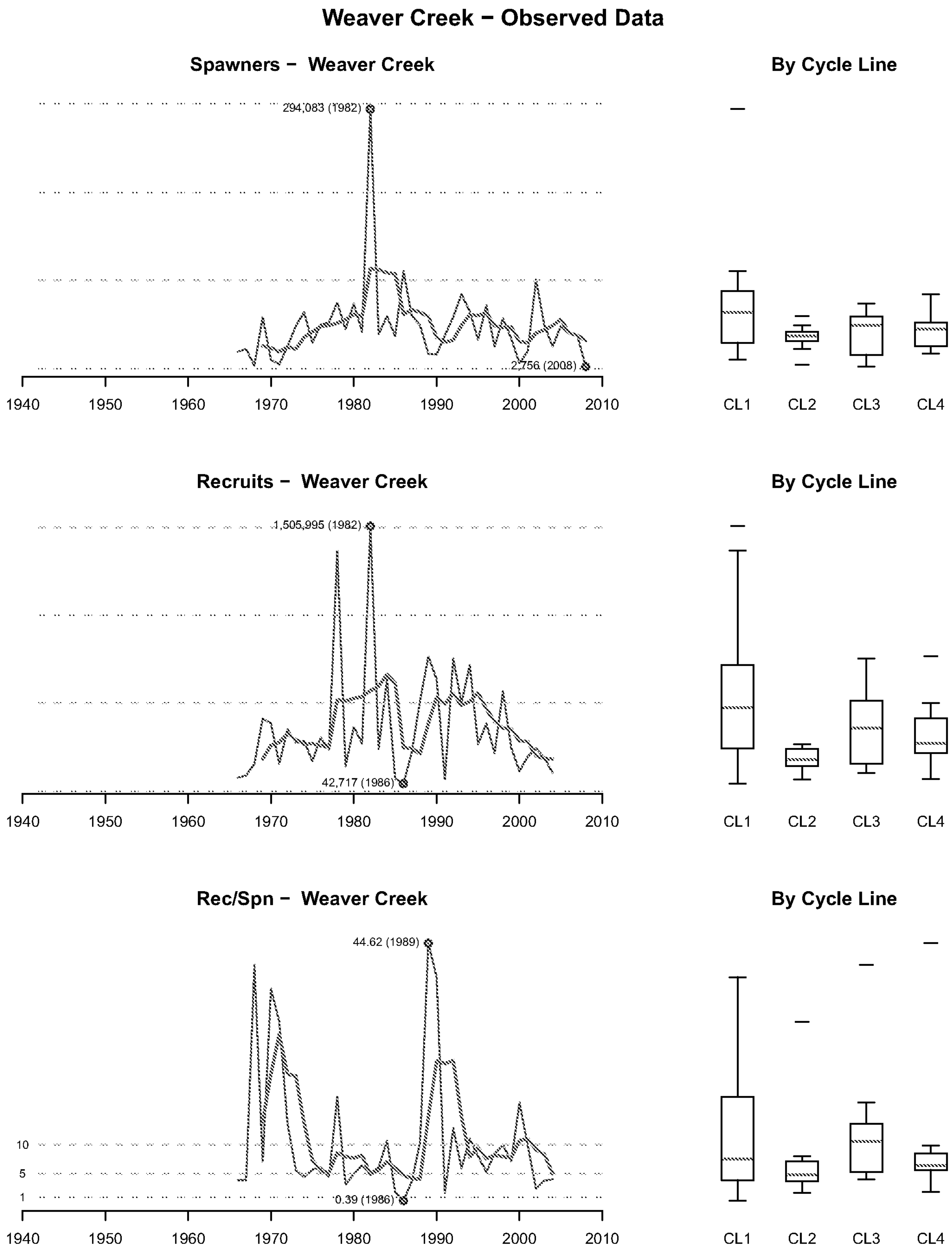


Figure A.17a: Observed Data − Weaver Creek

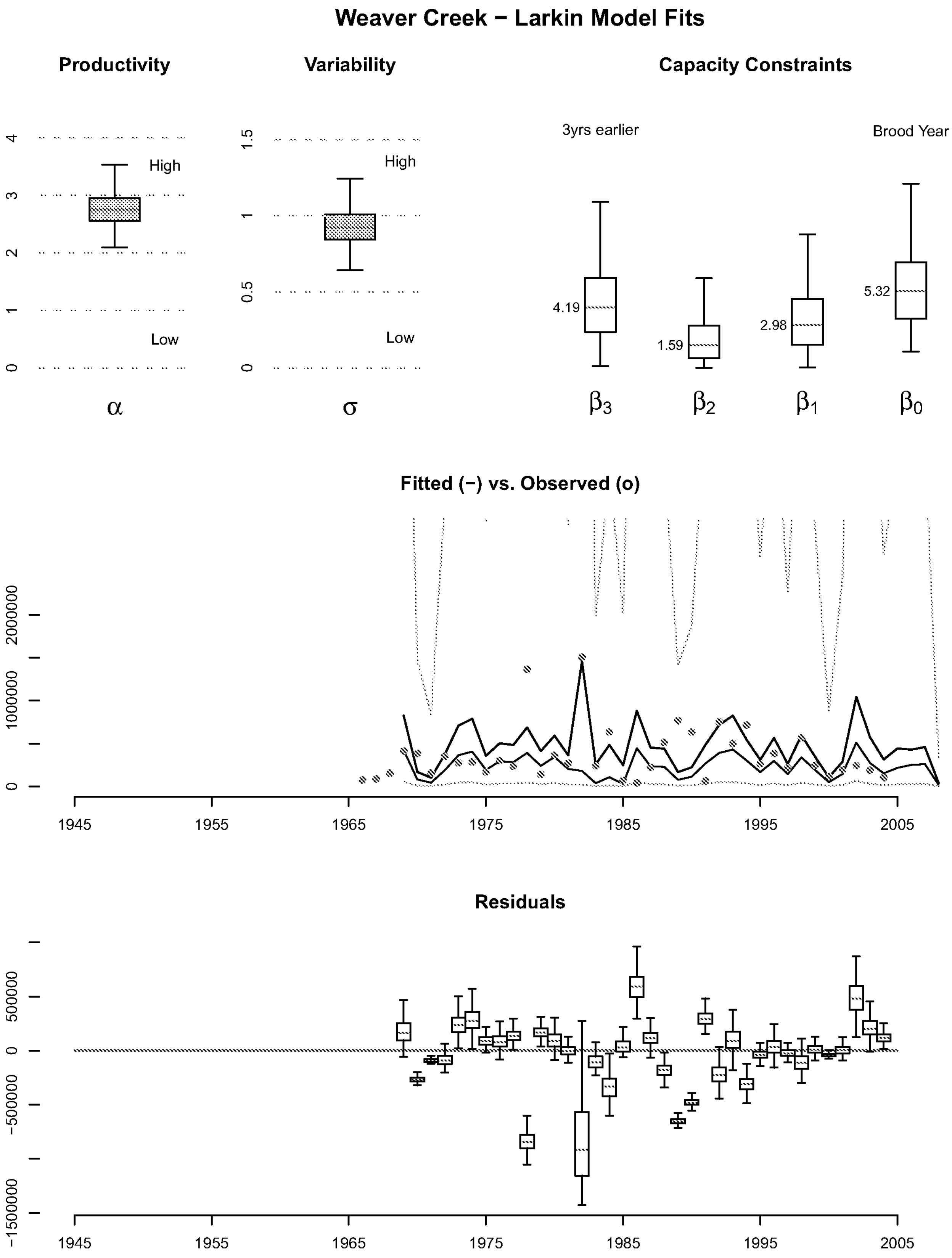


Figure A.17b: Larkin Model Fits − Weaver Creek

Weaver Creek

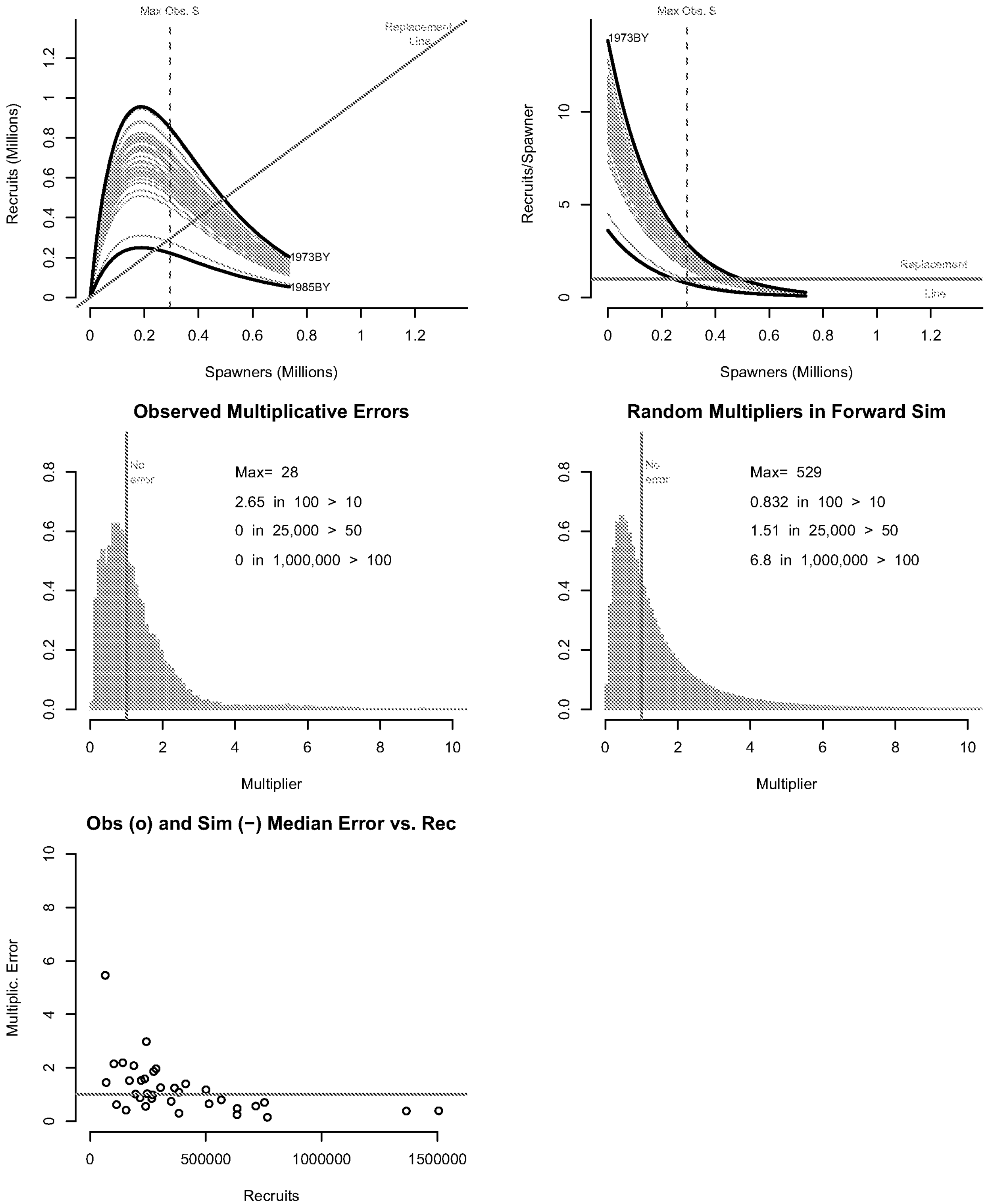


Figure A.17c: Delayed−density effects and error structure − Weaver Creek

