Ocean harvest real-time forecasts of

fall Chinook salmon (*Oncorhynchus tshawytscha*)

returns to the Columbia River

Pacific Salmon Commission Southern Fund 2008/09

Final report

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EXECUTIVE SUMMARY

Forecasts of fall Chinook salmon runs to the Columbia River are a critical management component for harvest decisions and monitoring abundance trends because Columbia River fall Chinook salmon form the largest contributing fish group to ocean Chinook fisheries north of Cape Falcon, Oregon, and also they include Snake River fish at extinction risk (Good et al. 2005). For the forecast importance, preseason forecasts of fall Chinook salmon runs have been made annually, using historical sibling runs. However their accuracy has not been consistent over years, and further uncertainty of preseason forecasts has not been measured.

The main motivation of this study is to improve the traditional forecast methods. We noted that catch and effort data from ocean troll fisheries during May – July have not been incorporated to the traditional preseason forecasts that are made before February or March. Such data could be available on a real-time basis, and thus incorporation of those data would enable us to make the real-time forecasts of fish runs.

Catch and effort data from Southeast (SE) Alaska ocean troll fisheries are available on a weekly basis. Stock- and age- specific proportions in the ocean abundance are estimated by the PSC CTC ocean model. Applying the proportion estimates to ocean catch data, we were able to extract data on stock- and age- specific ocean catches. With those data, we made in-season forecasts of fish runs on a weekly basis.

We blended the in-season forecast of fish run with the traditional preseason forecast to create an integrated forecast. To do so, we made the respective forecast as a probability density function (pdf). The pdf of the integrated forecast was built by the product of the in-season forecast and preseason forecast, assuming the independence between these two forecasts. We applied our methods to five stocks of Upriver Bright (URB), Mid Columbia River Bright (MCB), Lower River Wild (LRW), Lower River Hatchery (LRH), and Bonneville Pool Hatchery (BPH).

We evaluated performances of the in-season forecasts, the preseason forecasts, and the integrated forecasts respectively. We found the distributions of the traditional preseason forecasts were very narrow, and thus 90% prediction interval (PI) of the preseason

forecasts frequently missed actual runs. We inflated the preseason forecast's distribution by multiplying its standard deviation (SD) by five. The five times of its SD was chosen by our empirical exploration. The integrated forecast, which is from the inflated preseason forecast and the in-season forecast, performed best in terms of accuracy and 90% PI's coverage of actual run.

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

Columbia River fall Chinook salmon are major runs for the Pacific Salmon Commission (PSC), because they form the largest contributing fish group to ocean Chinook fisheries north of Cape Falcon, Oregon. Also, they include Snake River fish that are listed as threatened under the US Endangered Species Act. Because of this importance, preseason and in-season forecasts of Columbia River fall Chinook salmon runs are made by the US v. Oregon Technical Advisory Committee (TAC), and then the preseason forecasts are used as input values of the Pacific Salmon Commission (PSC) Chinook and Pacific Fishery Management Council (PFMC) ocean models whose outputs are forecasts of aggregated fish runs in the ocean fishery areas. These aggregates are used to set quotas either with negotiated rates or escapement objectives.

However, it is not a trivial task to make an accurate preseason forecast of salmon return because of uncertainty from environmental conditions, analysis methods, and data. Also, in-season forecasts made early during fish run usually have considerable uncertainty mainly because of large year-to-year variability in fish run timing.

The PSC Salmon Technical Team (STT) (G.S. Morishima, Quinault Indian Nation & the PSC STT, Mercer Island, WA, USA, personal communication) also acknowledges the forecast issues where traditional preseason forecasts tend to underestimate fish abundance, and in turn ocean fishery impacts can be seriously biased. Morishima said in a 2005 memo of his that "*The STT has long been aware of problems resulting from the types of preseason forecasts provided by the co-managers and has made numerous requests to revise methods to generate abundance projections in terms of ocean abundance*."

To improve traditional forecast methods, we incorporate new information, which is catch from ocean troll fisheries in the same year as fish return year. Columbia River fall Chinook salmon are mainly intercepted by ocean troll fisheries (commercial non-treaty troll, commercial treaty troll, and sport troll) during May – July in the Pacific Salmon Treaty (PST) fisheries off the coast of Southeast Alaska, British Columbia, Washington and Oregon. Catch from the fisheries is reported by age and population on a real-time basis (weekly), but presently no one incorporates the catch information into in-season forecasts of the fish returns to the Columbia River. We will add the catch information and start to make in-season forecasts even before fish return to the Columbia River mouth. These forecasts may be considered preseason forecasts but they are different from the U.S. v. Oregon Technical Advisory Committee (TAC)'s traditional preseason forecasts. The traditional preseason forecasts are made by about February or March, and they cannot incorporate ocean catch information from May through July. Our forecasts will be made on a real-time harvest basis for consideration by fishery managers. We will perform these new forecasts with historical data (i.e., retrospective analysis).

The objectives of this research are (i) to make retrospective forecasts of fall Chinook salmon returns to the Columbia River on a real-time basis of the ocean fisheries by incorporating real-time ocean fishery catch information in the PSC fisheries preceding the in-river terminal fisheries, (ii) to check whether this new incorporation would improve the traditional forecasts, and (iii) to present uncertainty in forecast measurement in terms of precision.

METHODS

We will incorporate information about ocean fisheries of Pacific Chinook salmon into preseason forecasts of fish returns to the river, and will make forecasts on an ocean harvest real-time basis (e.g., weekly). The ocean fishery information includes catch, CWT, fishing effort, fish body size (e.g., length), and fish scale data. The incorporation of these sources of ocean fishery data allows to update preseason forecasts because ocean fisheries occur after preseason forecast. For demonstration of our new forecast methods, we will use five fall Chinook salmon stocks from the Columbia River basin (Fig. 1).

The five fall stocks are Upriver Bright (URB), Mid Columbia River Bright (MCB)[1], Lower River Wild (LRW), Lower River Hatchery (LRH), and Bonneville Pool Hatchery (BPH). Those Columbia River stocks have been tagged for at least two decades, and CWT data for them are available. Notations and acronyms used in this proposal are listed in

[1] MCB stock is composed of Bonneville Upriver Bright (BUB) and Pool Upriver Bright (PUB) stocks.

Tables 1 and 2.

Data

Historical data on sibling runs (age-specific runs from the same brood years) of fall Chinook salmon are used in making preseason forecasts. They are available from the US v. Oregon TAC. The available data started in about brood year 1985 for UCS stock, and in about brood year 1975 for the other fall stocks.

Fall Chinook salmon in the ocean are mainly caught by troll fisheries. Weekly catch and fishing effort (boat days) data from southeast (SE) Alaska ocean troll fisheries were good, and they were available since 1981 (Ryan Briscoe, Alaska Department of Fish and Game, Homer, AK, USA, personal communication).

Stock- and age-specific proportions of yearly ocean troll catch in SE Alaska ocean area were calculated by the PSC CTC model (TC-Chinook 2008). Those calculated values were available since 1979. The proportions within a season (i.e., a year) were assumed to be constant. Applying these stock- and age- proportions in a year to those weekly catch data from SE Alaska ocean area in the corresponding year, we were able to decompose those catch data in a year into stock- and age- catches in the year.

Preseason forecast

The US v. Oregon TAC make preseason forecasts of Columbia River fall Chinook salmon returns using an ordinary regression model with sibling run data. Hyun et al. (2006) found that the US v. Oregon TAC's forecast model for Columbia River stocks has an autocorrelation problem, and 90% PIs from the model missed actual runs about 50% of the time. We will use a lag-1 autoregressive error (AR) model instead of the US v. Oregon TAC's model for Columbia River stocks.

For illustration purposes at the proposal stage, we use a general form for preseason forecast of stock- and age- run as follows.

$$R_{s,a}{}^{pre} = f(R_{s,a-1}{}^{pre}) + \varepsilon^{pre} \quad (1)$$

where $f(\,)$ represents a deterministic function, and the error term, ε^{pre} ~ *Normal*(0, *Var*(ε^{pre})). Candidate models for our preseason forecasts include an AR model or other regression models that have an additional covariate besides sibling run.

We will calculate the expected value and variance of a predictive variable from eq. 1: $E(\tilde{R}_{s,a}{}^{pre})$ and $Var(\tilde{R}_{s,a}{}^{pre})$. We use tilde (~) for a predictive variable to distinguish it from known data. The calculation is a routine process (Neter et al. 1996), and we don't show it here. Once we calculate the expected value and variance of a predictive variable of stock- and age- run, we will then need to show those quantities of stock-specific run ignoring age because forecast of stock-specific run is of interest to managers. The expected value and variance of an unknown stock-specific run (= $\tilde{R}_{s,\bullet}{}^{pre}$) are as follows:

$$E(\tilde{R}_{s,\bullet}{}^{pre}) = \sum_{a>2} E(\tilde{R}_{s,a}{}^{pre})$$
$$Var(\tilde{R}_{s,\bullet}{}^{pre}) = \sum_{a>2} Var(\tilde{R}_{s,a}{}^{pre}) \qquad (2)$$

Fish return size at age 2 are precocious jacks and are not considered in the forecast. The absence of a covariance term in eq. 2 is because the respective age-*a* returns in the same year are from different brood years, and thus the runs are treated independently (Hyun et al. 2005).

We apply a normal probability density function (pdf) to the preseason predictive function. Hyun et al. (2006) found that a normal pdf for a preseason forecast model showed no departure from residual normality.

$$\tilde{R}_{s,\bullet}{}^{pre} \sim Normal(E(\tilde{R}_{s,\bullet}{}^{pre}), Var(\tilde{R}_{s,\bullet}{}^{pre})) \qquad (3)$$

Ocean harvest real-time forecast

We will assemble all data about ocean fisheries on a weekly basis by year to allow ocean harvest real-time forecast. First, we will need data on the number of stock- and age-fish caught up to time *t* (= $C_{s,a,t}$). The data are directly available from PSC CTC for a fish stock that has been tagged with CWT. If CWT data are not available in the ocean fishery season when we make forecasts, we will infer stock compositions from historical catch and CWT data: e.g., the mean and variance of the proportion of a stock in ocean catch.

Fish abundance in the ocean can be inferred from ocean fishing effort and catch (Gulland 1983).

$$O_{s,a,t} = \frac{C_{s,a,t}}{q_a \cdot E_{\bullet,\bullet,t}} \tag{4}$$

where $O_{s,a,t}$ is stock- and age- fish abundance in the ocean to time *t*; q_a is catch-ability coefficient of a fishery that targets fish at age *a* ; and $E_{\bullet,\bullet,t}$ is cumulative fishing effort to time *t*. Catch-ability coefficient (=q_a) is unknown, but it is constant within the same age fish during the same fishing season. It may be difficult to collect fishing effort data (=$E_{\bullet,\bullet,t}$). If we fail to collect them, we will alternatively use catch data lumped over stock stratum (= $C_{\bullet,a,t}$ = $\sum_s C_{s,a,t}$), because fish abundance in the ocean is constant within the harvest season and fishing effort is proportional to catch. That it,

$$\begin{aligned} E_{\bullet,\bullet,t} &\propto C_{\bullet,a,t} \\ &= \sum_s C_{s,a,t} \end{aligned} \tag{5}$$

On the other hand, a deterministic relationship between fish return size and fish abundance in the ocean is as follows:

$$\begin{aligned} R_{s,a,t} &= O_{s,a,t} \cdot (1 - M_{s,a,t}) \cdot A_{s,a,t} \\ &= O_{s,a,t} \cdot (1 - \omega_1 \cdot C_{s,a,t}) \cdot A_{s,a,t} \end{aligned} \tag{6}$$

where $M_{s,a,t}$ is fish mortality in the ocean, and $A_{s,a,t}$ is maturation rate of stock- and age-fish. $M_{s,a,t}$ is unknown, and it is inferred from $C_{s,a,t}$ because fish mortality in the ocean is proportional to ocean fishery catch. ω_1 is a positive constant. $A_{s,a,t}$ is unknown but constant within the same age fish during the same fishing season.

Lumping unknown constants (q_a, $A_{s,a,t}$, and ω_1) and applying eq. 4 to eq. 6 to replace $O_{s,a,t}$, we have the following:

$$R_{s,a,t} = \omega_2 \cdot \frac{C_{s,a,t}}{E_{\bullet,\bullet,t}} - \omega_3 \cdot \frac{{C_{s,a,t}}^2}{E_{\bullet,\bullet,t}} \tag{7}$$

where unknown constants of α_2 and α_3 are positive because ω_2 = ($A_{s,a,t} / q_a$), and ω_3 = ($\omega_1 A_{s,a,t} / q_a$). Fishing effort data of $E_{\bullet,\bullet,t}$ in the above equation can be replaced with catch data lumped over stock by eq. 5 when effort data are not available on a harvest real-time basis.