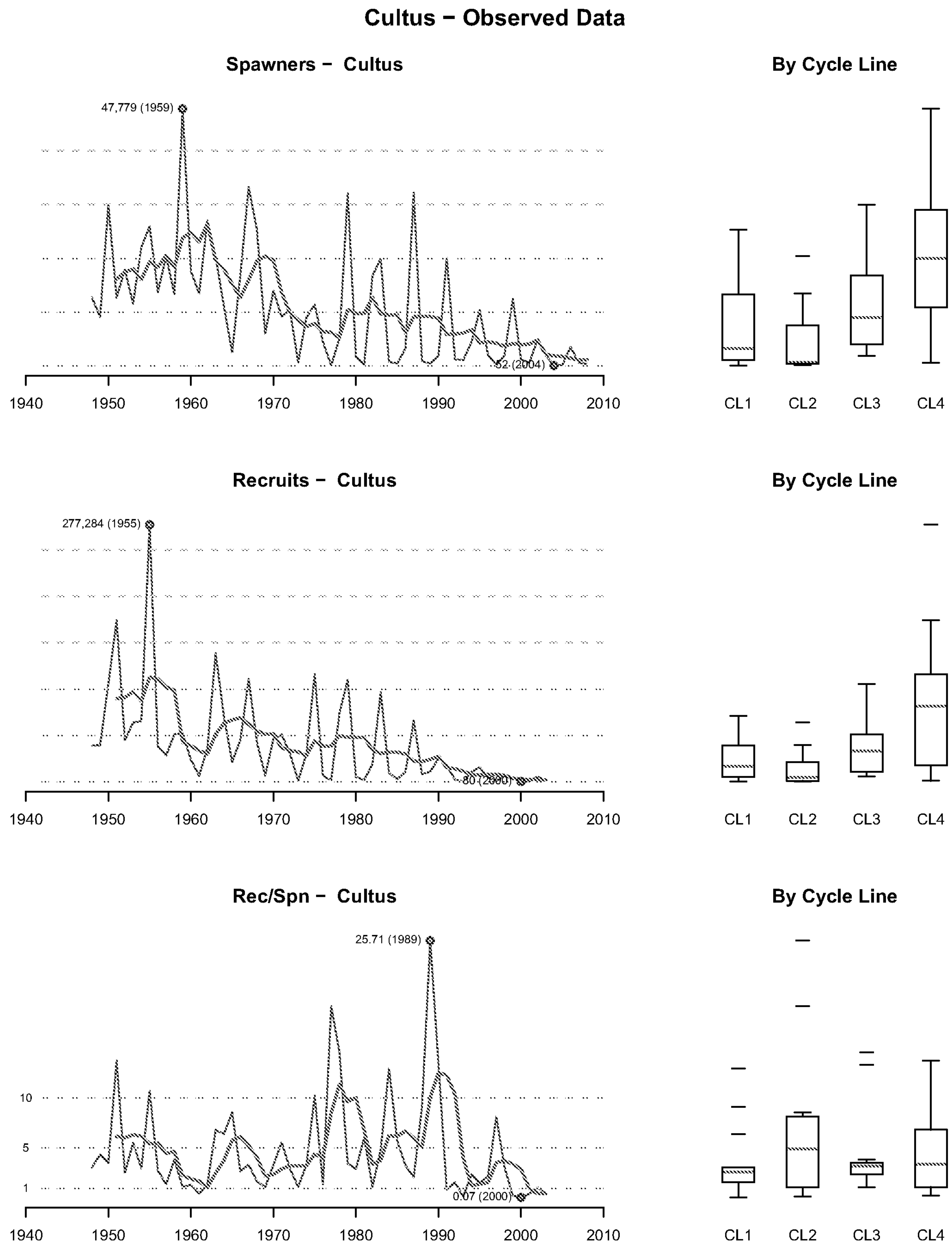


Figure A.18a: Observed Data − Cultus

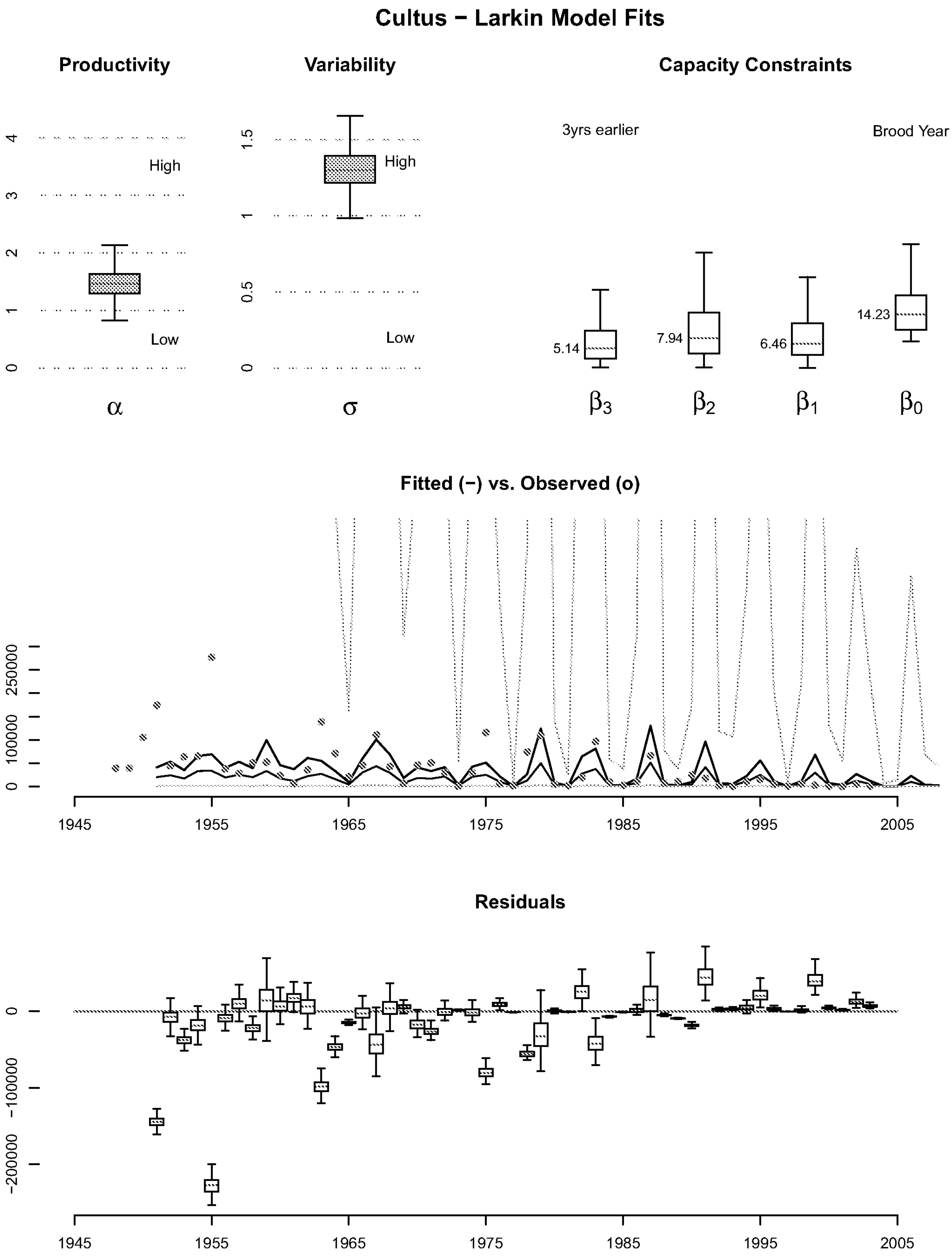


Figure A.18b: Larkin Model Fits − Cultus

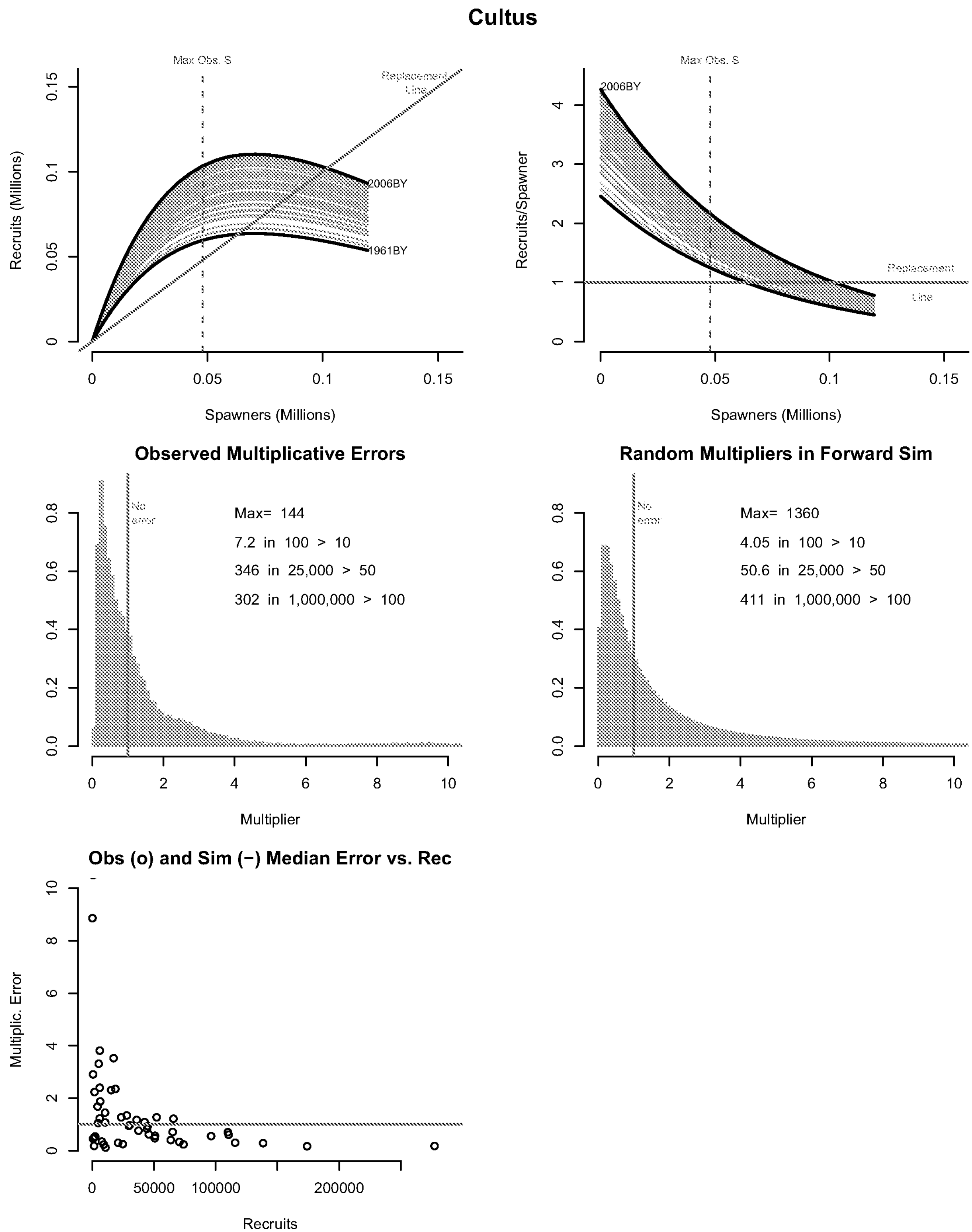
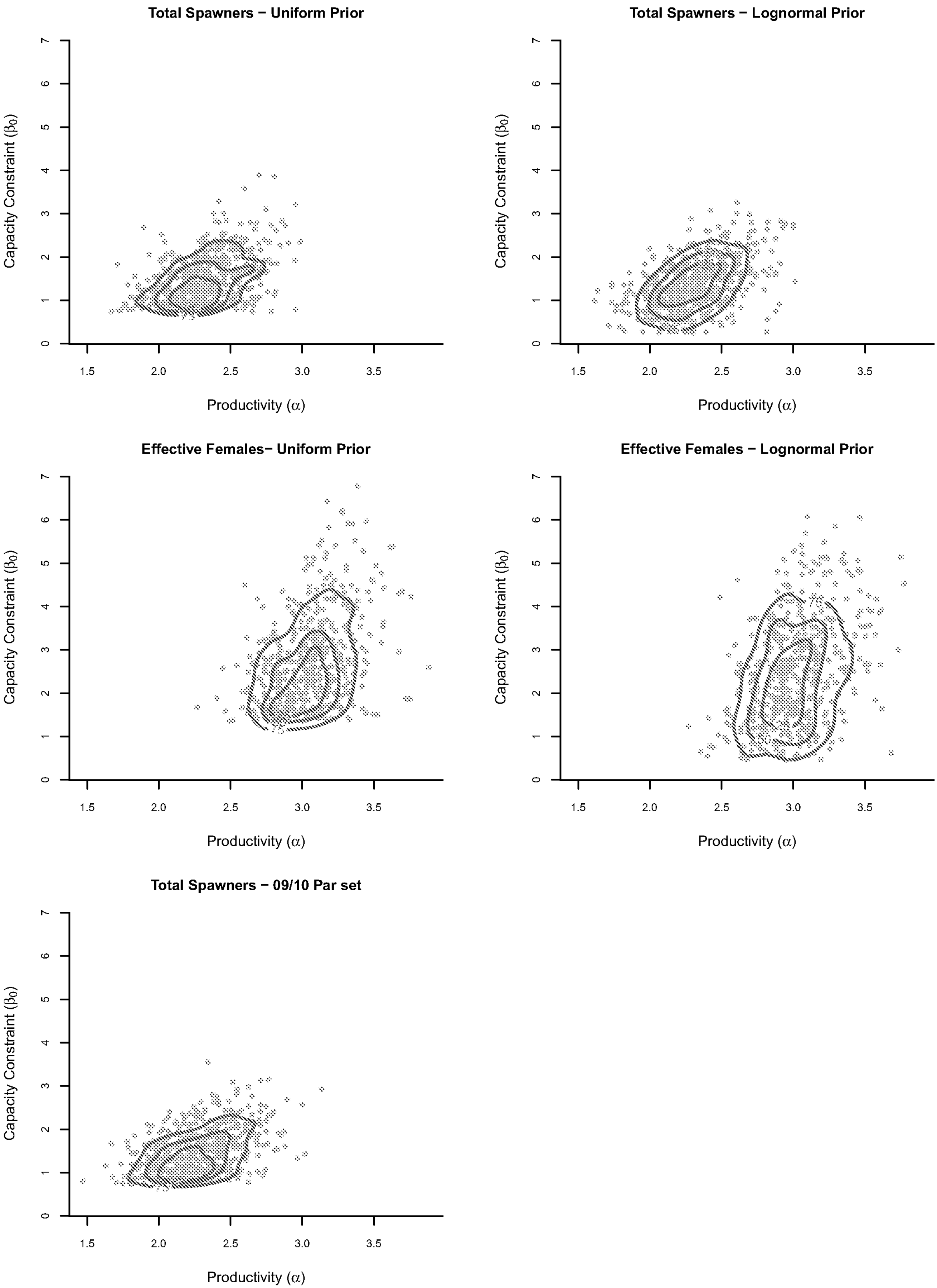


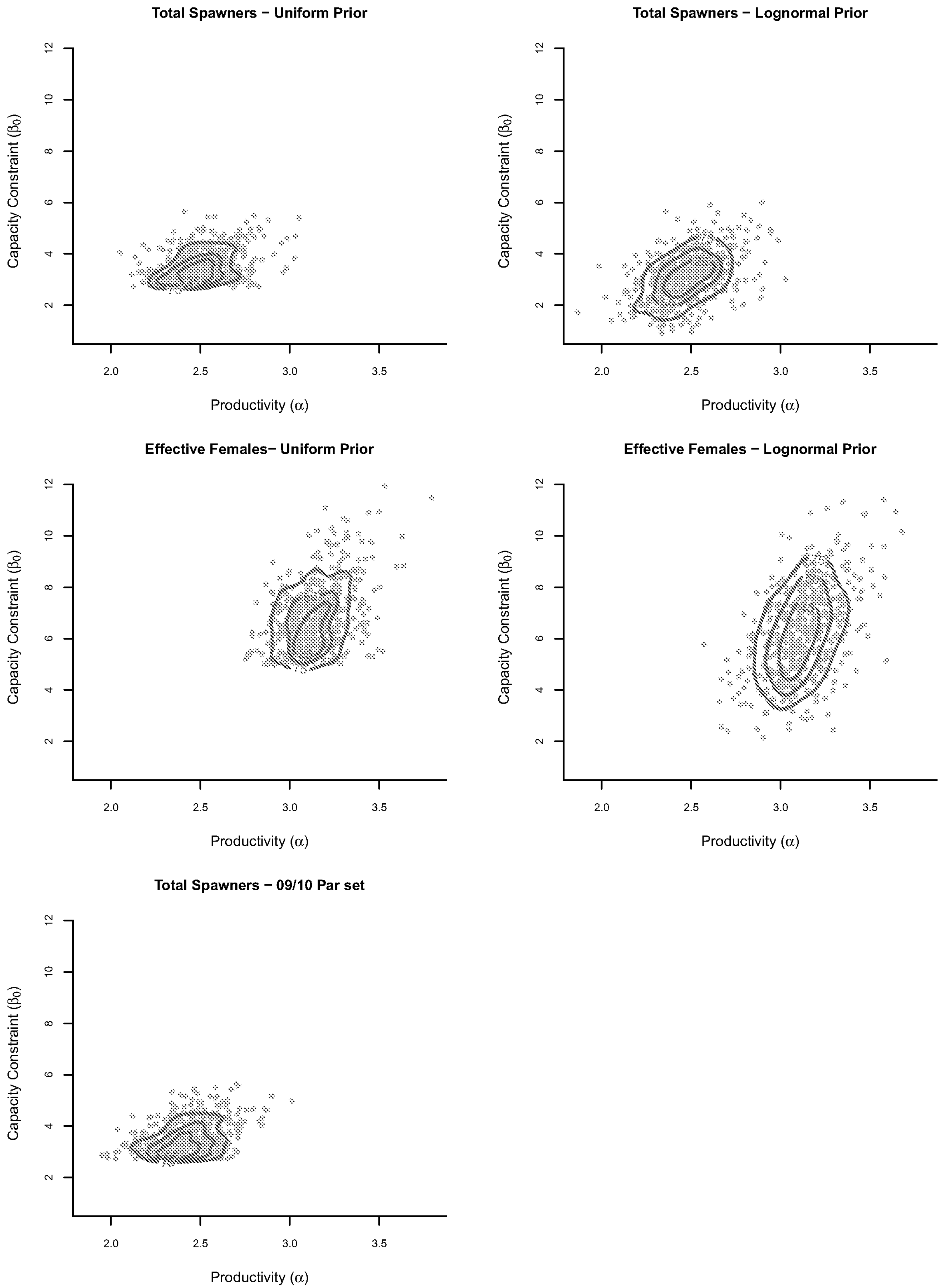
Figure A.18c: Delayed−density effects and error structure − Cultus

Appendix 5 : Alternative posterior distributions for SR parameters

2 Late Stuart

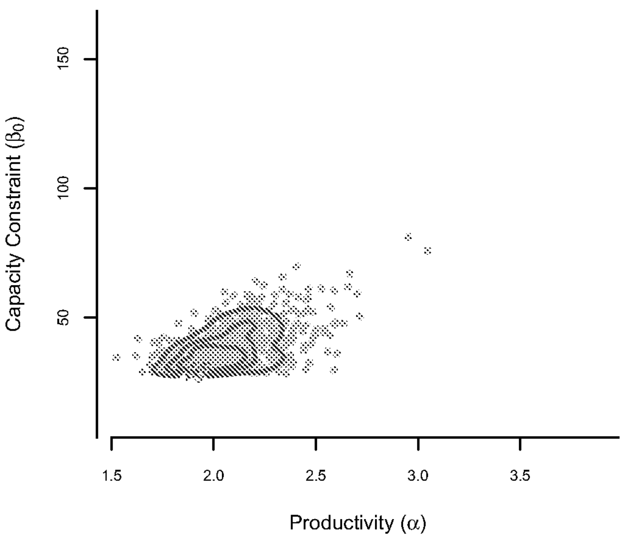


3 Stellako

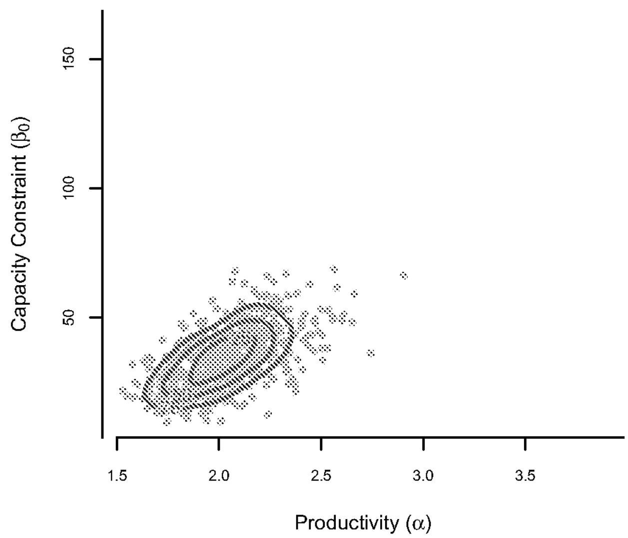

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint (β_0)
Productivity (α)
2
4
6
8
10
12
2.0
2.5
3.0
3.5

4 Bowron

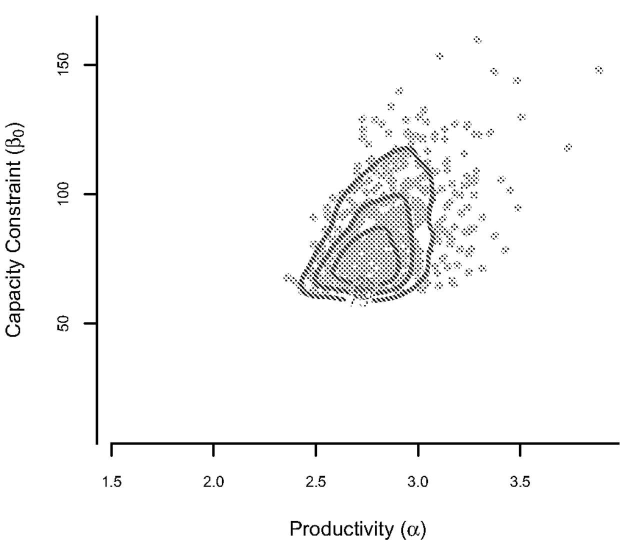
Total Spawners − Uniform Prior



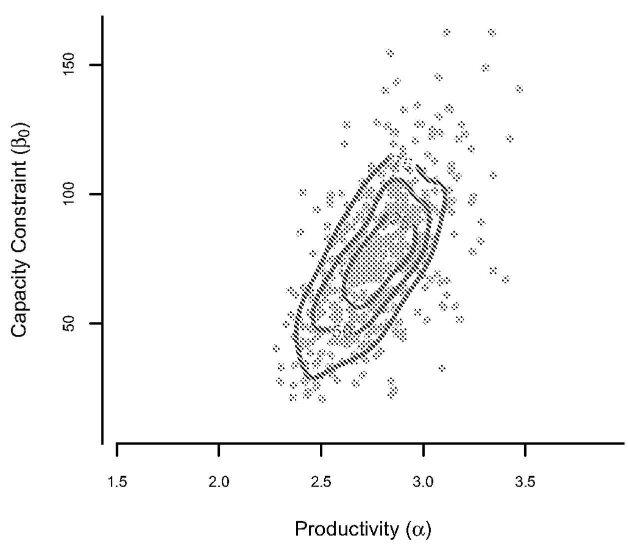
Total Spawners − Lognormal Prior



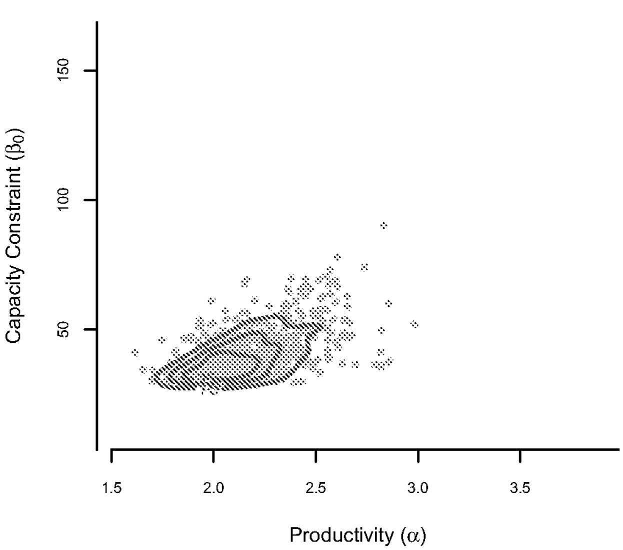
Effective Females− Uniform Prior



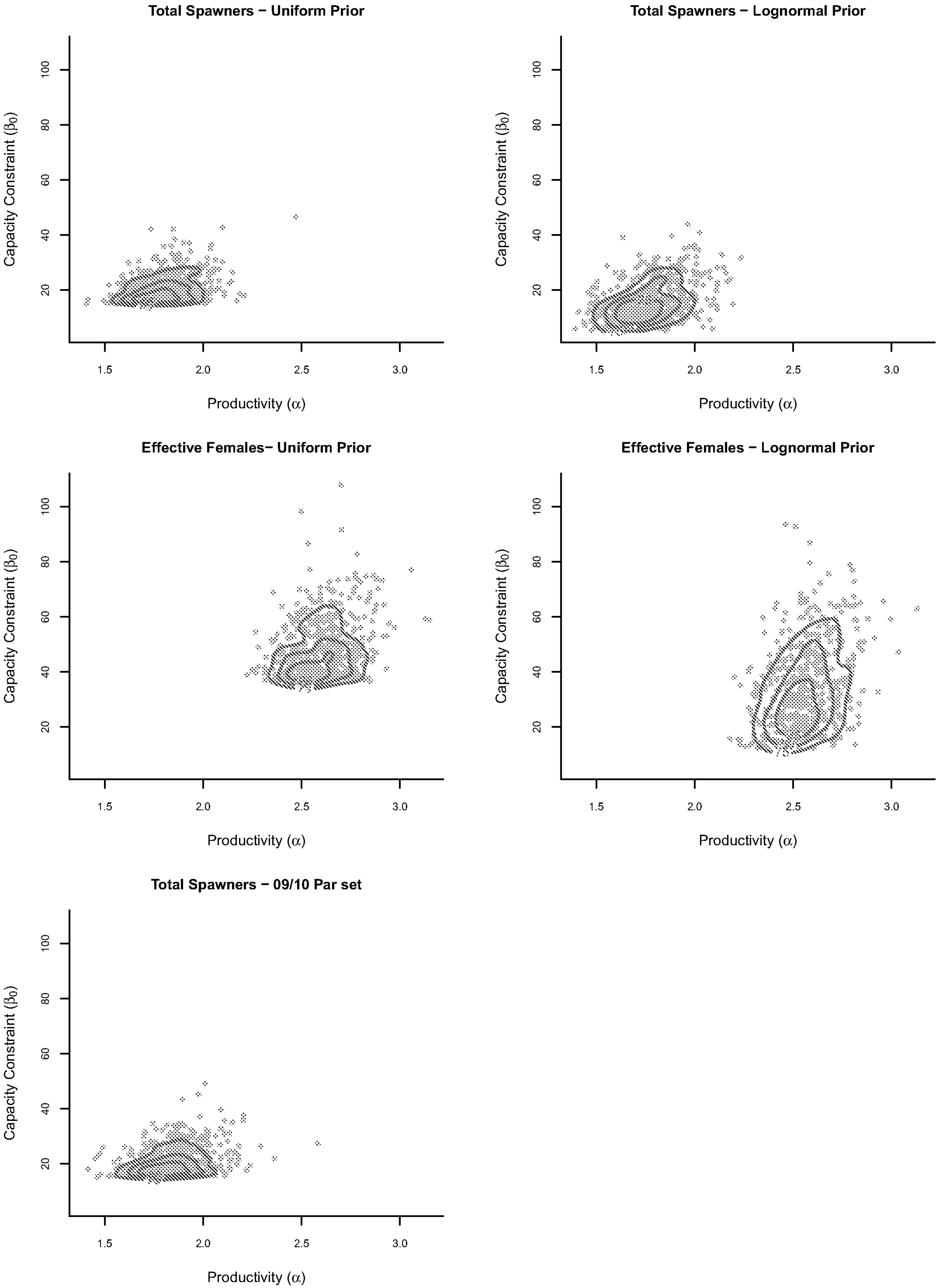
Effective Females − Lognormal Prior



Total Spawners − 09/10 Par set

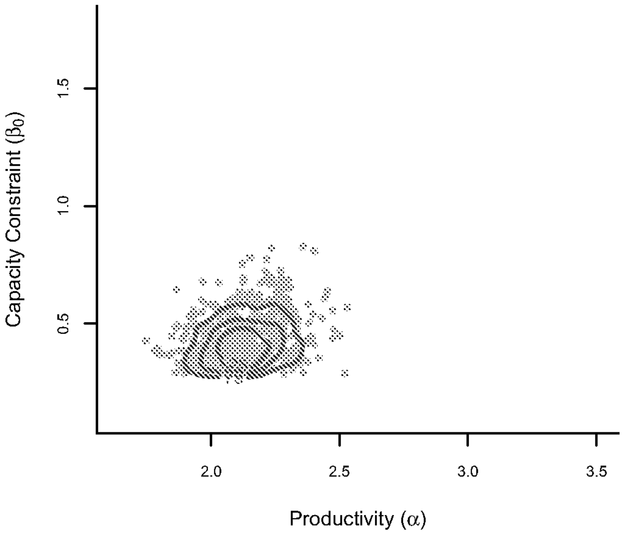


5 Raft

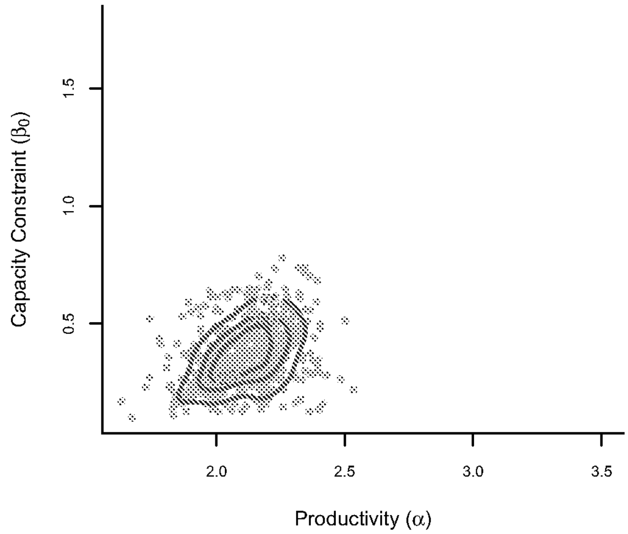

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint (β_0)
Productivity (α)
20
40
60
80
100
1.5
2.0
2.5
3.0