Allowing an error term in the model of eq. 7 and generalizing the coefficient's sign, we have the following stochastic model:

$$R_{s,a,t} = \omega_2 X_{1,t} + \omega_3 X_{2,t} + \varepsilon \tag{8}$$

where $X_{1,t} = \frac{C_{s,a,t}}{E_{\bullet,\bullet,t}}$, $X_{2,t} = \frac{{C_{s,a,t}}^2}{E_{\bullet,\bullet,t}}$, and ε ~ *Normal*(0, *Var*(ε)). When fitting the stochastic model of eq. 8 to known data from historical years, we will need to do so not only by year but also by time *t* within a year. Known $R_{s,a,t}$ is constant in a year, and subscript time *t* is not necessary in this case. Once we fit the stochastic model to known data of $R_{s,a,t}$, $p_{s,a,t}$, $C_{\bullet,\bullet,t}$, and $E_{\bullet,\bullet,t}$, we are ready for forecasting unknown stock- and age-run at time t (= $\tilde{R}_{s,a,t}$) during the ocean fishery season. In the forecast case, subscript time *t* is necessary for $\tilde{R}_{s,a,t}$ because $\tilde{R}_{s,a,t}$ changes over time *t*.

First, given a week, we fit the model of eq. 8 with historical data on $R_{s,a,t}$, $X_{1,t}$, and $X_{2,t}$ from 10 years prior to a forecast year. Once we fit the model given a week, then we predicted $\tilde{R}_{s,a,t}$ in a forecast year. This step is repeated for a different week.

It is a routine process to calculate the mean and variance of the predictive variable from the stochastic model of eq. 8 (Neter et al. 1996). Further, we will calculate the mean and variance of unknown stock-specific run ignoring age (= $\tilde{R}_{s,\bullet,t}$).

$$E(\tilde{R}_{s,\bullet,t}) = \sum_{a>2} E(\tilde{R}_{s,a,t})$$

$$Var(\tilde{R}_{s,\bullet,t}) = \sum_{a>2} Var(\tilde{R}_{s,a,t}) \tag{9}$$

As we described in the section of "Preseason forecast", age-2 fish are not adults and are excluded. Also, the respective age-*a* returns in the same year are not cohorts, and they are independent. The independence removes covariance terms in eq. 9.

Given the mean and variance of the predictive variable, $\tilde{R}_{s,\bullet,t}$ in eq. 9, we can consider a predictive pdf. At the proposal stage, we choose a normal pdf, but we will examine the choice by a goodness-of-fit test. If we find a better pdf, we will replace the normal pdf. A gamma pdf would be also possible because the predictive variable must be positive.

$$\tilde{R}_{s,\bullet,t} \sim Normal\left(E(\tilde{R}_{s,\bullet,t}), Var(\tilde{R}_{s,\bullet,t})\right) \tag{10}$$

Integration

Finally we will integrate preseason forecast and ocean harvest real-time forecast. The joint probability of these two forecasts is the product of the respective predictive pdf, because those two forecasts are independent. The independence is justified because data used for preseason forecasts are different from those for ocean harvest real-time forecasts, and also preseason forecast timing is different from the ocean harvest season. That is,

$$p(\tilde{R}_{s,\bullet}{}^{pre}, \tilde{R}_{s,\bullet,t}) = p(\tilde{R}_{s,\bullet}{}^{pre}) \cdot p(\tilde{R}_{s,\bullet,t}) \tag{11}$$

Each predictive pdf of $p(\tilde{R}_{s,\bullet}{}^{pre})$ and $p(\tilde{R}_{s,\bullet,t})$ is from eqs. 3 and 10. We will update the joint probability on an ocean harvest real-time basis.

Based on the joint predictive pdf of eq. 11, we will build the forecast distribution. We can identify the mode of the distribution and a PI. For identification of a PI, we will use the same idea as highest posterior density (HPD) region. That is, starting around the mode of the distribution not from both tails of the distribution, we will build a PI. The idea guarantees that the pdf values are equal over lower and upper bounds of a PI.

Demonstration: hind-casting forecasts

We will demonstrate our forecasts on a retrospective basis where we use historical data. We will use a hind-casting procedure, where we make a forecast of unknown stock-specific run at an ocean harvest time in a year, using only data prior to the time. That is, we pretend we don't know actual return size in the year. We used data from 10 years prior to a forecast time. Sample size of 10 is not small in terms of statistical significance, and data from 10 years prior to a forecast time reflect recent environmental conditions near the forecast time.

We can make hind-casting forecasts several times (i.e., weeks) over the ocean harvest season within a year. Finally, we will compare the forecasts over time with actual run in terms of bias and PI's coverage of actual run. A measurement of bias is relative error (%) (= 100$\times$(forecast – actual run)/(actual run)). We will check a frequency that (1-α)% PI cover actual run.

RESULTS

Catch by stock and age from southeast Alaska ocean

Stock- and age- catches of Chinook salmon in the SE Alaska ocean from 1998 - 2007 are shown in Figures 1 – 6. Age 4 catches are most abundant in URB and MCB stocks (Figures 1 – 4) while age 5 catches are in LRW stock (Figures 5 and 6). Out of the 10 years of 1998-2007, ocean catches of URB and MCB from 2003 were largest as 53 009 fish and 25 168 fish (Figures 1 - 4) while that of LRW from 2004 was largest as 2 912 fish (Figures 5 and 6). SE Alaska ocean catches of LRH and BPH were almost zero.

Troll fishing effort

Troll fishing efforts (vessel-days) in SE Alaska ocean from 1998 - 2007 are displayed in Figure 7. Efforts vary by years. Out of the 10 year efforts, that from 1998 was largest as 11 924 whereas that from 1999 was smallest as 4 674 (Figure 7).

Forecast performance

We applied the above forecast methods to five stocks: URB, MCB, LRW, LRH, and BPH. SE Alaska ocean catches of LRH and BPH were zero, and thus the ocean real-time forecasts of these stocks' runs were not possible. We show forecasts of 1998-2007 runs made at weeks 27, 29, 31, and 33 in each year (Figures 8 – 25).

In-season forecast distributions changed over weeks, and they were wider than preseason forecast distributions. Integrated forecasts occurred between in-season and preseason forecasts (Figures 8 - 25). Variances of preseason forecasts were so narrow, and prediction intervals of preseason forecasts often missed actual runs. The resultant integrated forecasts had the same problem. Inflating preseason forecast variances, we found performance of the resultant integrated forecasts improved. We empirically found that inflation of the original preseason forecast's standard deviation (SD) five times led to good performance of integrated forecasts.

Upriver Bright (URB)

Forecasts of URB runs in 1998 - 2007 are shown in Figures 8 – 15. SE Alaska ocean catches, on which in-season forecasts of URB runs are based, included Lyons Ferry URB stock. Preseason forecasts of URB runs were not bad in term of bias. Absolute values of relative error (%) of the preseason forecasts were all less than 50% except for 2007 preseason forecasts (Figures 12 and 13). However, preseason forecasts of URB runs were problematic in forecast variances. Variances of the preseason forecast were so narrow (Figures 8-9). 90% prediction interval (PI) of the preseason forecasts frequently missed actual runs except for those in only three years of 1998, 2000, and 2002 (Figure 14).

In-season forecasts of URB runs were not poor in terms of bias. Absolute values of relative errors of in-season forecasts of URB runs were all less than 50% except for those in 2004 (Figures 12 and 13). Note that in-season forecasts change over weeks within a year (Figures 8 - 15), because they are updated with SE Alaska ocean catch and effort data over weeks. 90% PI of the in-season forecasts covered most actual runs only except for 2003 runs (Figures 14 and 15).

The narrow distributions of preseason forecasts led to narrow distributions of integrated forecasts. 90% PI of the integrated forecasts often missed actual runs except for those in only three years of 1998, 2000, and 2002 (Figure 14).

Inflating the SD of the original preseason forecasts five times improved forecast power (Figures 13 and 15). Absolute values of relative errors (%) of the integrated forecasts from the inflated preseason forecasts were all less than 50% (Figure 13), and 90% PI of the integrated forecasts covered most actual runs except for those in only one year of 2003 (Figure 15).

Mid Columbia River Bright (MCB)

Forecasts of MCB runs in 1998 - 2007 are shown in Figures 16 - 23. Like preseason forecasts of URB runs, those of MCB runs were not poor in terms of bias. Absolute values of relative error (%) of the preseason forecasts were all less than 50% except for 2007 preseason forecasts (Figures 20 and 21). But, as in preseason forecasts of MCB runs, variances of those preseason forecasts were too narrow to cover actual runs (Figures 16-17). 90% PI of the preseason forecasts frequently missed actual runs except for those in 2002, 2005, and 2006 (Figure 22).

In-season forecasts of MCB runs were biased in a few years. Absolute values of relative errors (%) of in-season forecasts of MCB runs in 1998, 2003, and 2004 were larger than 50% (Figures 20 and 21). 90% PI of in-season forecasts covered actual runs only except for year of 2003 (Figure 22).

Like forecasts of URB runs, the narrow distributions of MCB preseason forecasts led to narrow distributions of integrated forecasts. 90% PI of the integrated forecasts often missed actual runs except for those in years of 2002, 2005 and 2006 (Figure 22).

Inflating the variance of the original MCB preseason forecasts (by multiplying their SD by five) improved forecast power (Figures 21 and 23). Absolute values of relative errors (%) of the integrated forecasts from the inflated preseason forecasts were all less than 50% except for 1998 forecasts (Figure 21), and 90% PI of the integrated forecasts covered most actual runs except for those in only one year of 2003 (Figure 23).

Lower River Wild (LRW)

Forecasts of LRW runs in 1998 - 2007 are shown in Figures 24-31. Preseason forecasts of LRW runs were not as good as those of URB and MCB runs. Absolute values of relative error (%) of preseason forecasts of MCB runs in 1999, 2005, and 2007 were larger than 50% (Figures 28 and 29). Also the problem of the narrow distributions of preseason forecasts was found in MCB preseason forecasts (Figures 24, 25, and 30). 90% PI of the preseason forecasts missed actual runs in 1998, 2000, 2001, 2002, 2005, and 2007 (Figure 30).

In-season forecasts of LRW runs were not seriously biased. Absolute values of relative errors (%) of in-season forecasts of LRW runs were less than 50% except for two years of 1999 and 2004 (Figures 28 and 29). 90% PI of in-season forecasts covered actual runs in all years (Figure 30). However, there was a serious variability in in-season forecast performance between weeks within 2004. 90% PI of in-season forecast of LRW run made at week 27 in 2004 covered its actual run but those made at the other weeks in the year missed its actual runs (Figure 30).

Like preseason forecasts of URB and MCB runs, the narrow distributions of LRW preseason forecasts led to narrow distributions of integrated forecasts. 90% PI of the integrated forecasts often missed actual runs except for those in years of 1999, 2003, 2004 and 2006 (Figure 30).

Inflating the variance of the original LRW preseason forecasts (by multiplying their SD by five) improved forecast power (Figures 29 and 31). Absolute values of relative errors (%) of the integrated forecasts from the inflated preseason forecasts were all less than 50% except for 1999 forecasts (Figure 29), and 90% PI of the integrated forecasts covered actual runs in all years (Figure 31). The inconsistency of 2004 integrated forecasts over weeks was due to the variability of in-season forecast performance in the year.

Lower River Hatchery (LRH) and Bonneville Pool Hatchery (BPH)

In-season and integrated forecasts of LRH and BPH runs were not made because SE Alaska ocean catches of LRH and BPH were almost zero.

Discussion

Age-specific ocean catches in LRW stock were different in abundance from those in URB and MCB stocks. The difference in age-specific catch implies that LRW stock differs in maturation rate from URB and MCB stocks. Ocean catch of LRW stock from 2004 was largest while those of URB and MCB stocks from 2003 were largest. The difference in yearly catch indicates that survival, maturation rate or catch-vulnerability is not the same over years between stocks. Ocean catches were not proportional to fishing efforts, because ocean catches of 2003 URB and MCB and those of 2004 LRW (Figures 1-6) were most abundant whereas 1998 fishing efforts were largest (Figure 7).

Commonly for all three stocks, preseason forecasts were not seriously biased but their narrow distributions were problematic. As a result, 90% PI of the preseason forecasts often missed actual runs. Interestingly, managers, who involve the preseason forecasts of Columbia River fall Chinook salmon runs, do not pay attention to nor evaluate prediction intervals. We suggest that the current method of sibling run regression should be modified to fix the problem of narrow prediction intervals.

In-season forecasts impressively performed, which were made with catch and effort data from the SE Alaska ocean troll fisheries and stock- and age- specific composition estimates from the PSC CTC ocean model (TC-Chinook 2008). Only except for in-season forecasts of URB and MCB runs in 2003 and LRW run in 2004, in-season forecasts were satisfactory. The satisfactory performance of in-season forecasts seems to be due to quality data on catches and efforts from SE Alaska troll ocean fisheries.

Overall the performance of integrated forecasts was best, which are blended by preseason forecasts with inflated variance and in-season forecasts. Because of the problem of preseason forecast variance, we inflated the preseason forecast distributions by multiplying its SD by five. The five times were determined by our empirical analysis. If the problem of preseason forecast variance were fixed, the inflation artifact would not be needed.

Some of the merits in our study lie in blending preseason and in-season forecasts, and in efficiently generating forecasts, which are satisfactory. The idea of blending two forecasts is comparable to Bayesian philosophy, which incorporating all available information through a prior function as well as a likelihood function. The efficiency of our methods means that data on environmental conditions were not used but the integrated forecasts performed satisfactorily.