6 Quesnel

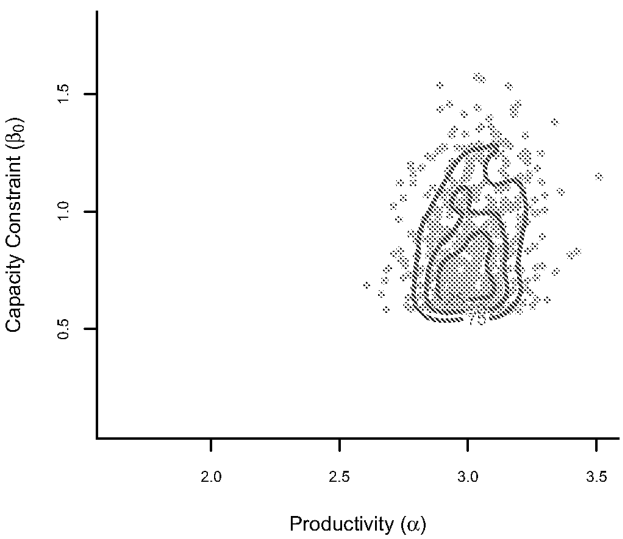
Total Spawners − Uniform Prior



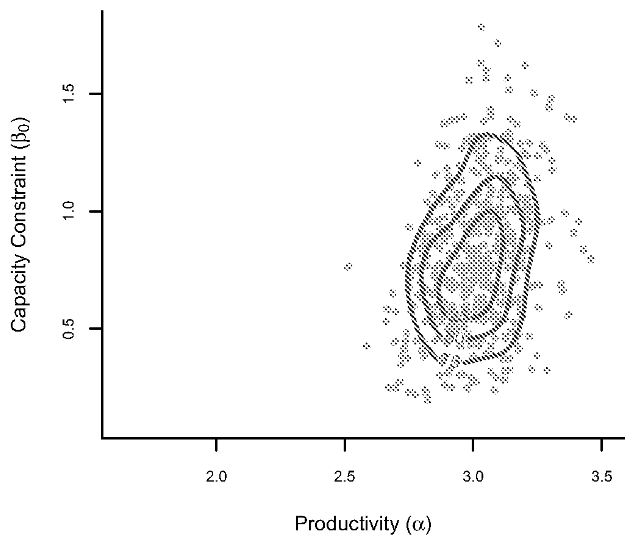
Total Spawners − Lognormal Prior



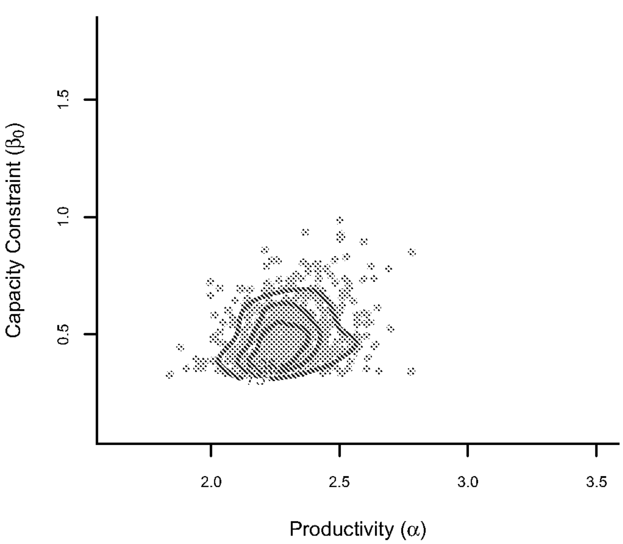
Effective Females− Uniform Prior



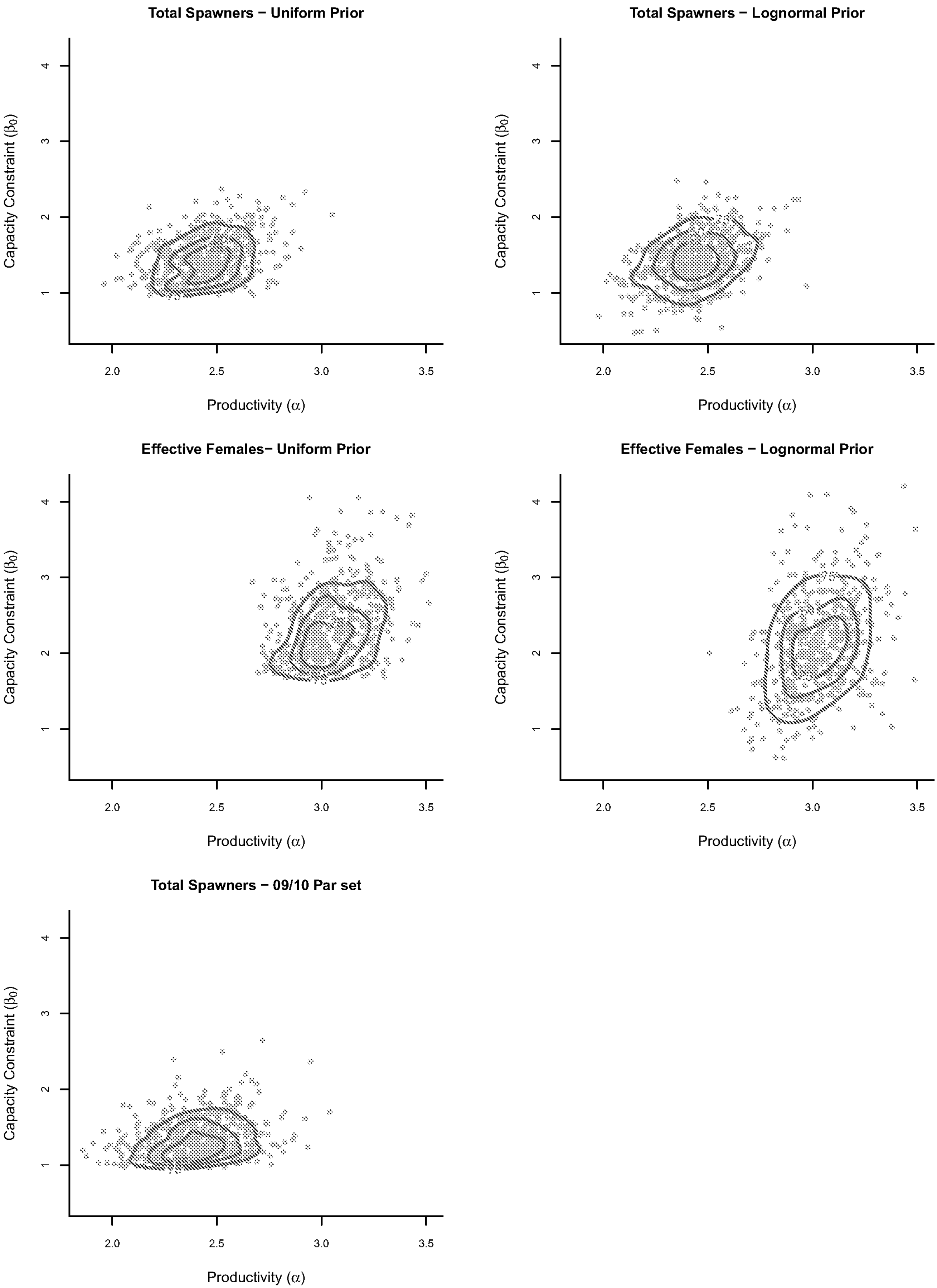
Effective Females − Lognormal Prior



Total Spawners − 09/10 Par set

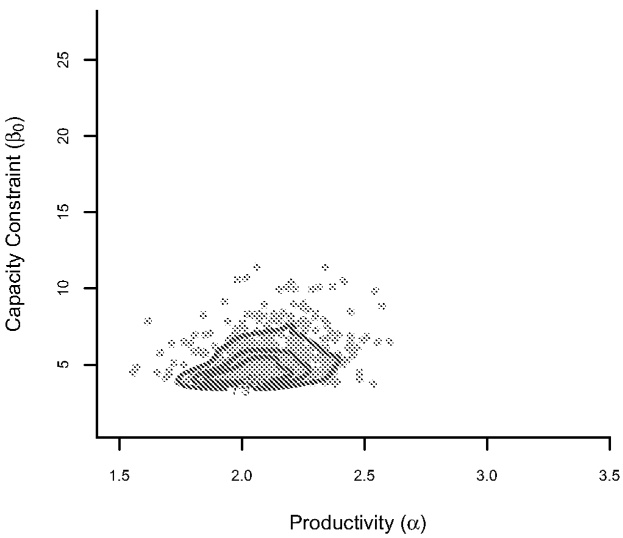


7 Chilko

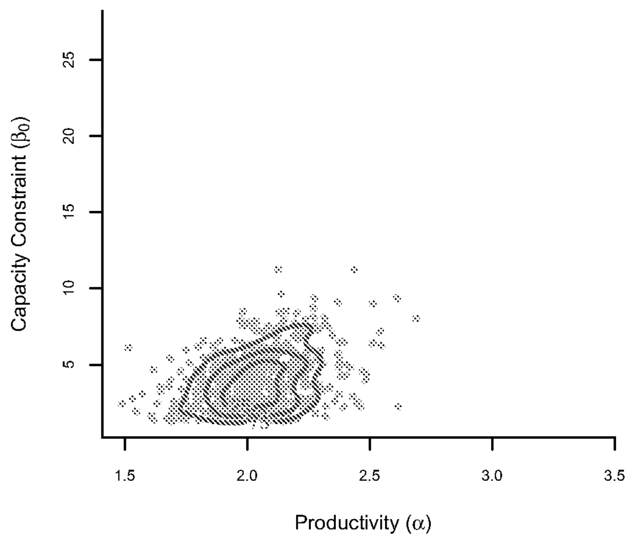

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint (β_0)
Productivity (α)
1
2
3
4
2.0
2.5
3.0
3.5