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Table 1. Notations. Traditional notations in statistics are self-explanatory (e.g., α = Type I error; *E*( ) = expected value operation; etc.), and they are not listed here.

Indices	
s	Stock
a	Age
t	Time (day or week) within the ocean fishery season
pre	Superscript "pre" denotes preseason forecast
R	Return size (abundance). It is the number of a fish stock's return to the natal river from the ocean.
C	Catch abundance from the ocean fisheries
E	Ocean fishing effort.
O	Fish abundance in the ocean
q	Catch-ability coefficient from the relationship, $C = q \cdot E \cdot O$
A	Maturation rate (fraction) of fish in the ocean
M	Ocean mortality rate (fraction) of fish
~	Unknown predictive variable. Tilde mark (~) notation helps to distinguish between observed and predictive quantities. For example, $\tilde{R}$ is predictive (unknown) variable whereas R without tilde mark is random variable or observed data.
Data	
$R_{s,a}$; $R_{s,a,t}$	Return size (number) of stock- and age- fish to river in a year. For known return sizes from historical years, subscript time *t* is not necessary because known return size is constant within a year.
$C_{s,a,t}$	Cumulative number of stock- and age- catch from the ocean fisheries up to time *t*.
$p_{s,a,t}$	Stock- and age- proportion of fish out of an entire catch from the ocean fisheries up to time *t*.
$E_{\bullet,\bullet,t}$	Cumulative fishing effort to time *t*. If the data are not available on an ocean harvest real-time basis, we will alternatively use aggregated catch over stock (eq. 5).
Parameters	

Coefficients, and variances of error terms	Coefficients in preseason and ocean harvest real-time forecast models (eqs. 1 and 8), and variances of error terms in the respective models.
$E(\tilde{R}_{s,a}{}^{pre})$; $Var(\tilde{R}_{s,a}{}^{pre})$	Expected value and variance of preseason forecast of stock- and age- run. These are used for calculation of those estimators of stock- run aggregated over age (= $\tilde{R}_{s,\bullet}{}^{pre}$) (eq. 2).
$E(\tilde{R}_{s,a,t})$; $Var(\tilde{R}_{s,a,t})$	Expected value and variance of ocean harvest real-time forecast at time *t* of stock- and age- run. These are used for calculation of those estimators of stock- run aggregated over age (= $\tilde{R}_{s,\bullet,t}$) (eq. 9).
Predictive variable	
$\tilde{R}_{s,a,t}$; $\tilde{R}_{s,\bullet,t}$	Unknown stock- and age- run or only stock-specific run in a year. For unknown return sizes, subscript time *t* is necessary because the predictive variable changes within a year as ocean harvest data are updated over time *t*.

Table 2. Acronyms found in this proposal.

Acronym	
ADFG	Alaska Department of Fish and Game
BPH	Bonneville Pool Hatchery
BUB	Bonneville Upriver Bright
CRITFC	Columbia River Inter-Tribal Fish Commission
CTC	Chinook Technical Committee
CWT	Coded-wire-tag
GSI	Genetic stock identification
HPD	Highest posterior density
ISBM	Individual Stock Based Management
LRH	Lower River Hatchery
LRW	Lower River Wild
ODFW	Oregon Department of Fish and Wildlife
PFMC	Pacific Fishery Management Council
PI	Prediction interval. It is the same meaning as forecast interval.
PSC	Pacific Salmon Commission
PSMFC	Pacific States Marine Fisheries Commission
RFP	Request for proposals
RMPC	Regional Mark Processing Center
STT	Salmon Technical Team
TAC	Technical Advisory Committee
URB	Upriver Bright

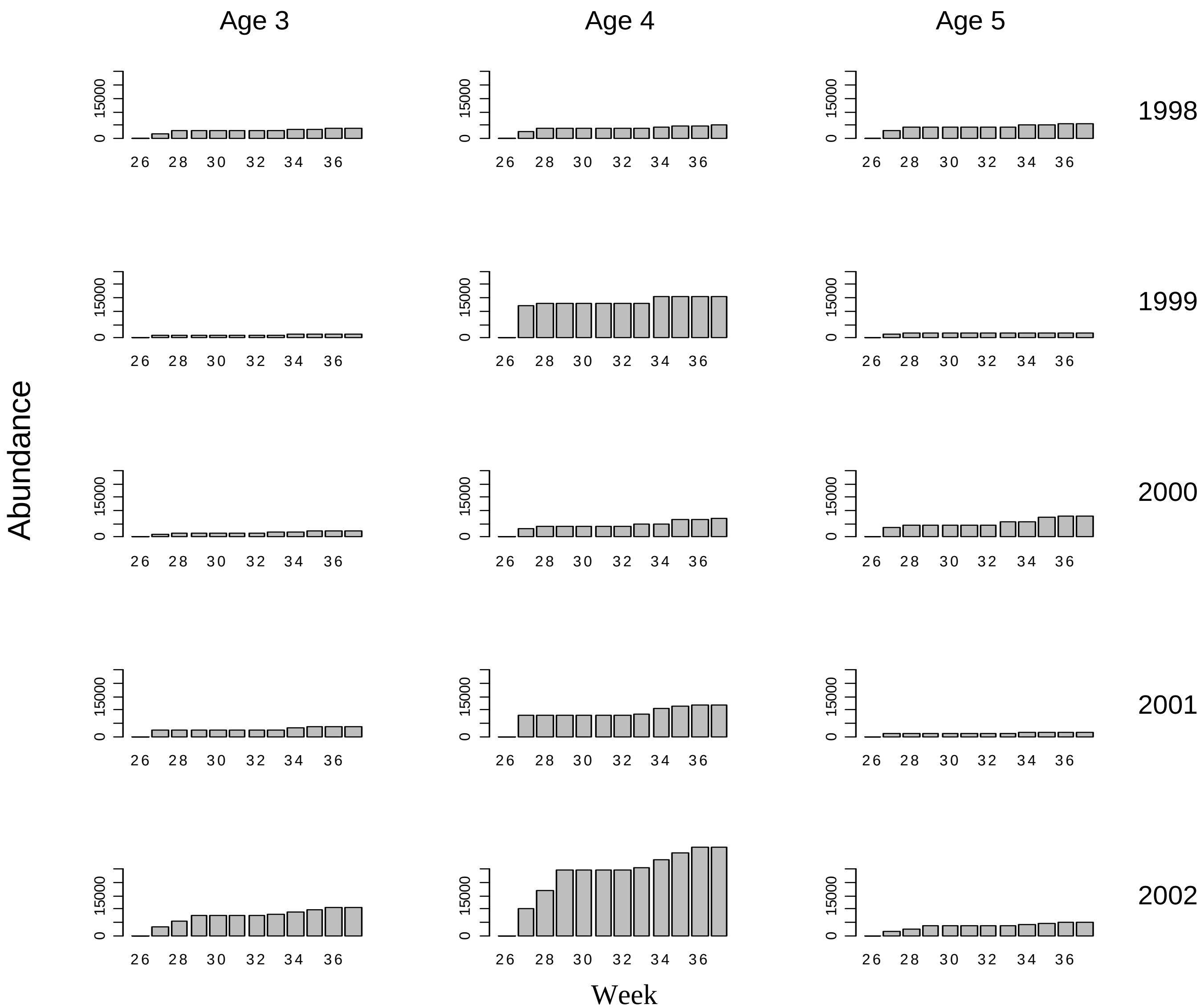

Figure 1. Cumulative catch of Upriver Bright (URB) stock over week from southeast Alaska ocean in 1998 - 2002. The catch of URB stock includes that of Lyons Ferry Bright.

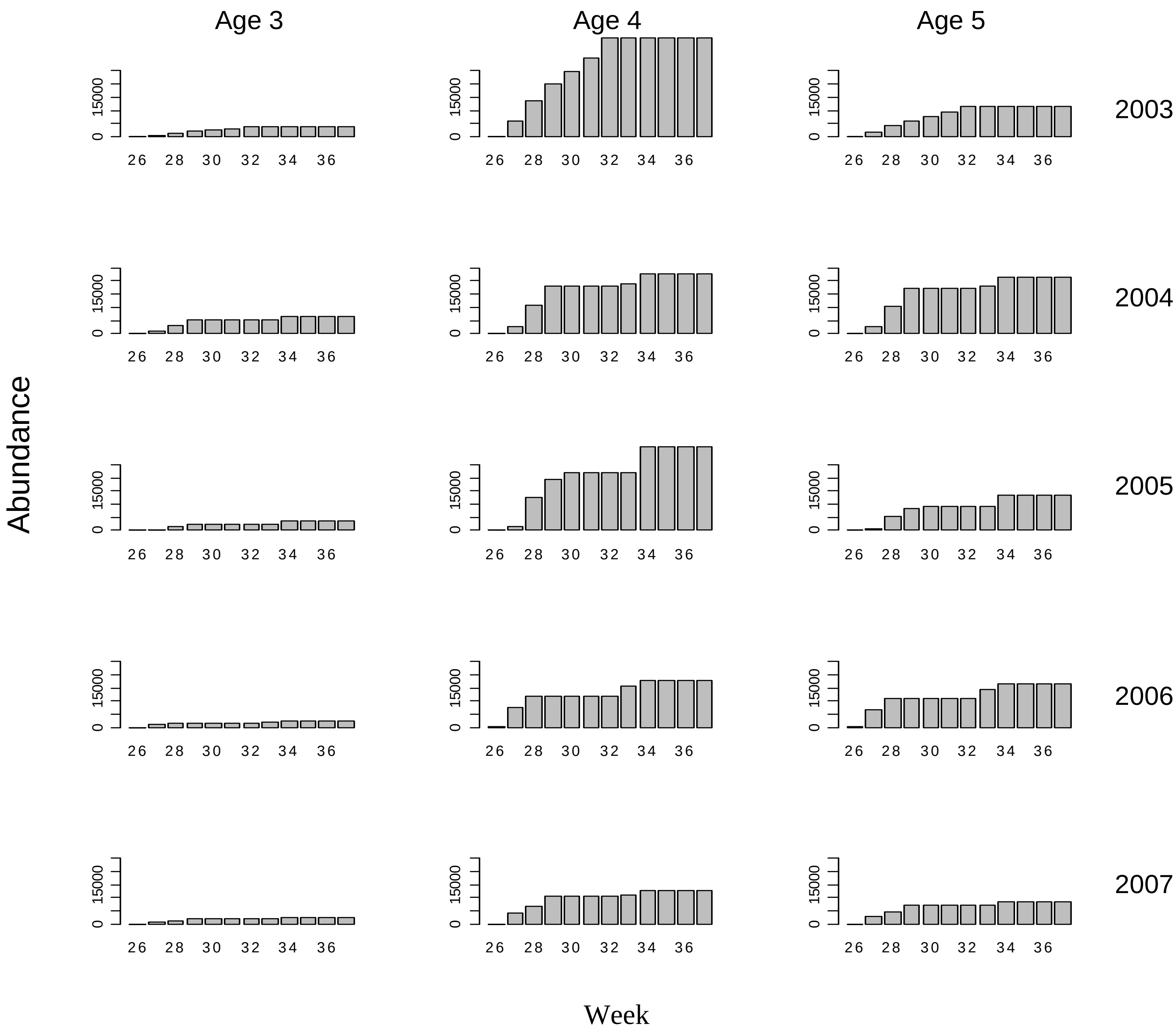

Figure 2. Cumulative catch of Upriver Bright (URB) stock over week from southeast Alaska ocean in 2003 - 2007. The catch of URB stock includes that of Lyons Ferry Bright.

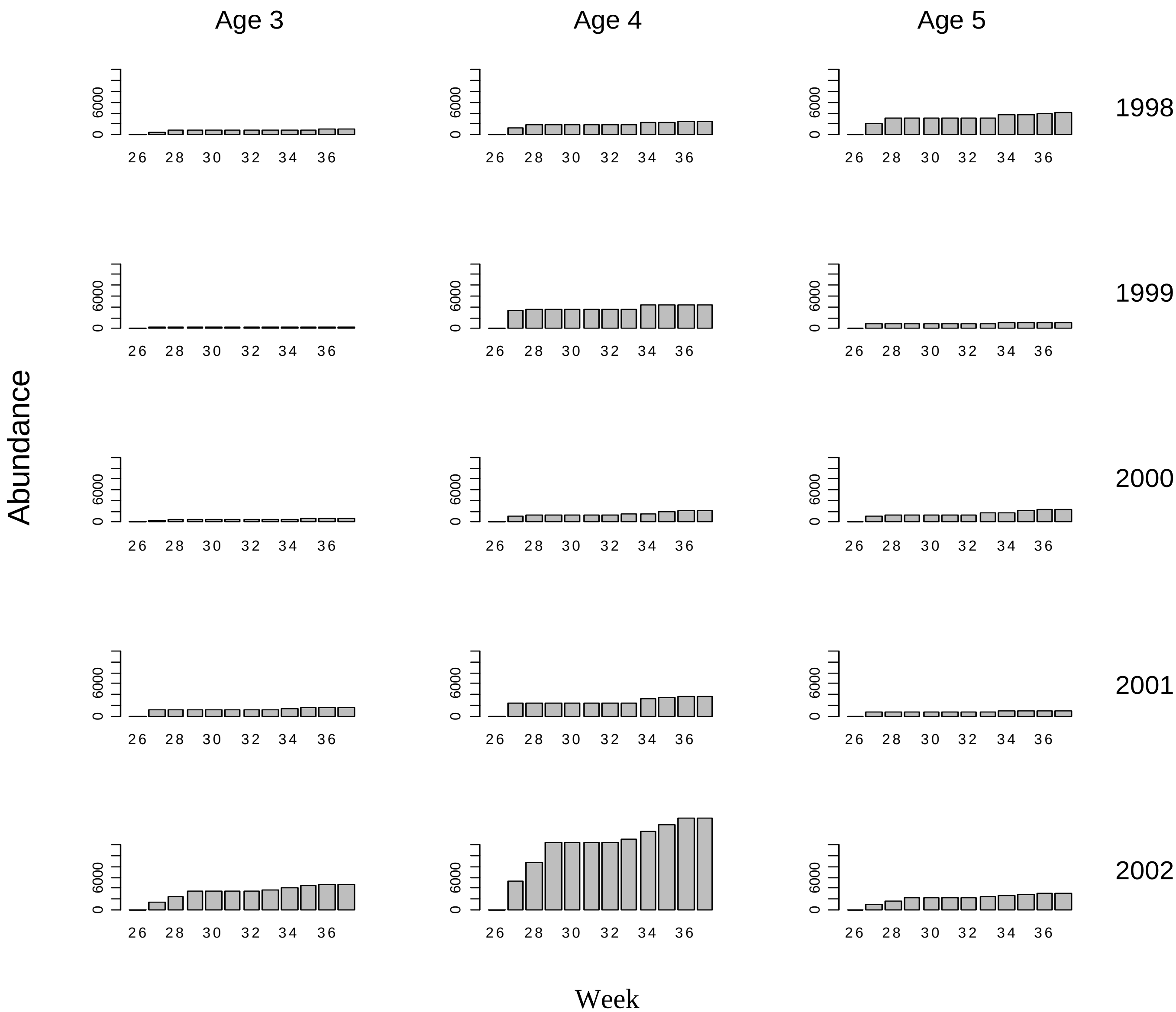

Figure 3. Cumulative catch of Mid Columbia River Bright (MCB) stock over week from southeast Alaska ocean in 1998 - 2002.

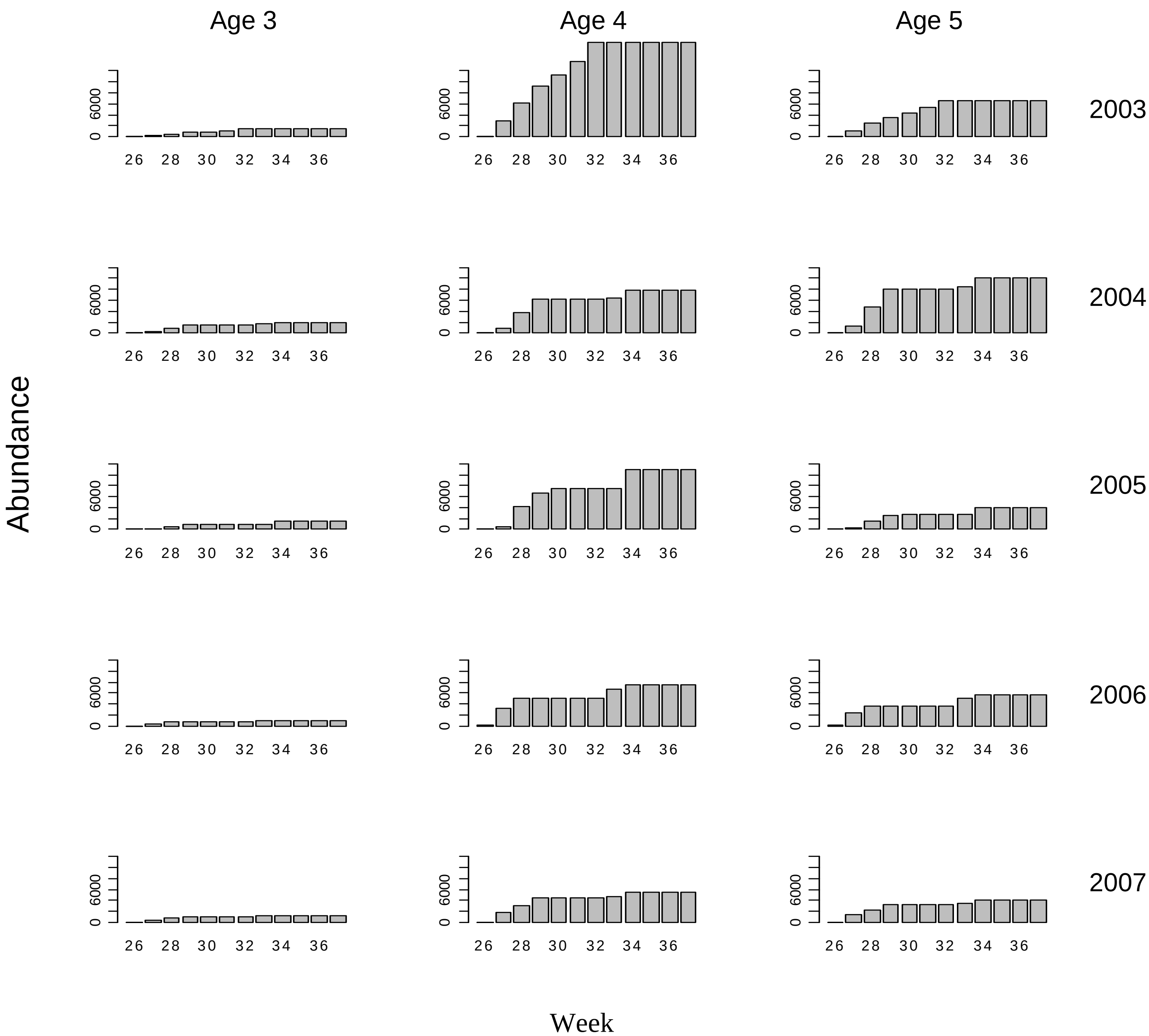

Figure 4. Cumulative catch of Mid Columbia River Bright (MCB) stock over week from southeast Alaska ocean in 2003 - 2007.

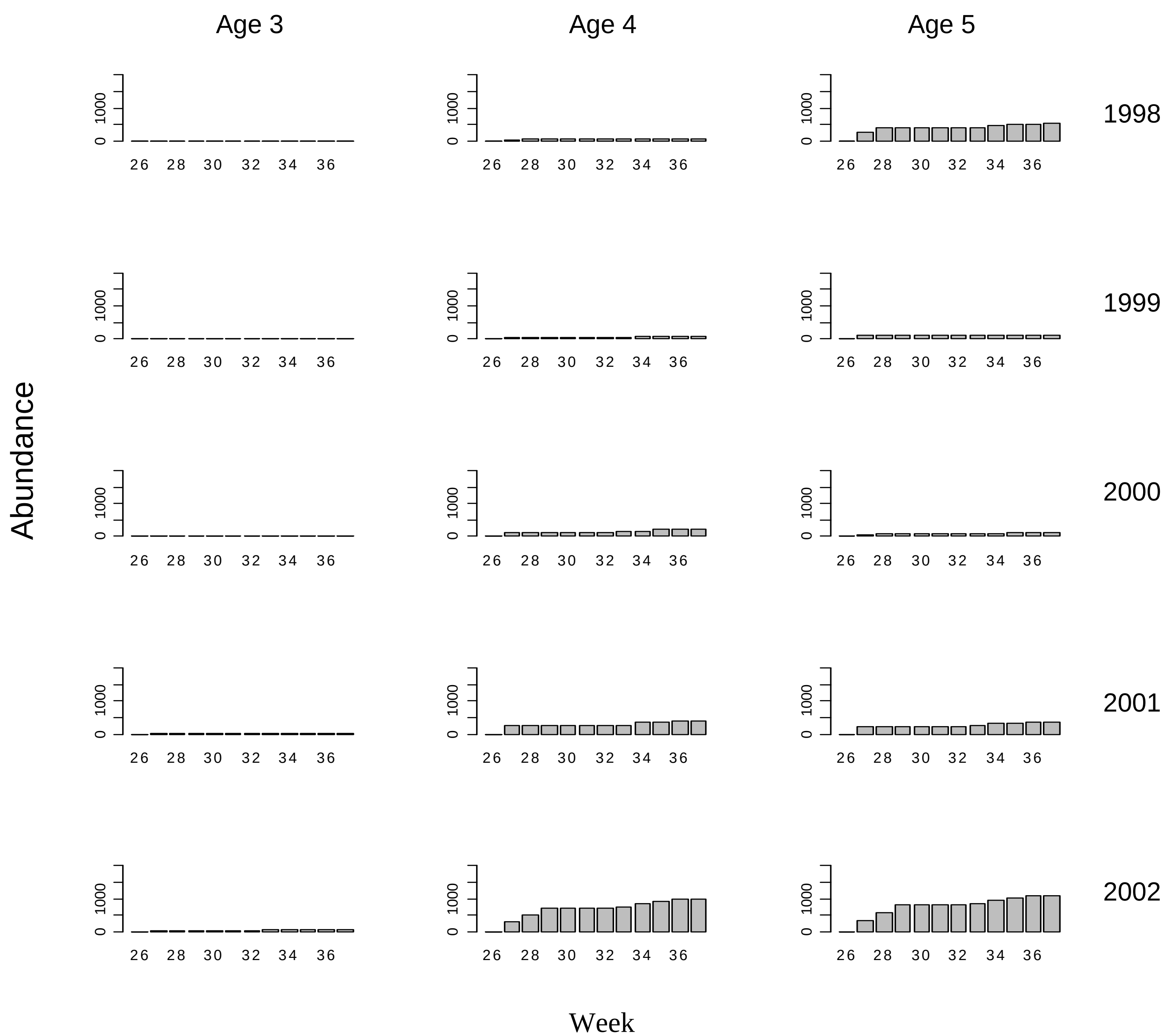

Figure 5. Cumulative catch of Lewis River Wild (LRW) stock over week from southeast Alaska ocean in 1998 - 2002.

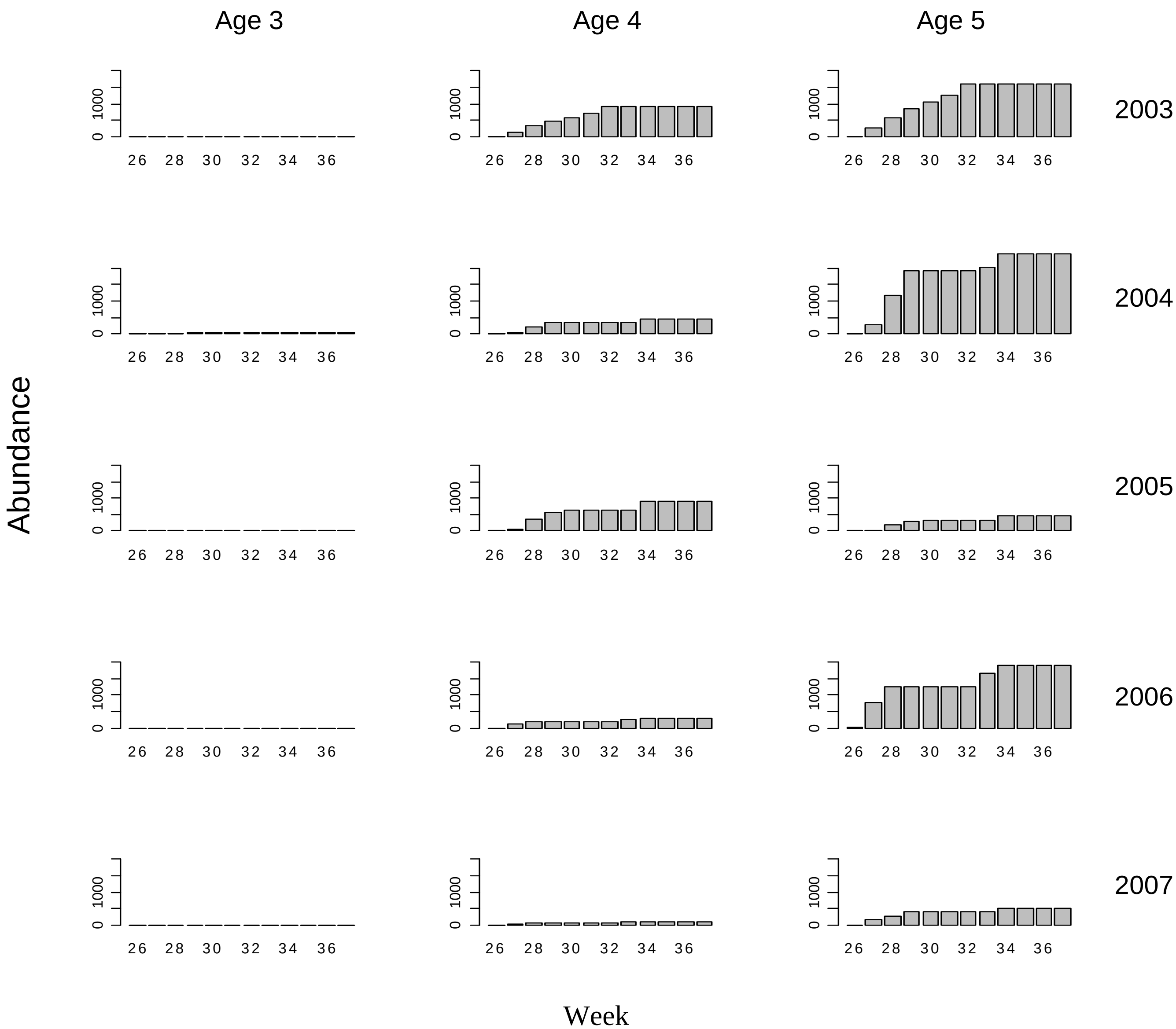

Figure 6. Cumulative catch of Lewis River Wild (LRW) stock over week from southeast Alaska ocean in 2003 - 2007.