8 Seymour

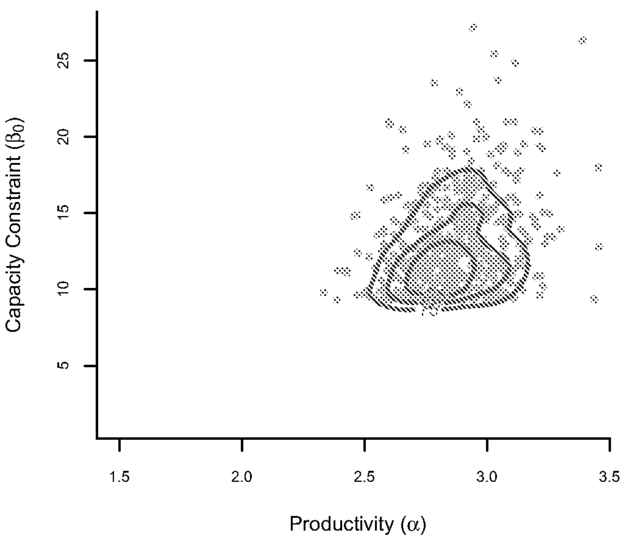
Total Spawners − Uniform Prior



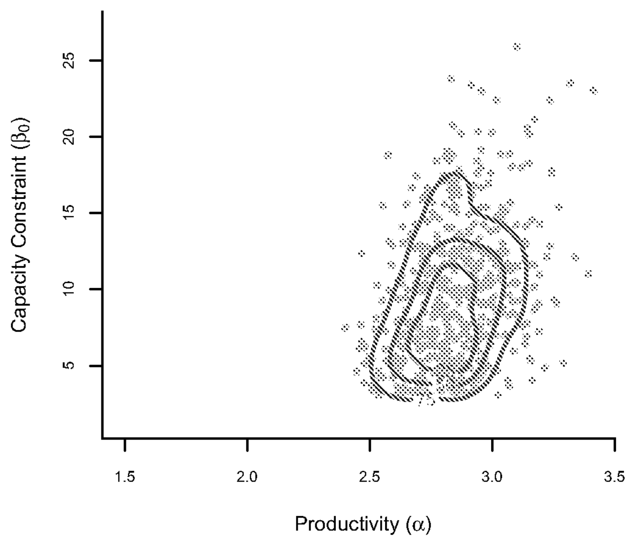
Total Spawners − Lognormal Prior



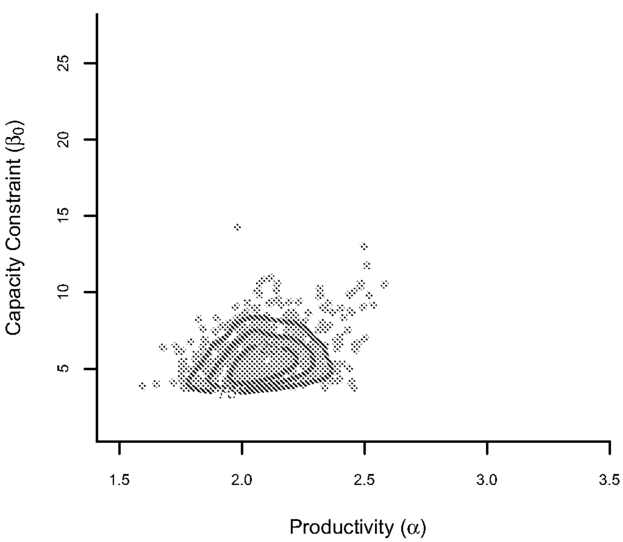
Effective Females− Uniform Prior



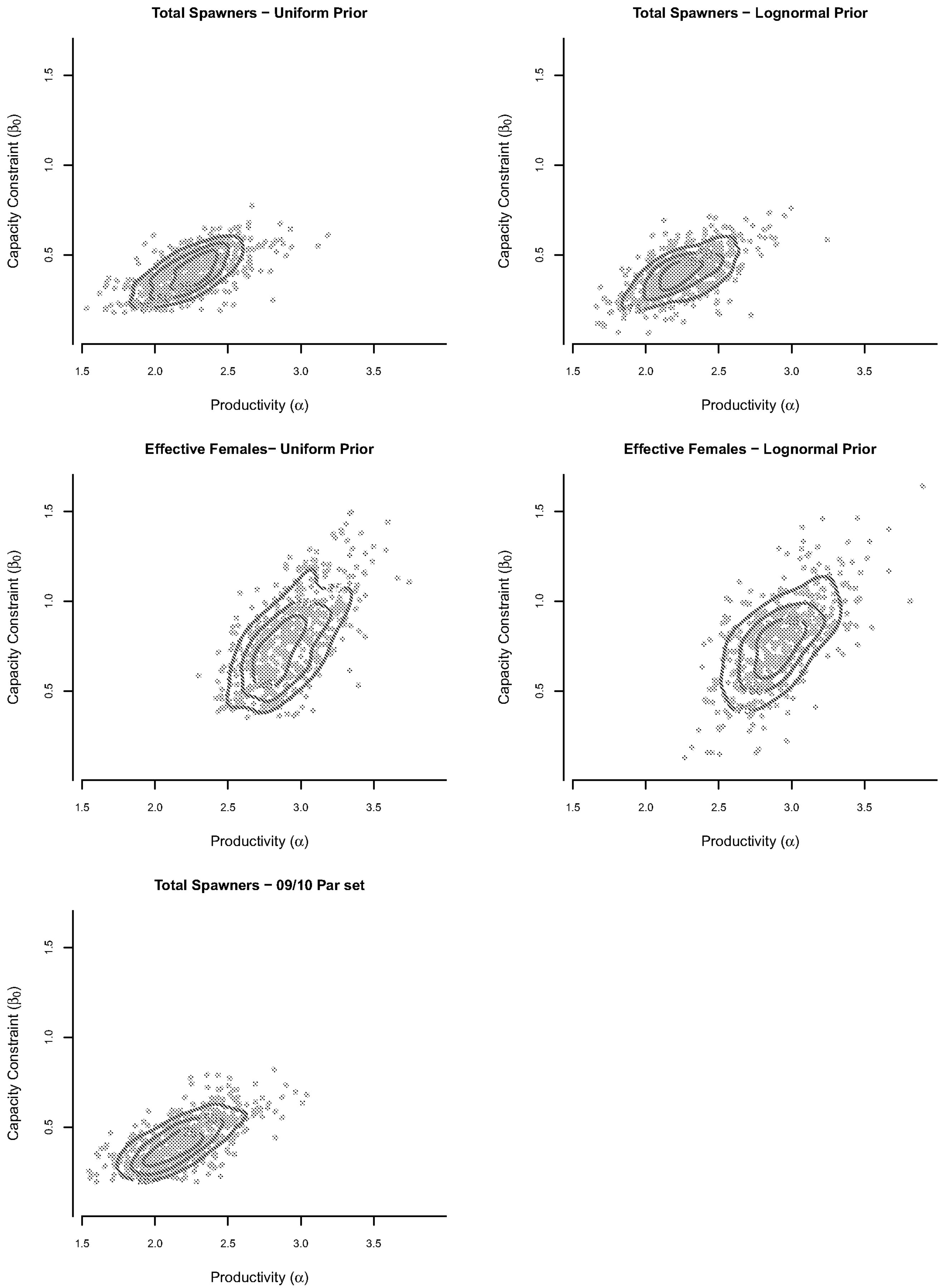
Effective Females − Lognormal Prior



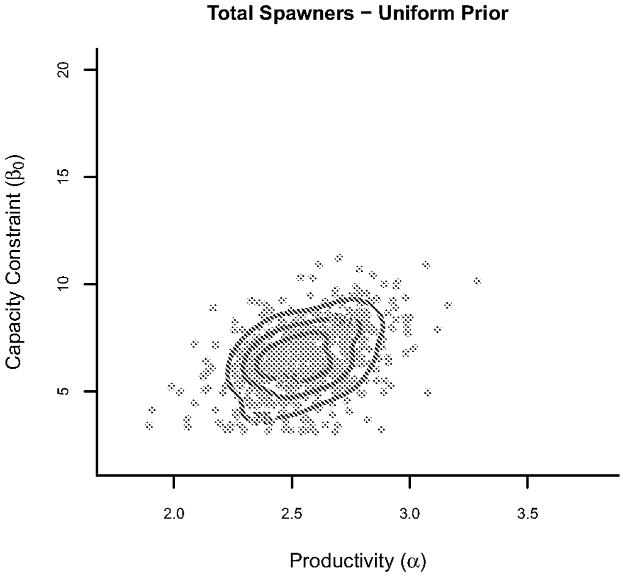
Total Spawners − 09/10 Par set

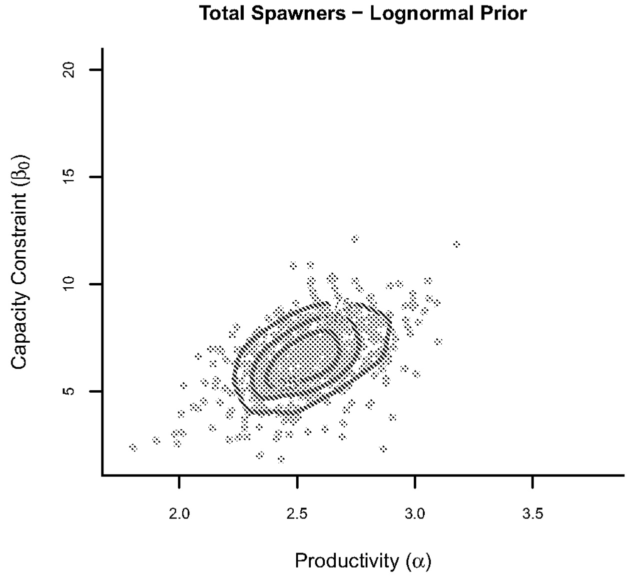


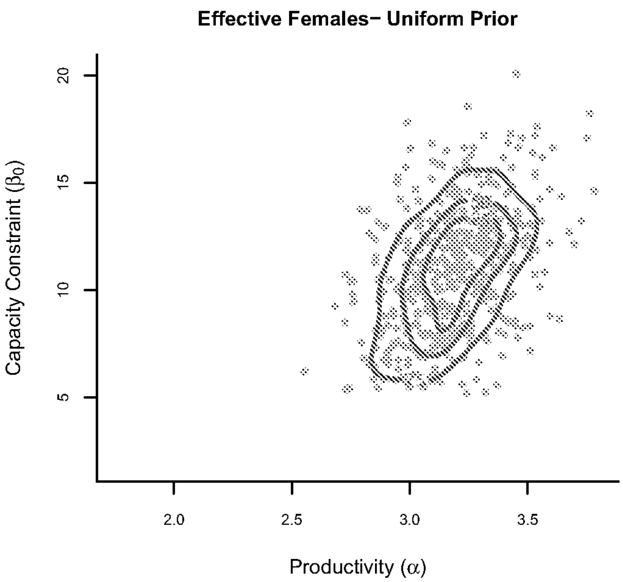
9 Late Shuswap

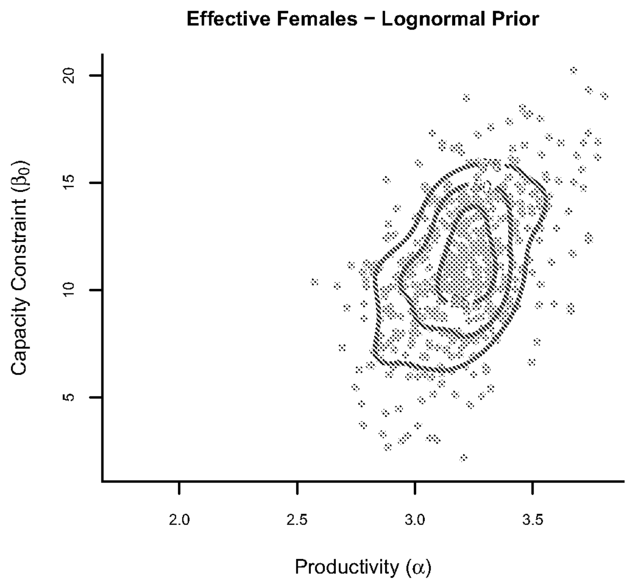


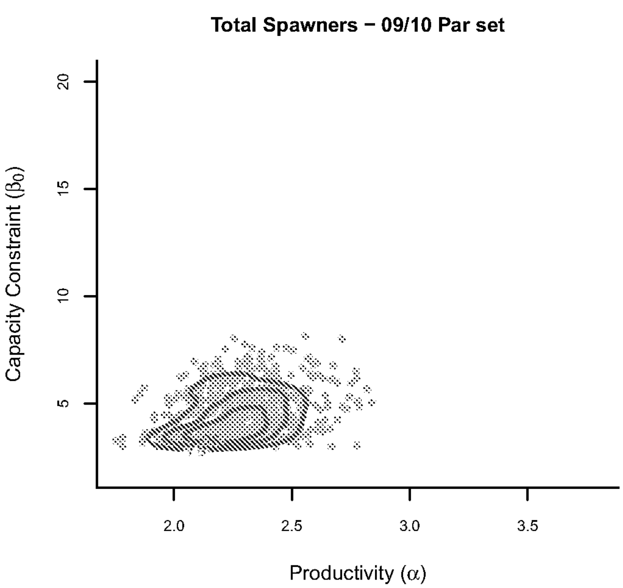
10 Birkenhead



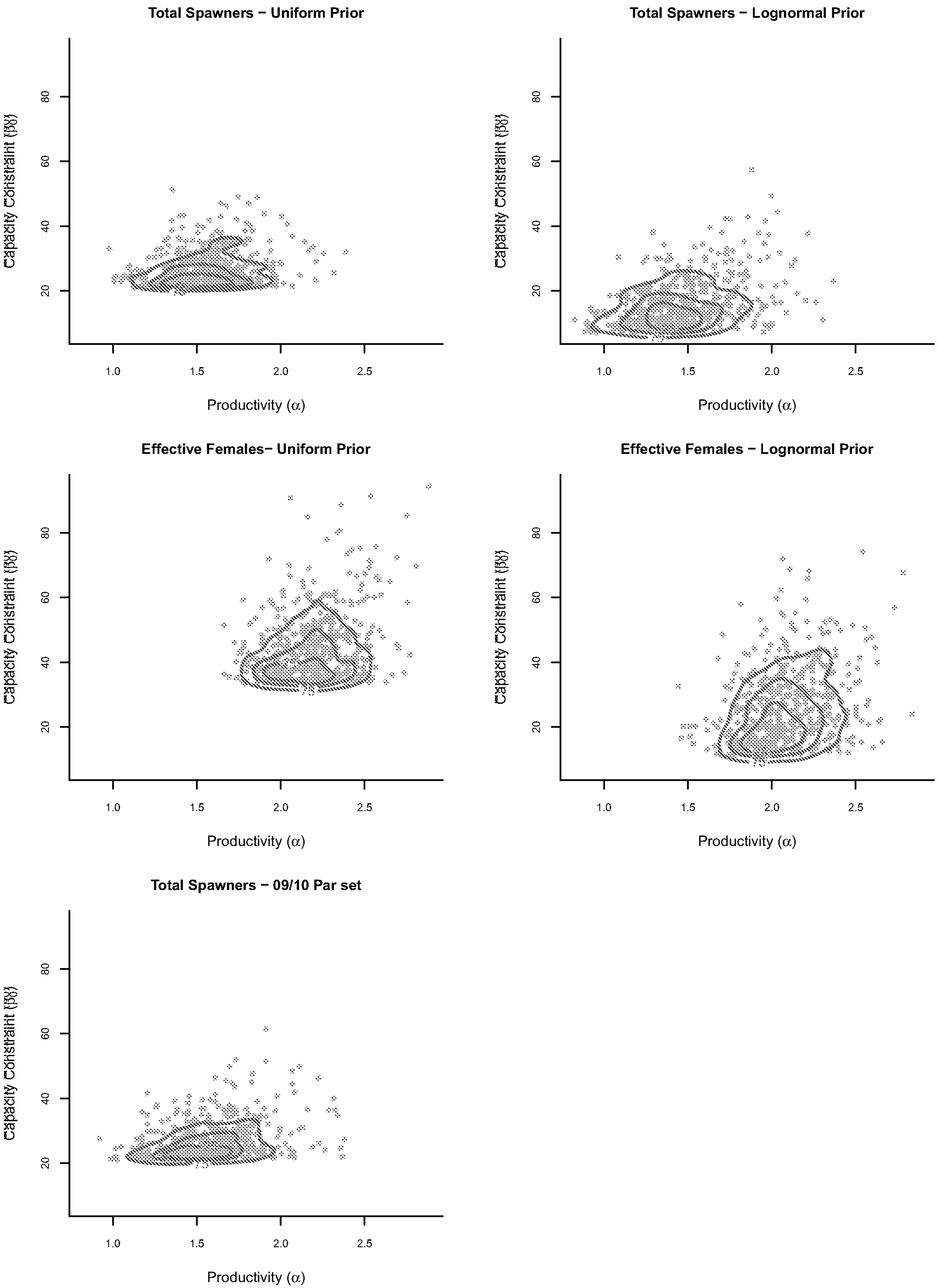




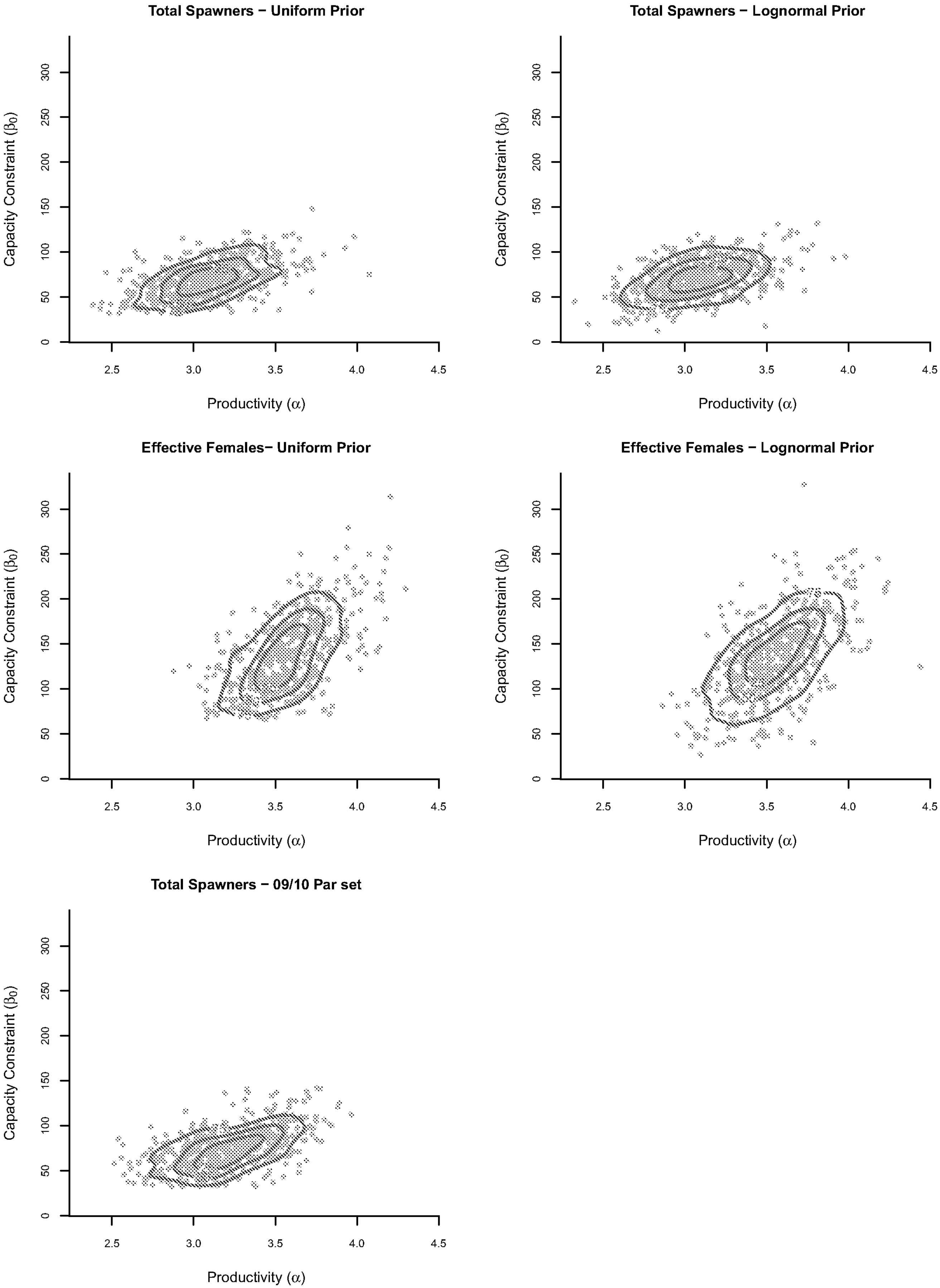




11 Cultus

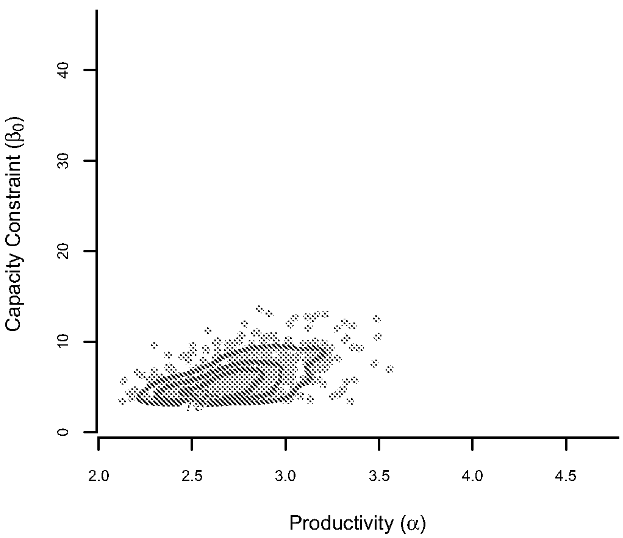

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint
Productivity (α)
20
40
60
80
1.0
1.5
2.0
2.5

12 Portage

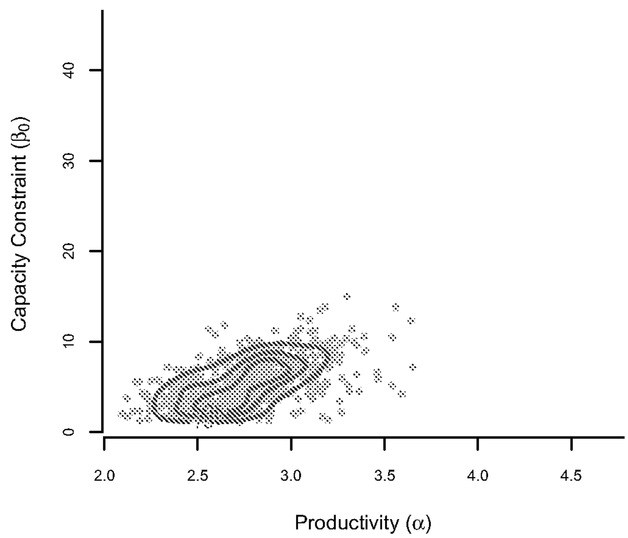

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint (β_0)
Productivity (α)
0
50
100
150
200
250
300
2.5
3.0
3.5
4.0
4.5