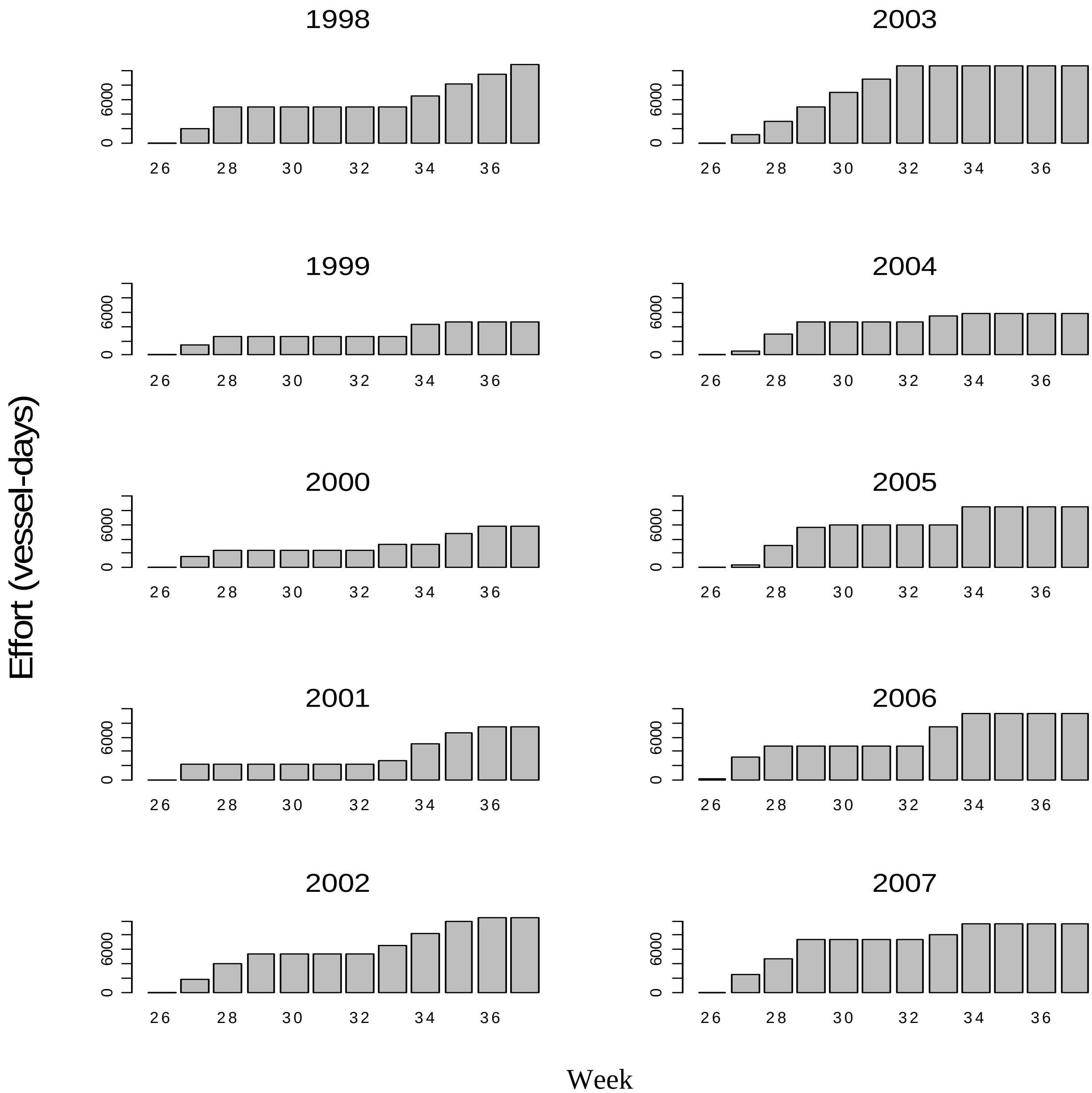

Figure 7. Cumulative fishing effort (vessel-days) over week from southeast Alaska ocean in 1998 – 2007.

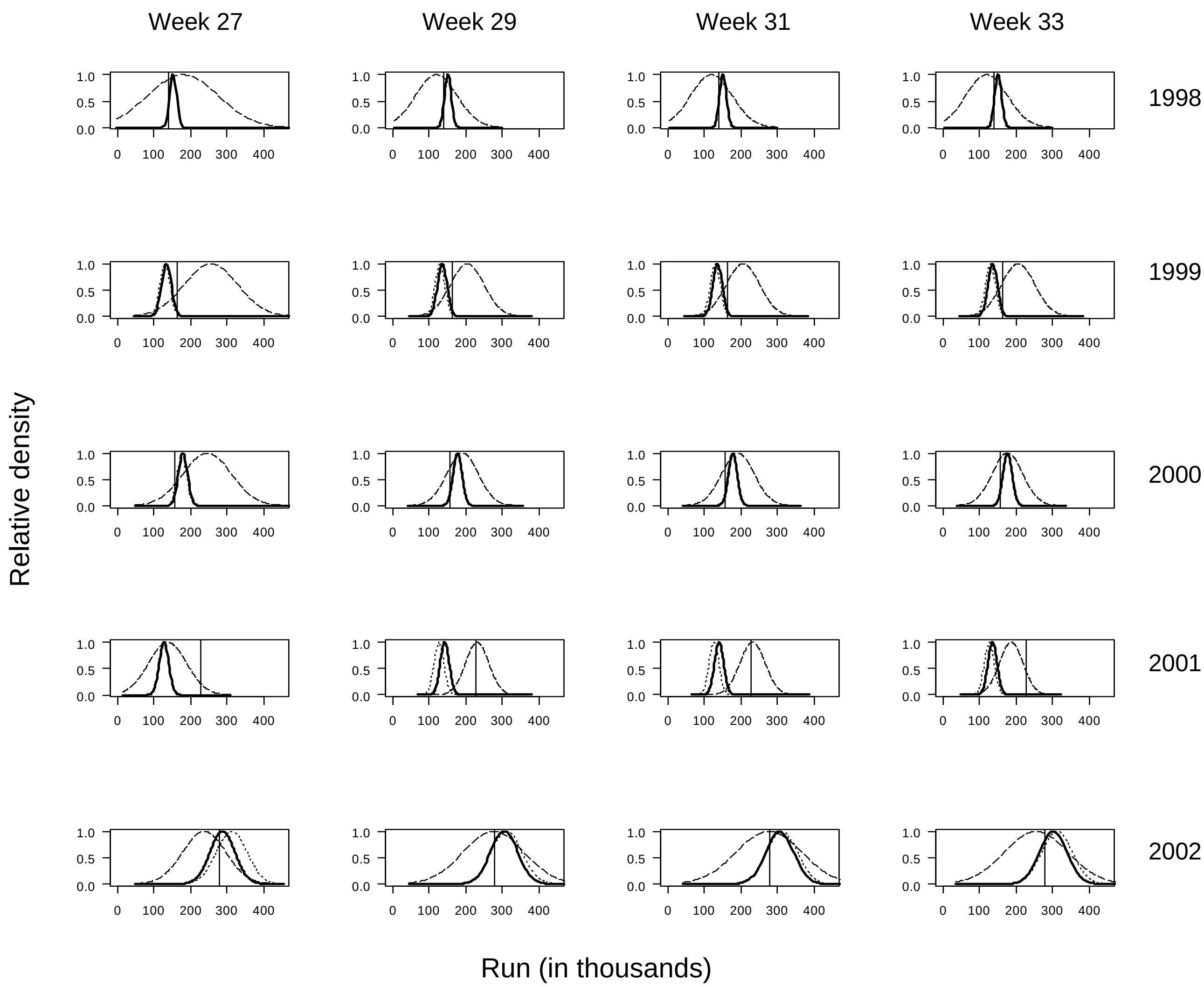

Figure 8. In-season (broken line) and preseason (dot line) forecasts of Upriver Bright (URB) return sizes at ages 3-5 in 1998 - 2002, and the integrated forecasts (solid line). Vertical line indicates actual return size. URB stock includes Lyons Ferry Bright.

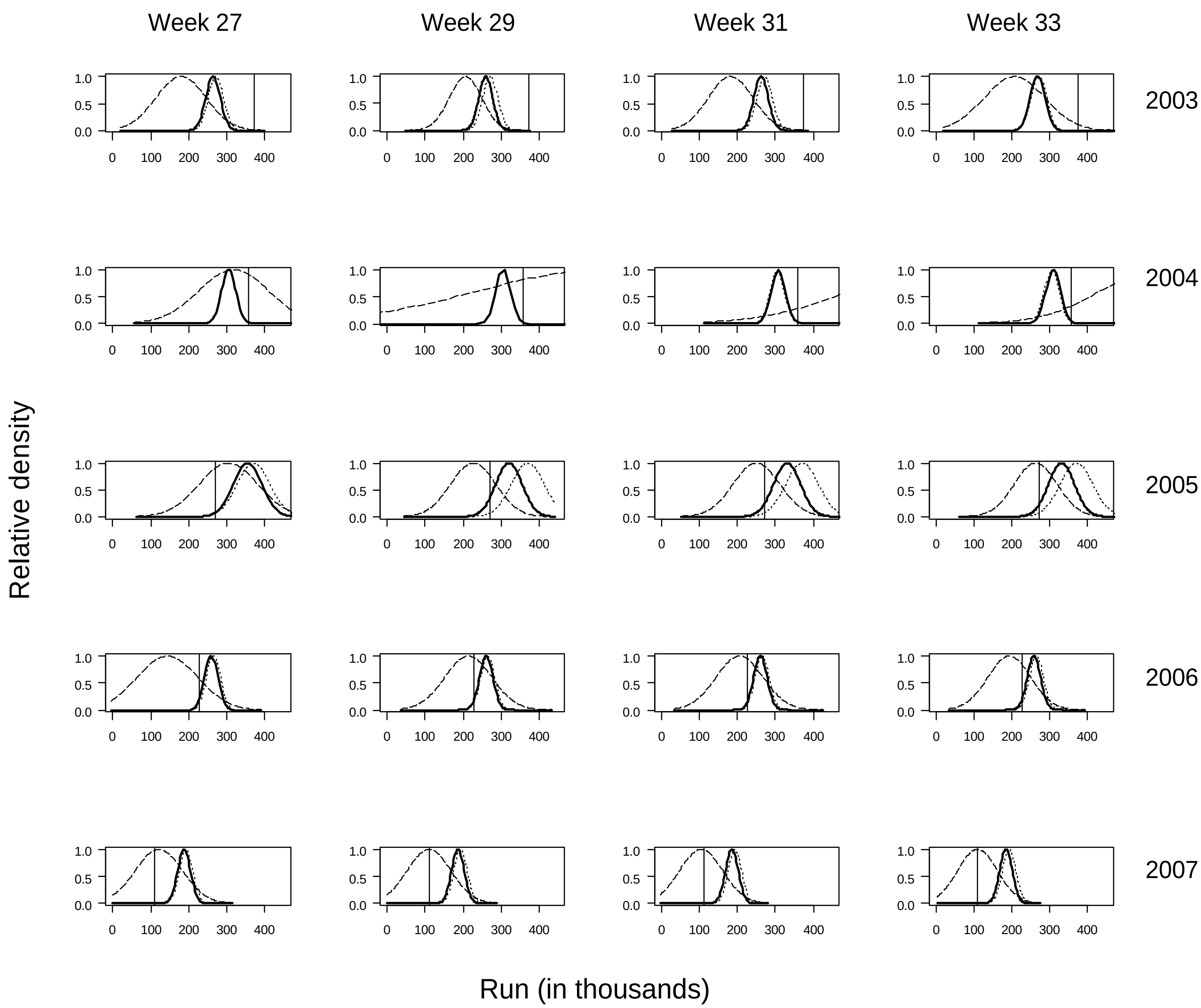

Figure 9. In-season (broken line) and preseason (dot line) forecasts of Upriver Bright (URB) return sizes at ages 3-5 in 2003 - 2007, and the integrated forecasts (solid line). Vertical line indicates actual return size. URB stock includes Lyons Ferry Bright.

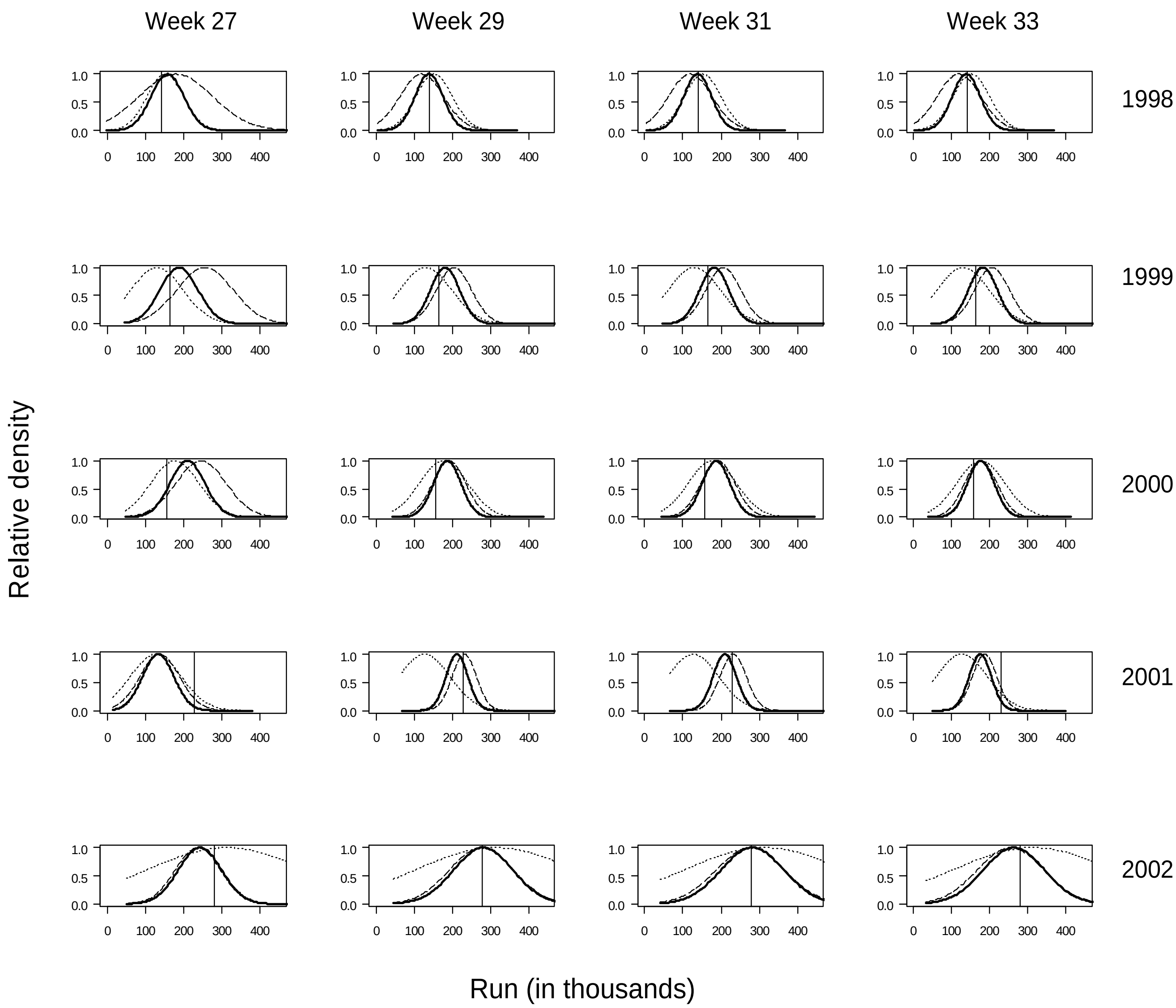

Figure 10. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Upriver Bright (URB) return sizes at ages 3 - 5 in 1998 - 2002 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size. URB stock includes Lyons Ferry Bright.

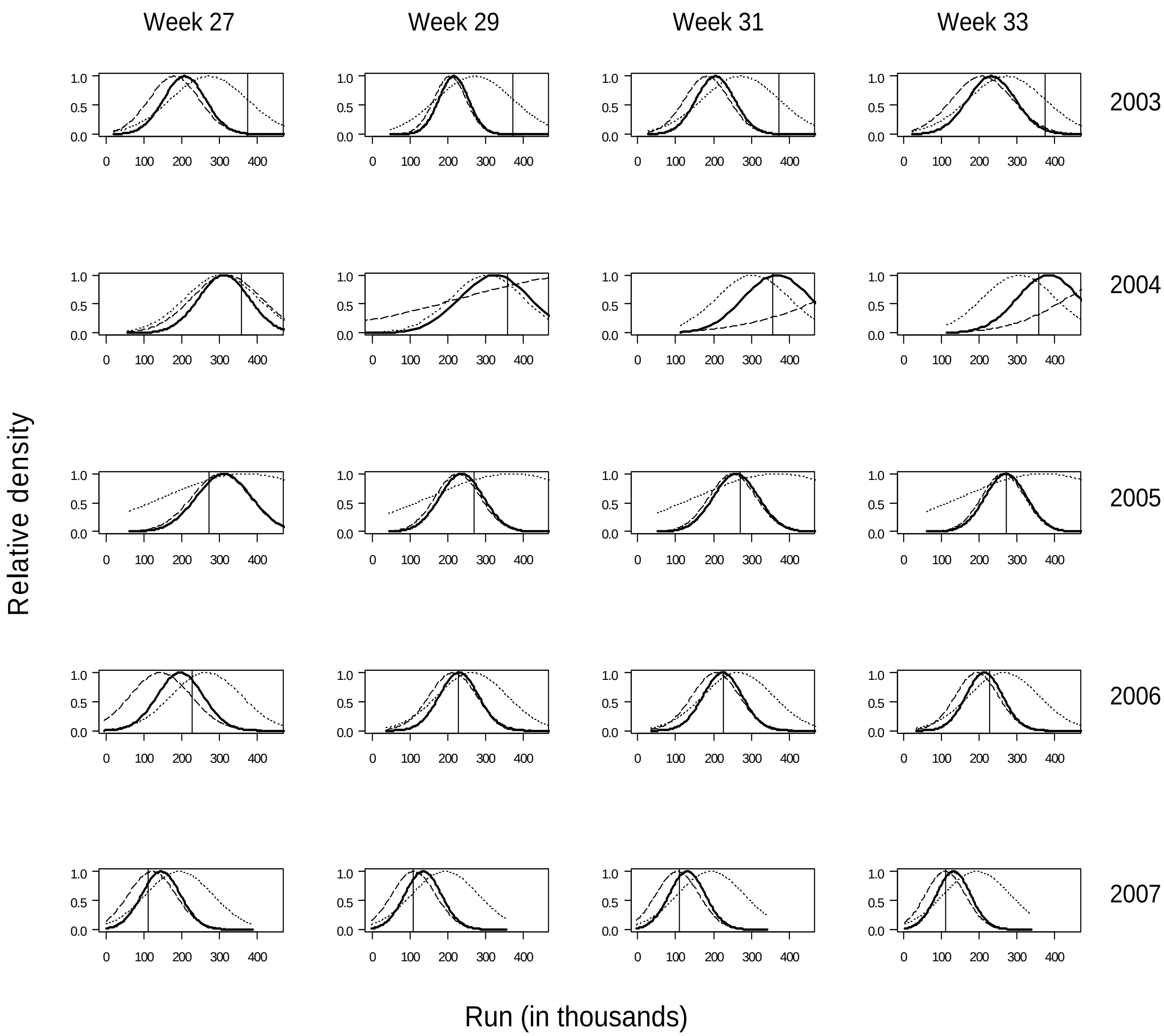

Figure 11. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Upriver Bright (URB) return sizes at ages 3 - 5 in 2003 - 2007 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size. URB stock includes Lyons Ferry Bright.

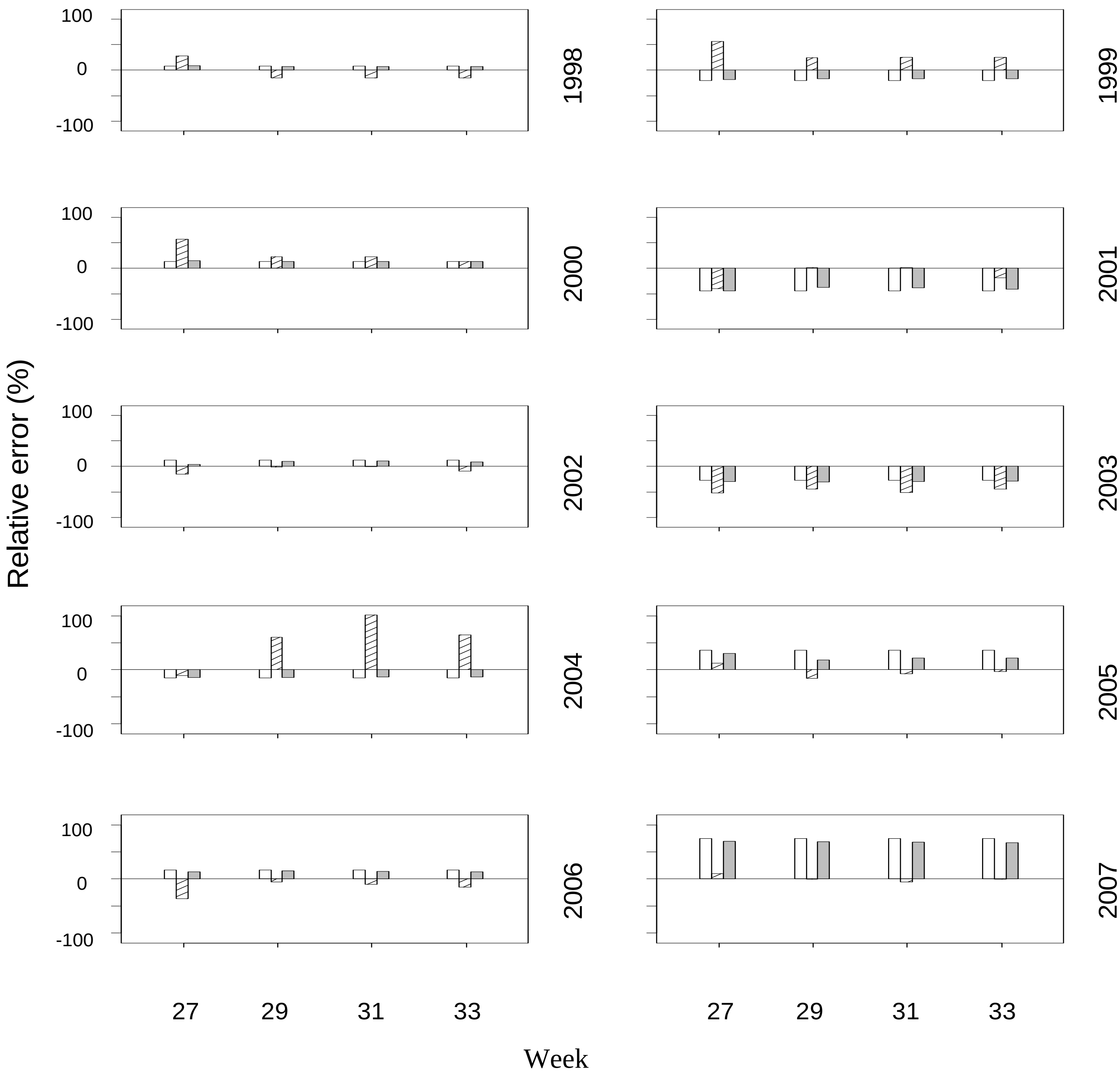

Figure 12. Relative error (%) in preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Upriver Bright (URB) runs in 1998 - 2007. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