13 Weaver Creek

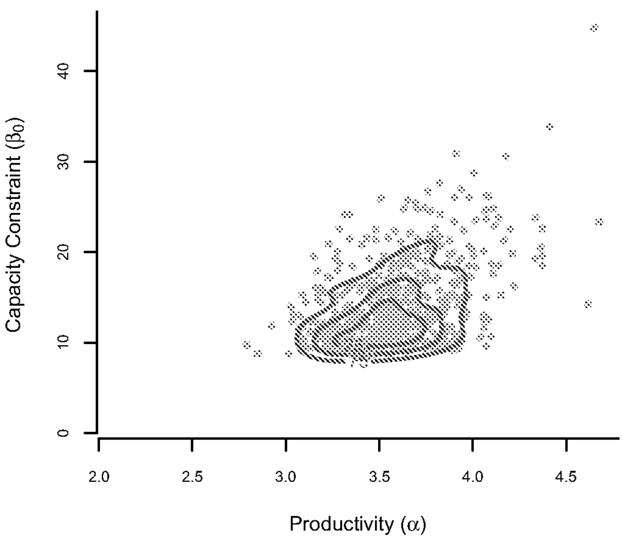
Total Spawners − Uniform Prior



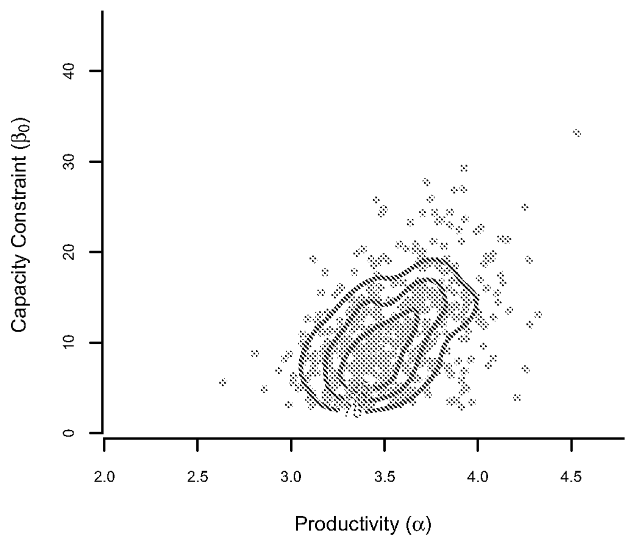
Total Spawners − Lognormal Prior



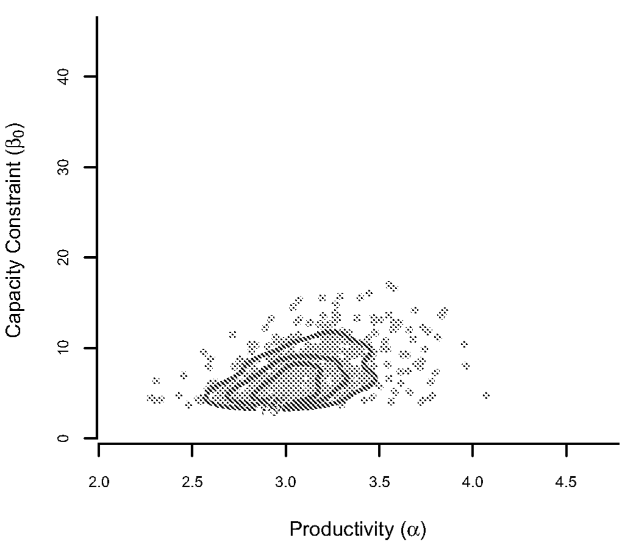
Effective Females− Uniform Prior



Effective Females − Lognormal Prior

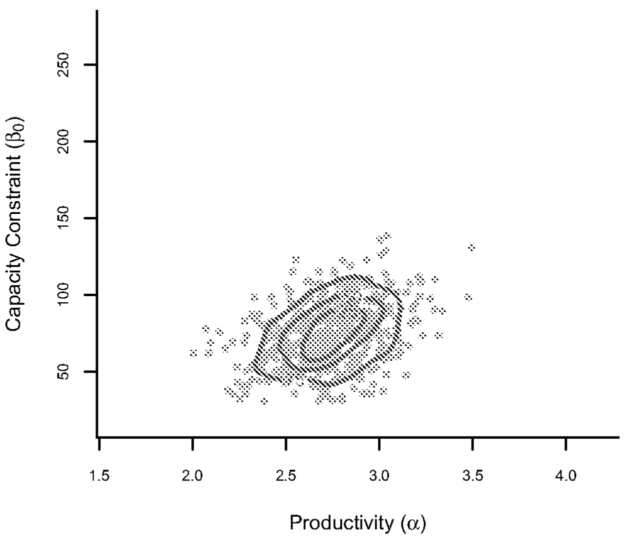


Total Spawners − 09/10 Par set

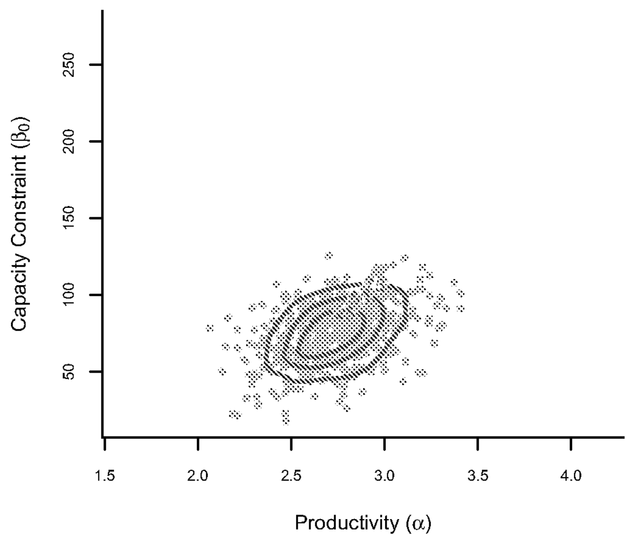


14 Fennel Creek

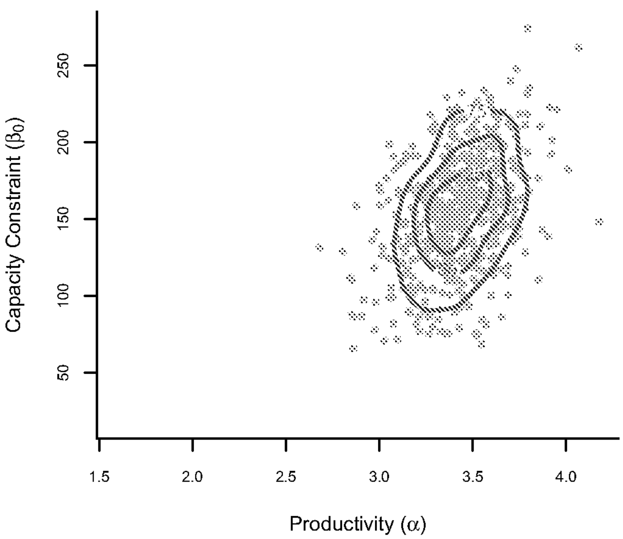
Total Spawners − Uniform Prior



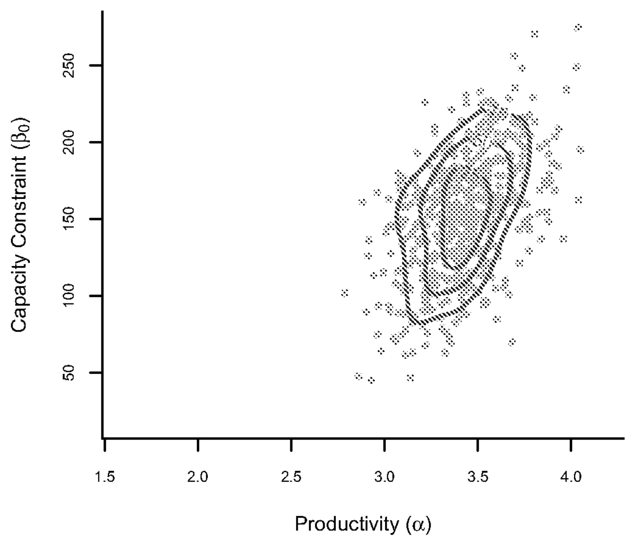
Total Spawners − Lognormal Prior



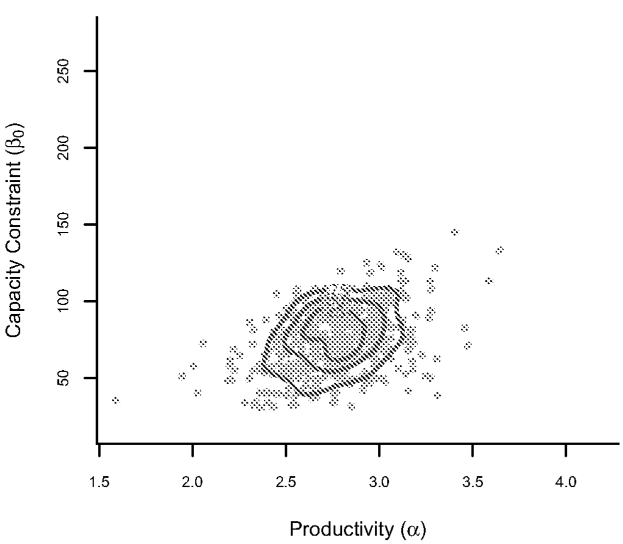
Effective Females− Uniform Prior



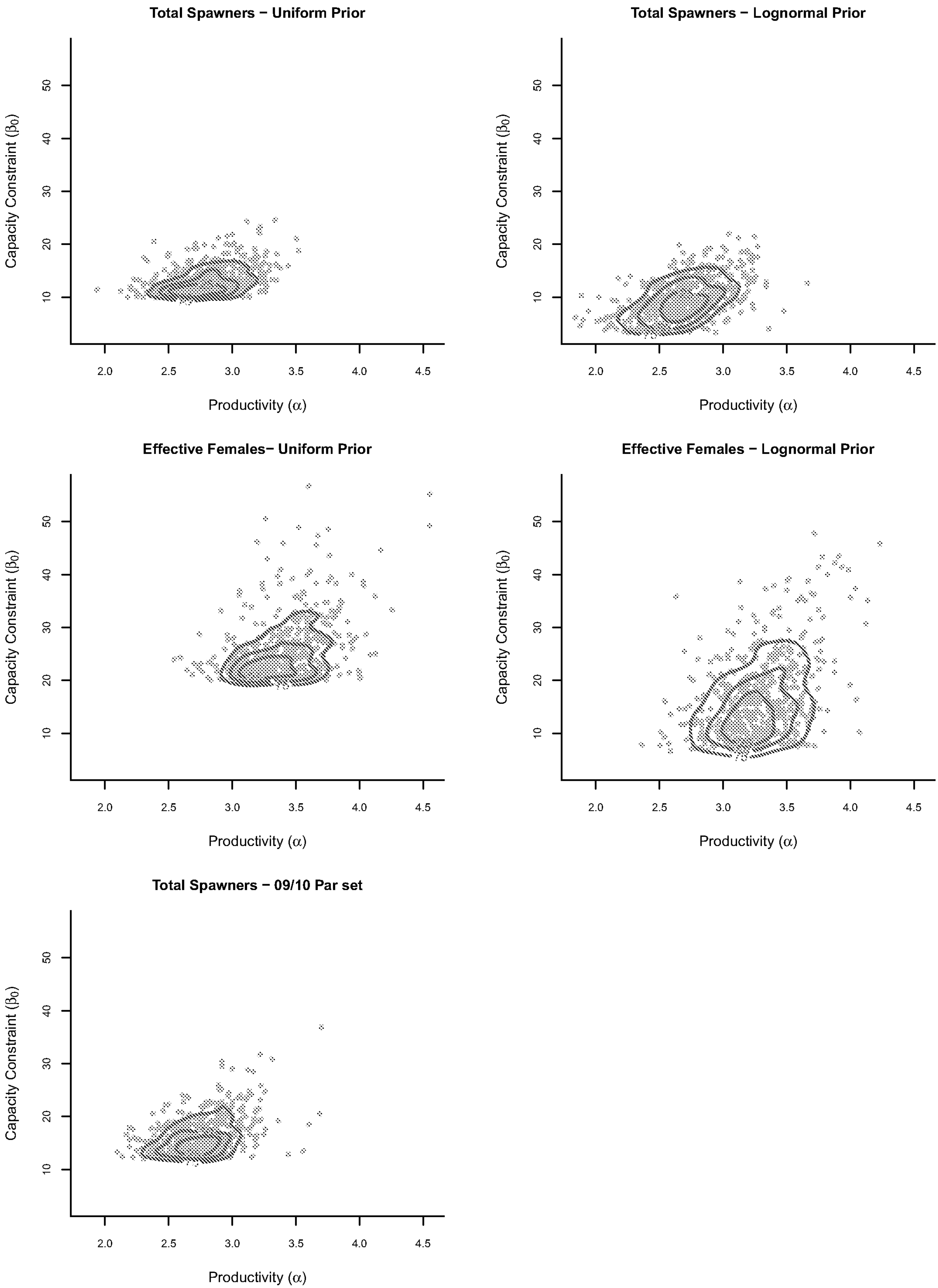
Effective Females − Lognormal Prior



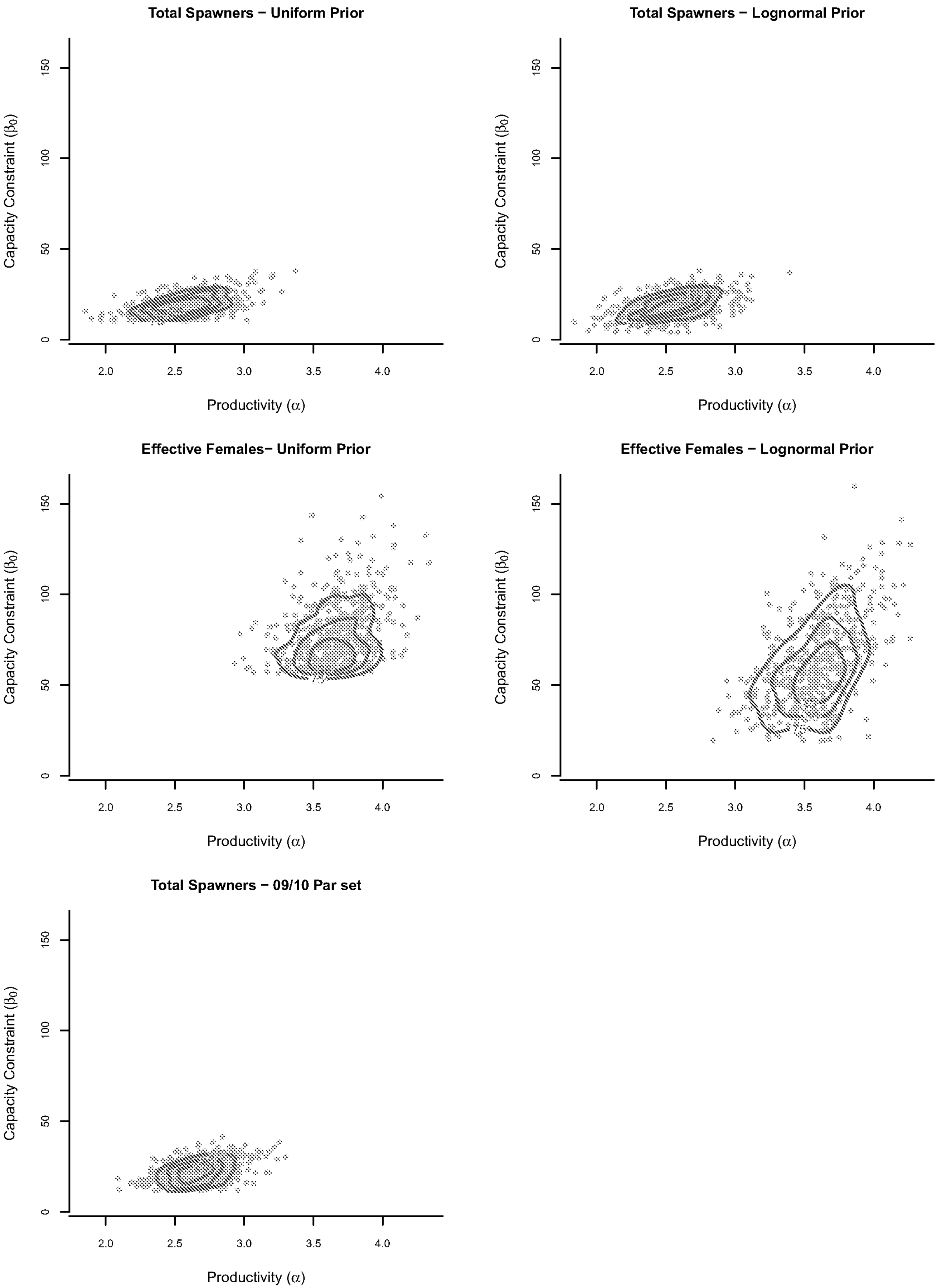
Total Spawners − 09/10 Par set



15 Scotch Creek

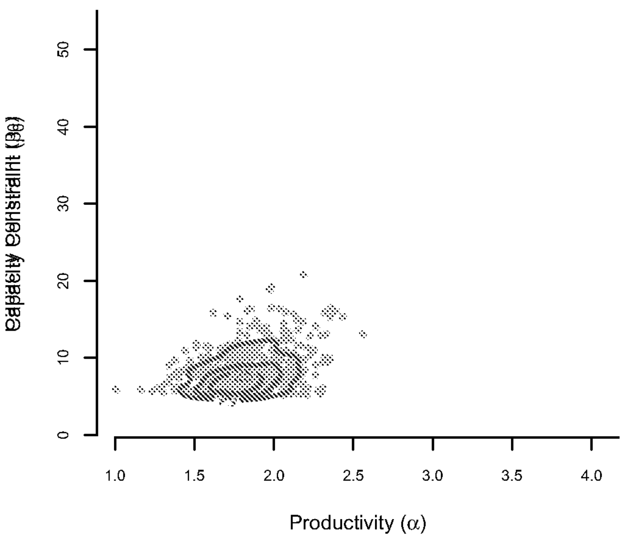


16 Gates

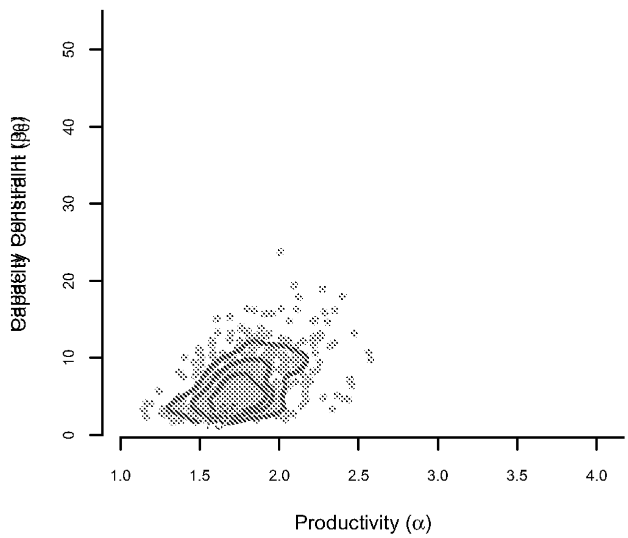

Total Spawners − Uniform Prior
Total Spawners − Lognormal Prior
Effective Females− Uniform Prior
Effective Females − Lognormal Prior
Total Spawners − 09/10 Par set
Capacity Constraint (β_0)
Productivity (α)
0
50
100
150
2.0
2.5
3.0
3.5
4.0