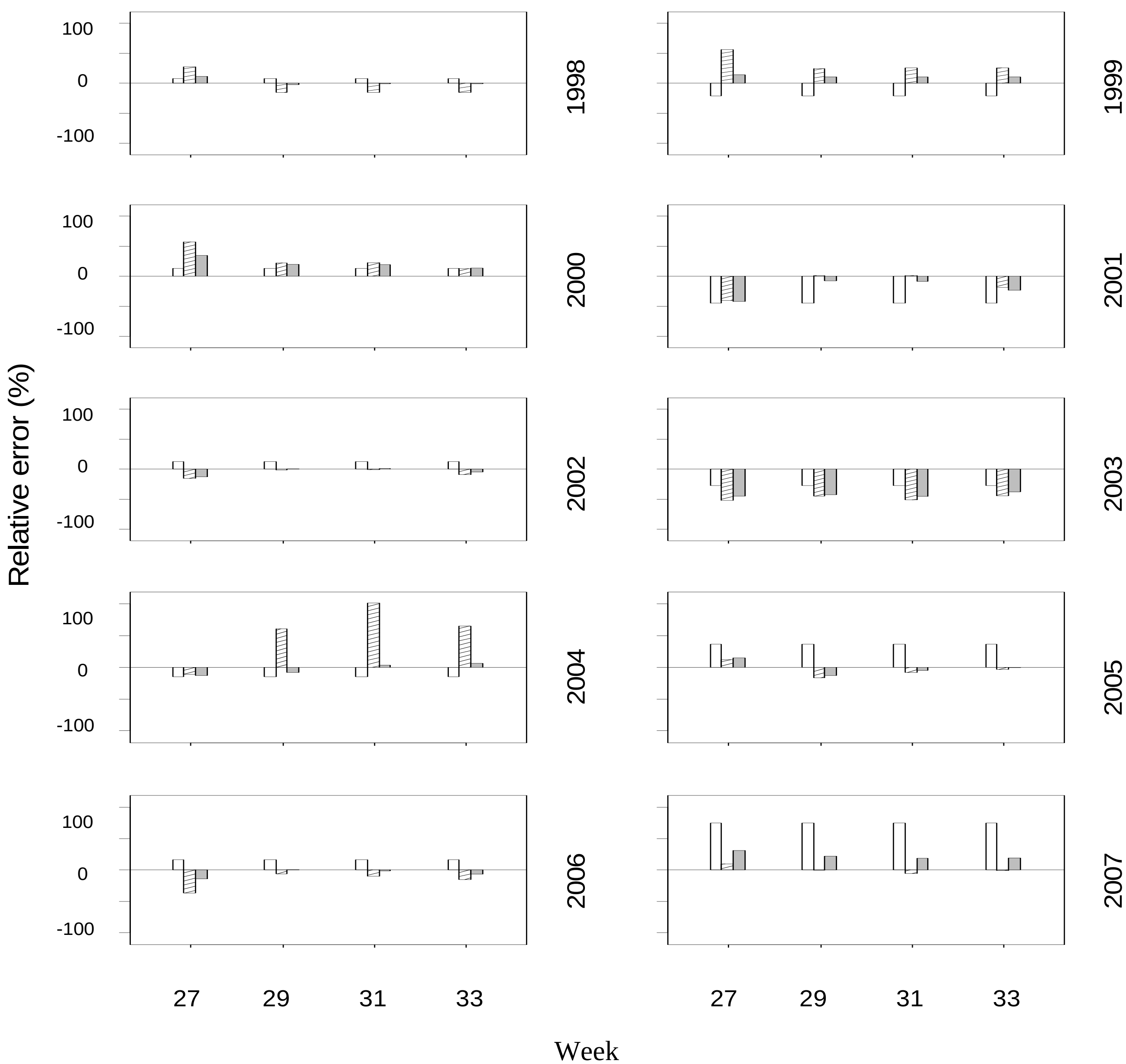

Figure 13. Relative error (%) in modified preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Upriver Bright (URB) runs in 1998 – 2007, where modified preseason forecasts were made by inflating the distribution by five times the standard deviation (SD) of the original preseason forecast distributions. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

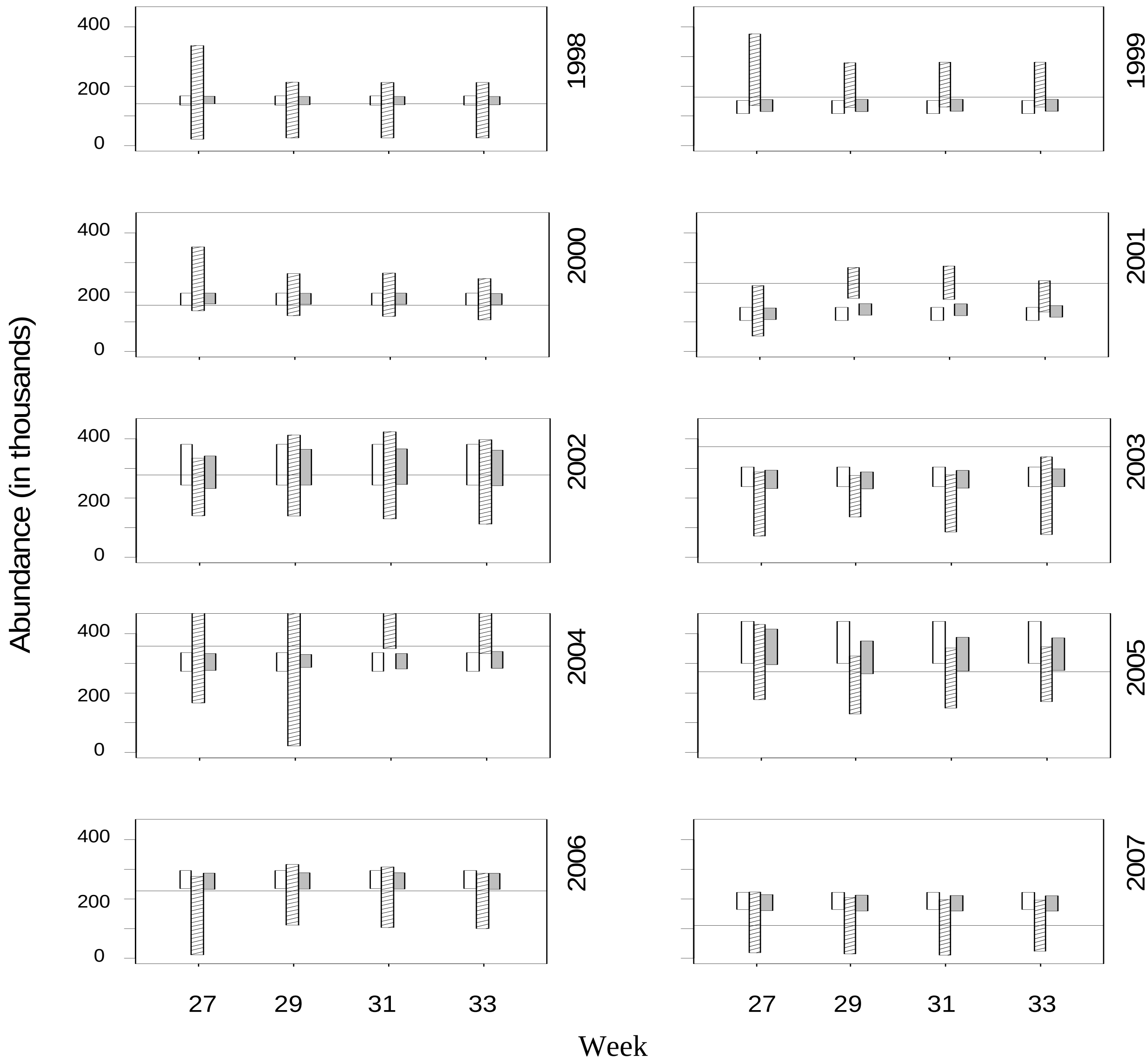

Figure 14. Comparison of preseason forecasts (blank bar), in-season forecasts (shaded bar), and blended forecasts (grey bar) of Upriver Bright (URB) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Preseason forecasts are used whose variances are not inflated.

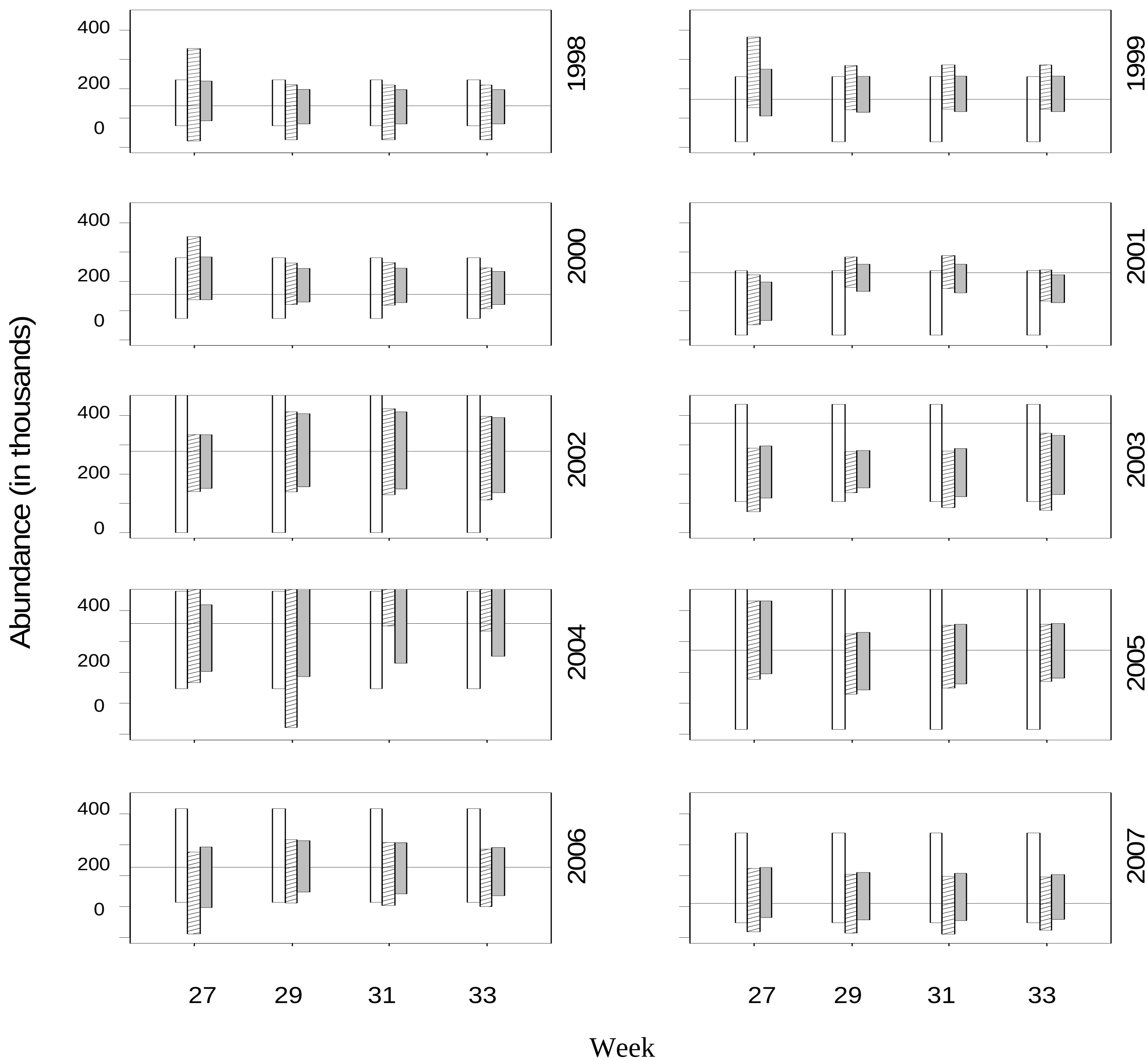

Figure 15. Comparison of modified preseason forecasts (blank bar), in-season forecasts (shaded bar), and blended forecasts (grey bar) of Upriver Bright (URB) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Modified preseason forecasts are used whose variances are inflated by multiplying their standard deviation by five.

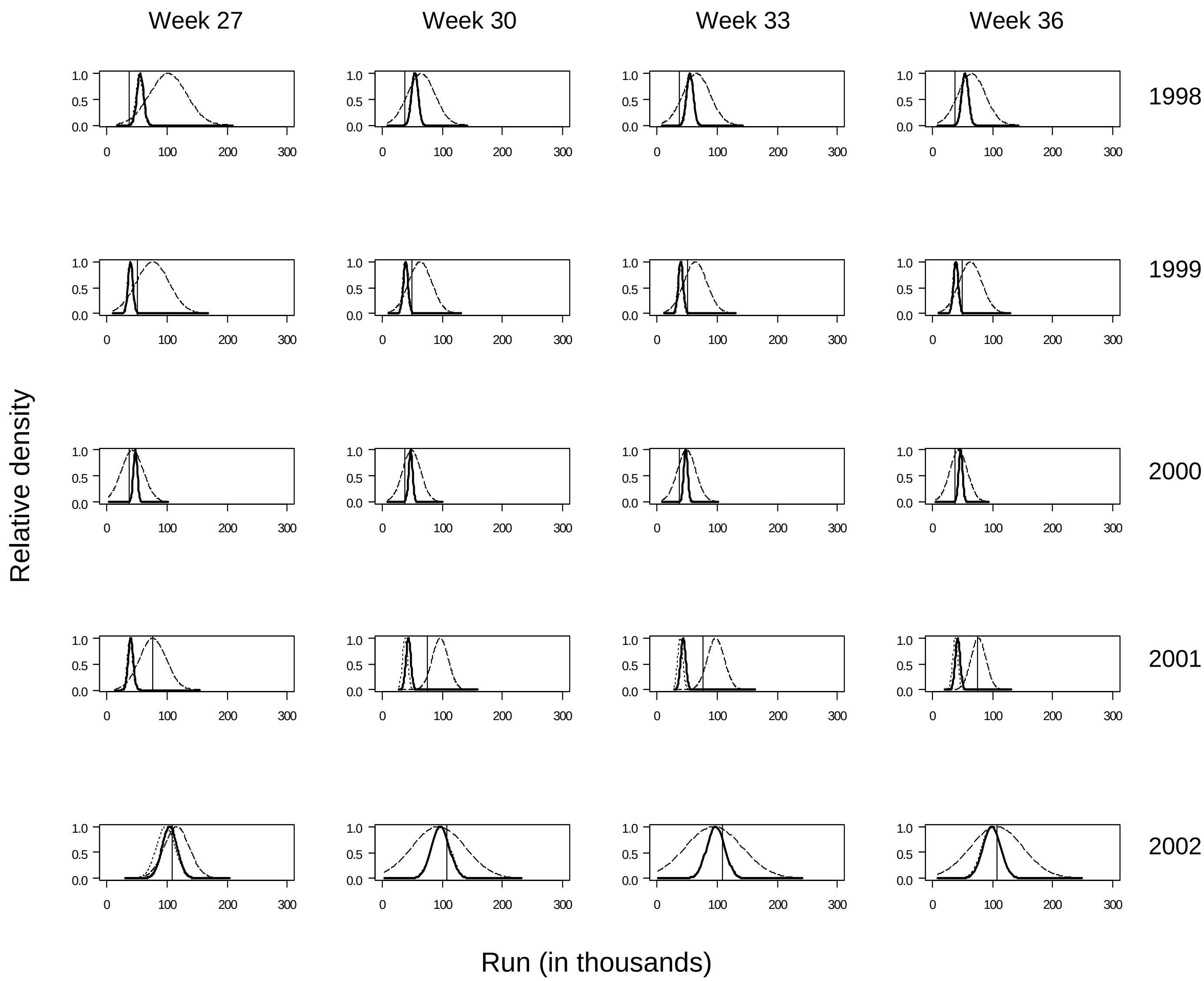

Figure 16. In-season (broken line) and preseason (dot line) forecasts of Mid Columbia River Bright (MCB) return sizes at ages 3 - 5 in 1998 - 2002, and the integrated forecasts (solid line). Vertical line indicates actual return size.