17 Nadina

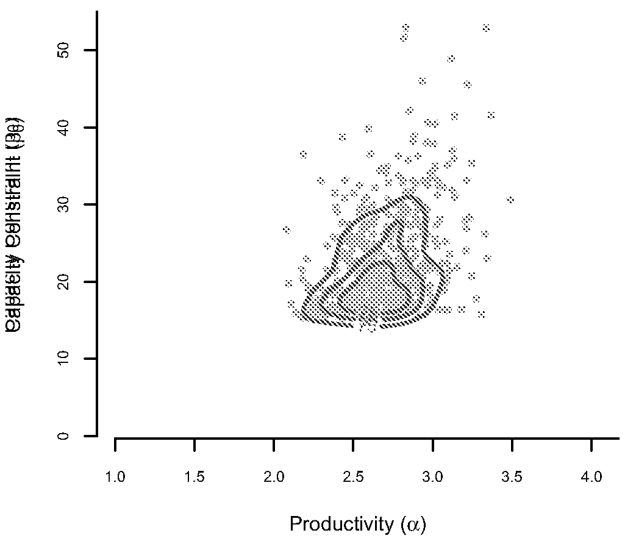
Total Spawners − Uniform Prior



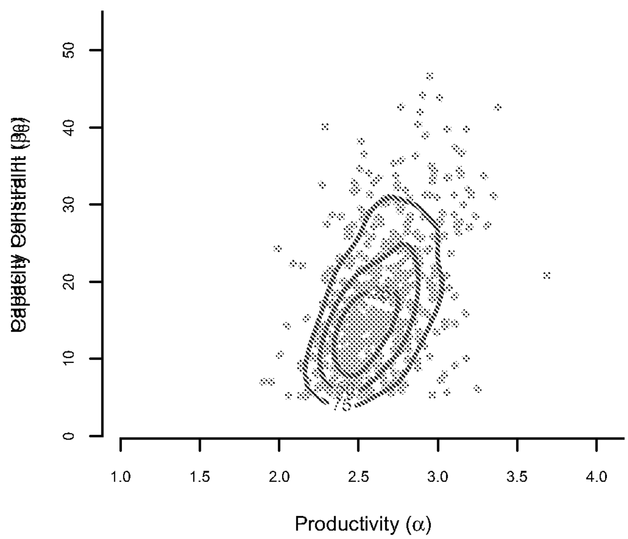
Total Spawners − Lognormal Prior



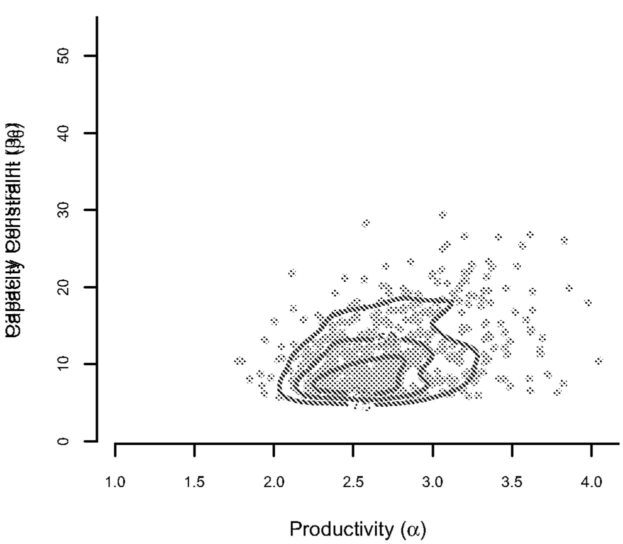
Effective Females− Uniform Prior



Effective Females − Lognormal Prior

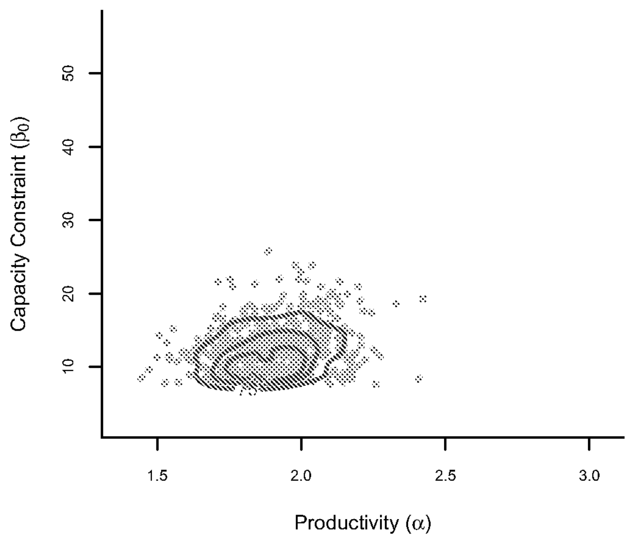


Total Spawners − 09/10 Par set

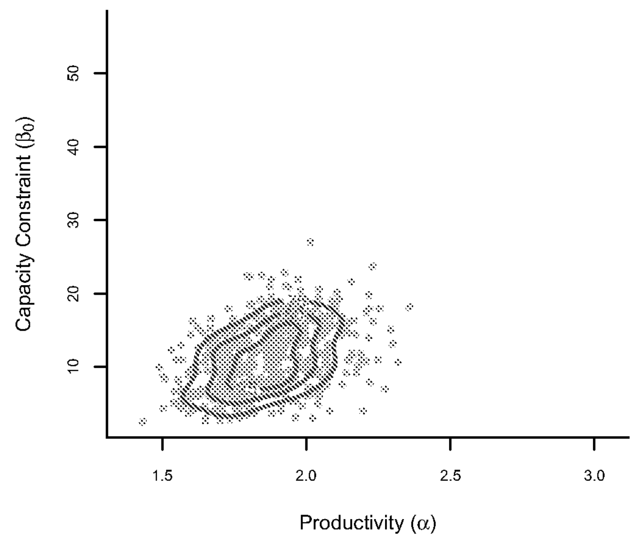


18 Upper Pitt River

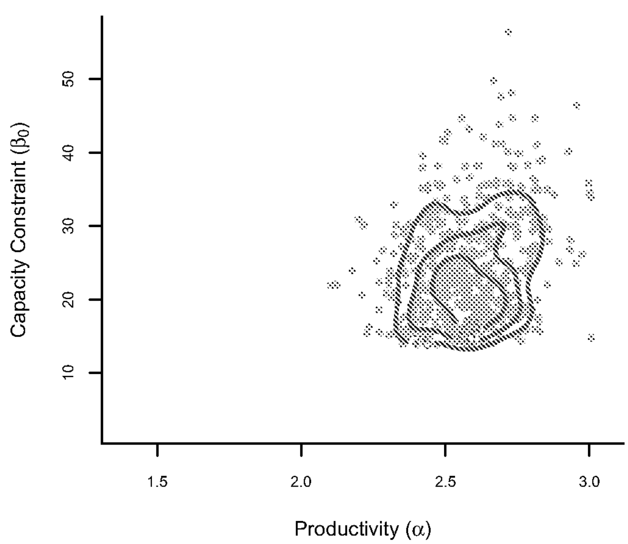
Total Spawners − Uniform Prior



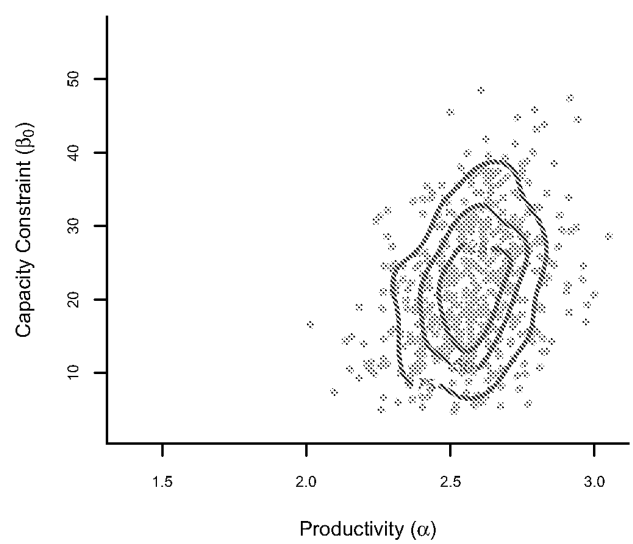
Total Spawners − Lognormal Prior



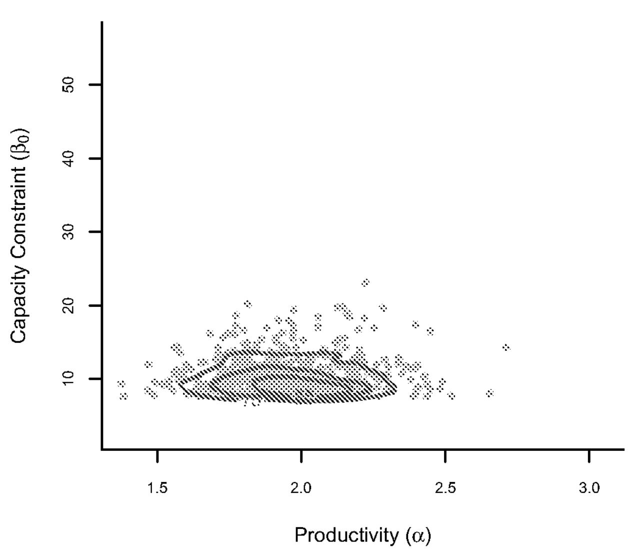
Effective Females− Uniform Prior



Effective Females − Lognormal Prior

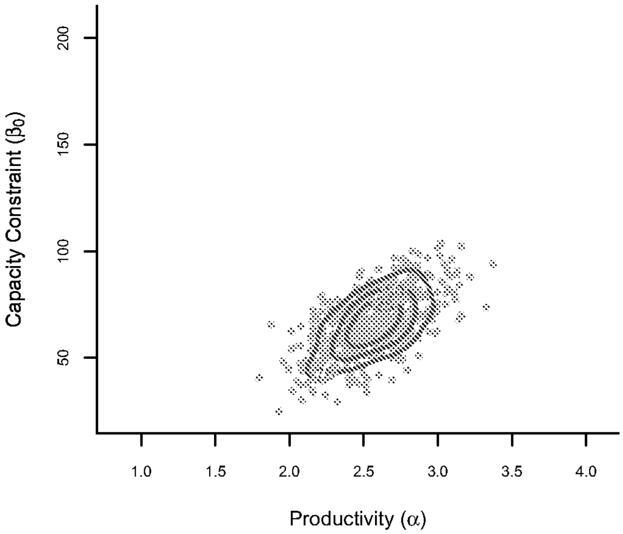


Total Spawners − 09/10 Par set

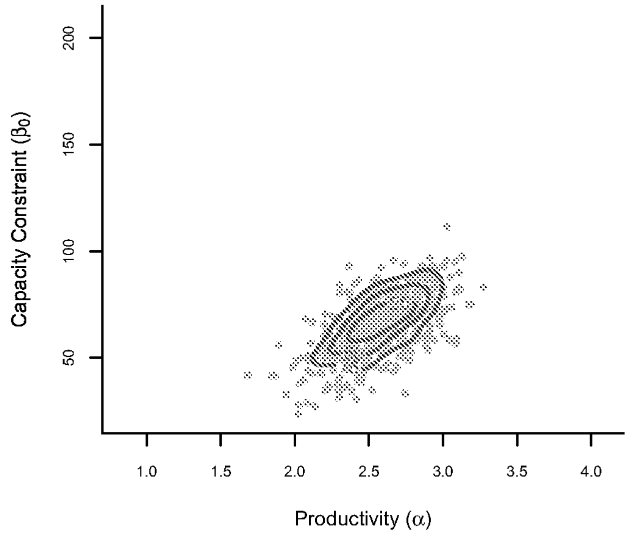


19 Harrison

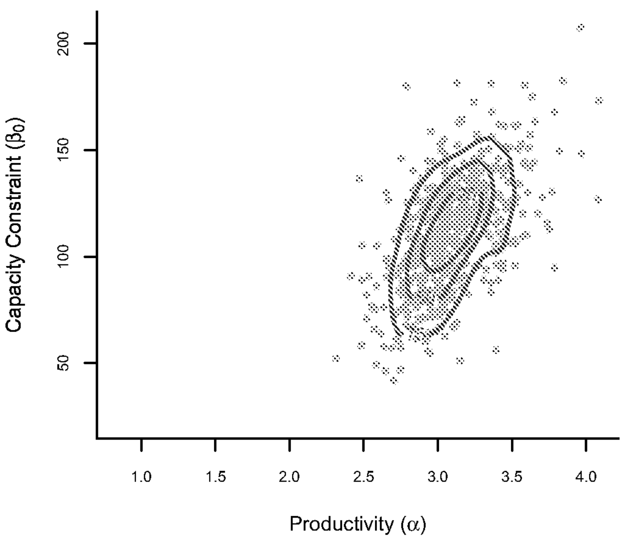
Total Spawners − Uniform Prior



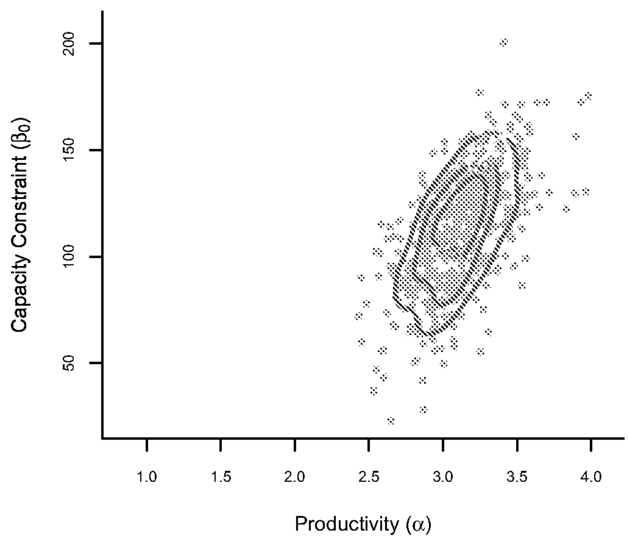
Total Spawners − Lognormal Prior



Effective Females− Uniform Prior



Effective Females − Lognormal Prior



Total Spawners − 09/10 Par set