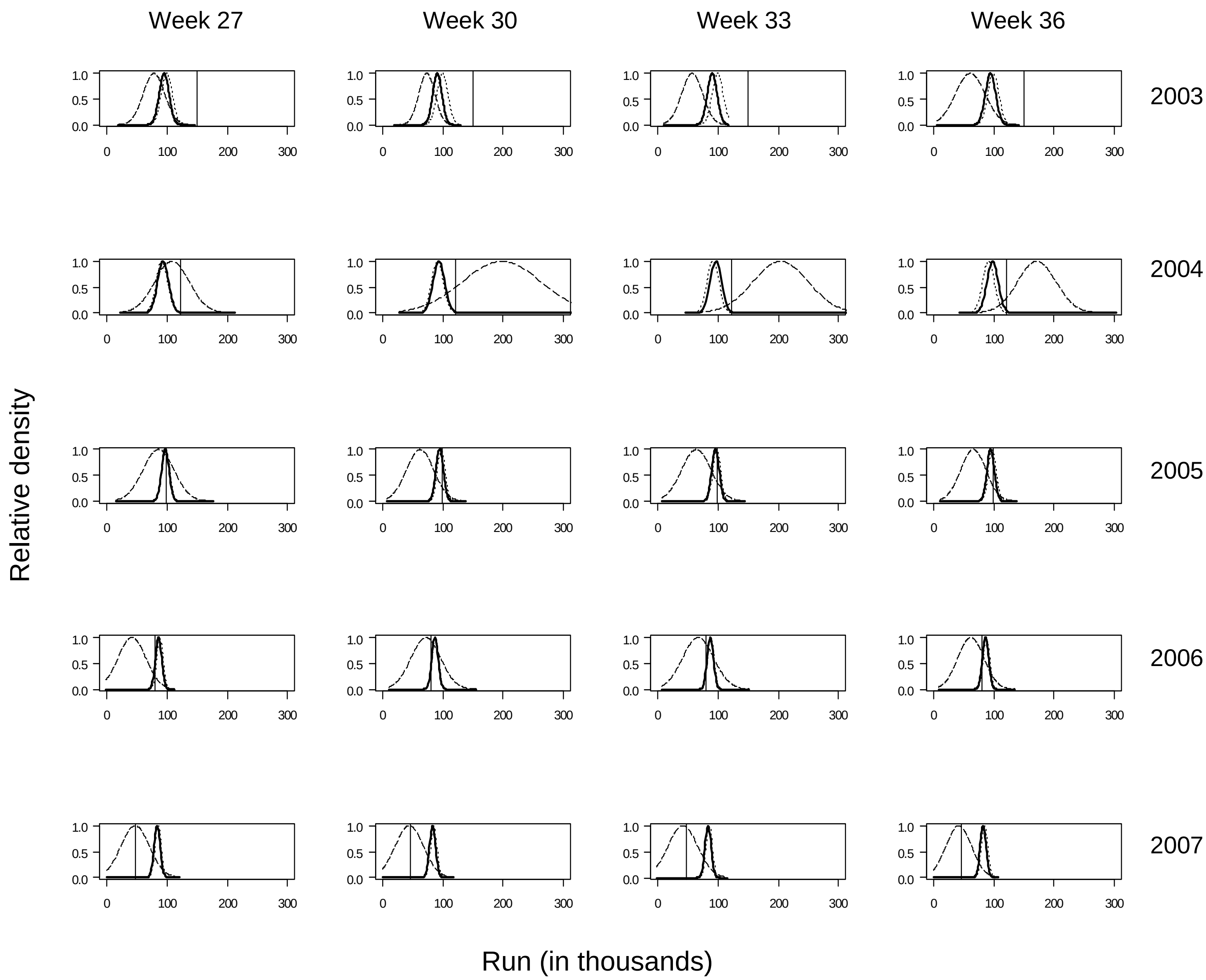

Figure 17. In-season (broken line) and preseason (dot line) forecasts of Mid Columbia River Bright (MCB) return sizes at ages 3-5 in 2003 - 2007, and the integrated forecasts (solid line). Vertical line indicates actual return size.

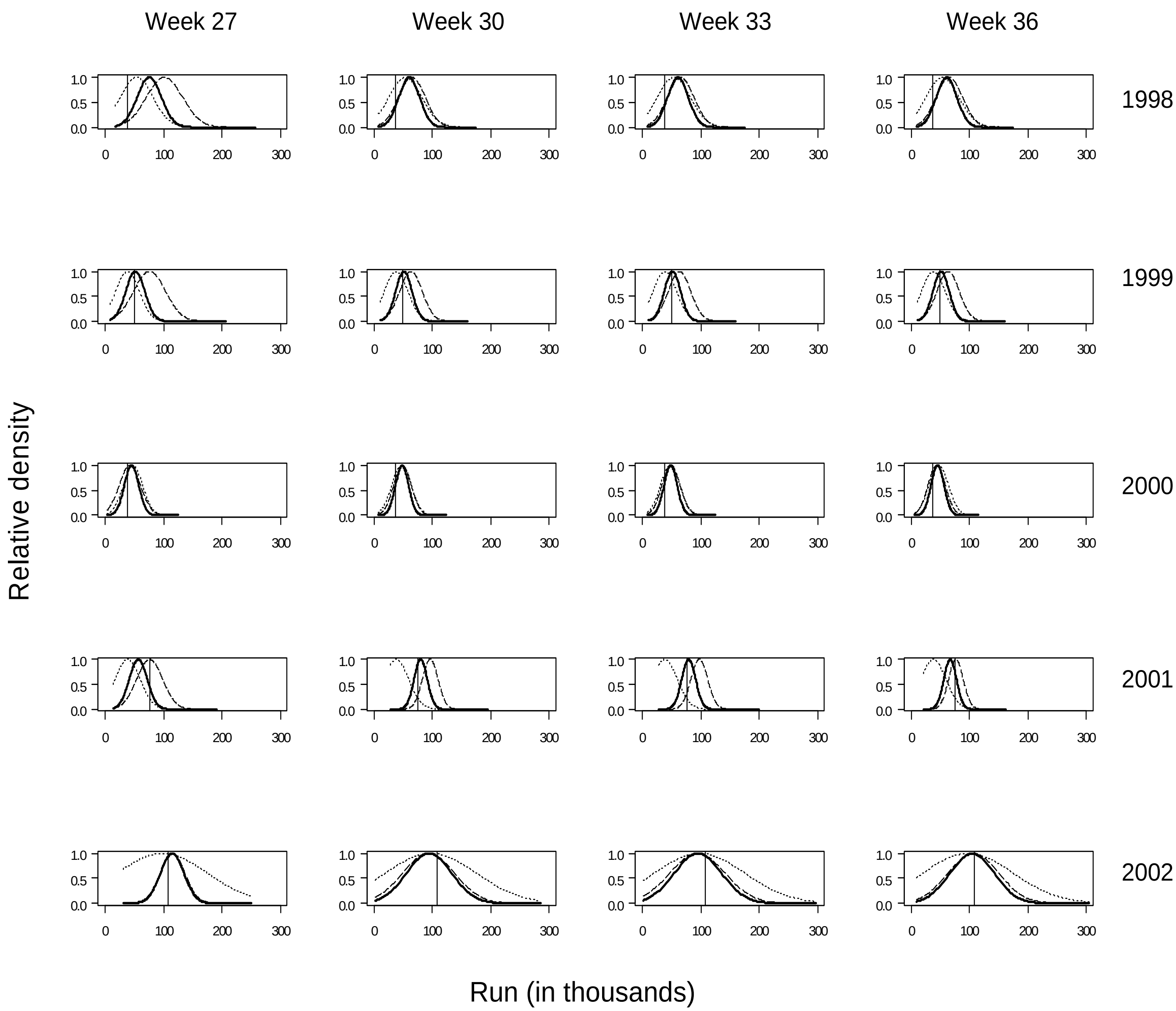

Figure 18. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Mid Columbia River Bright (MCB) return sizes at ages 3 - 5 in 1998 - 2002 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size.

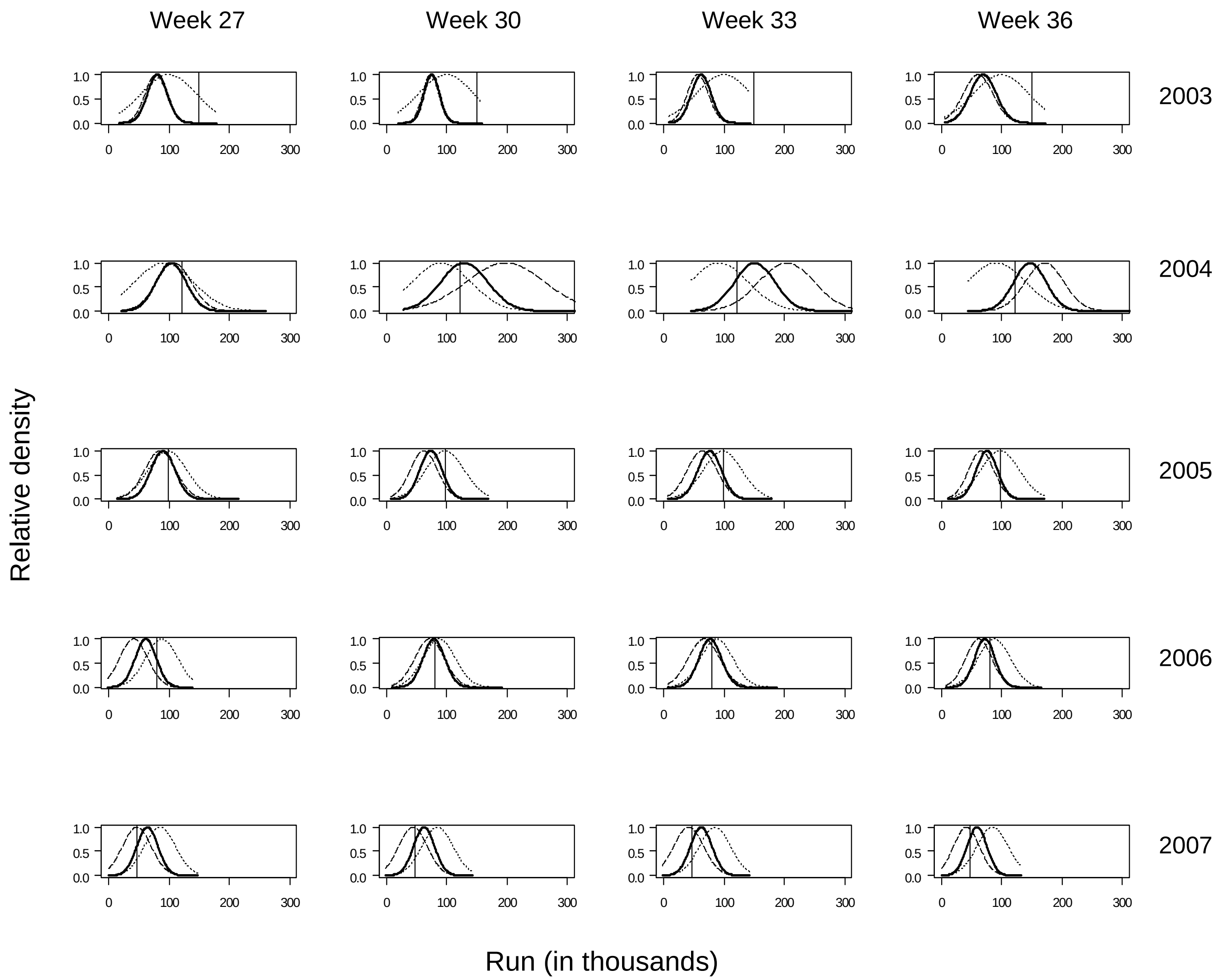

Figure 19. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Mid Columbia River Bright (MCB) return sizes at ages 3 - 5 in 2003 - 2007 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size.

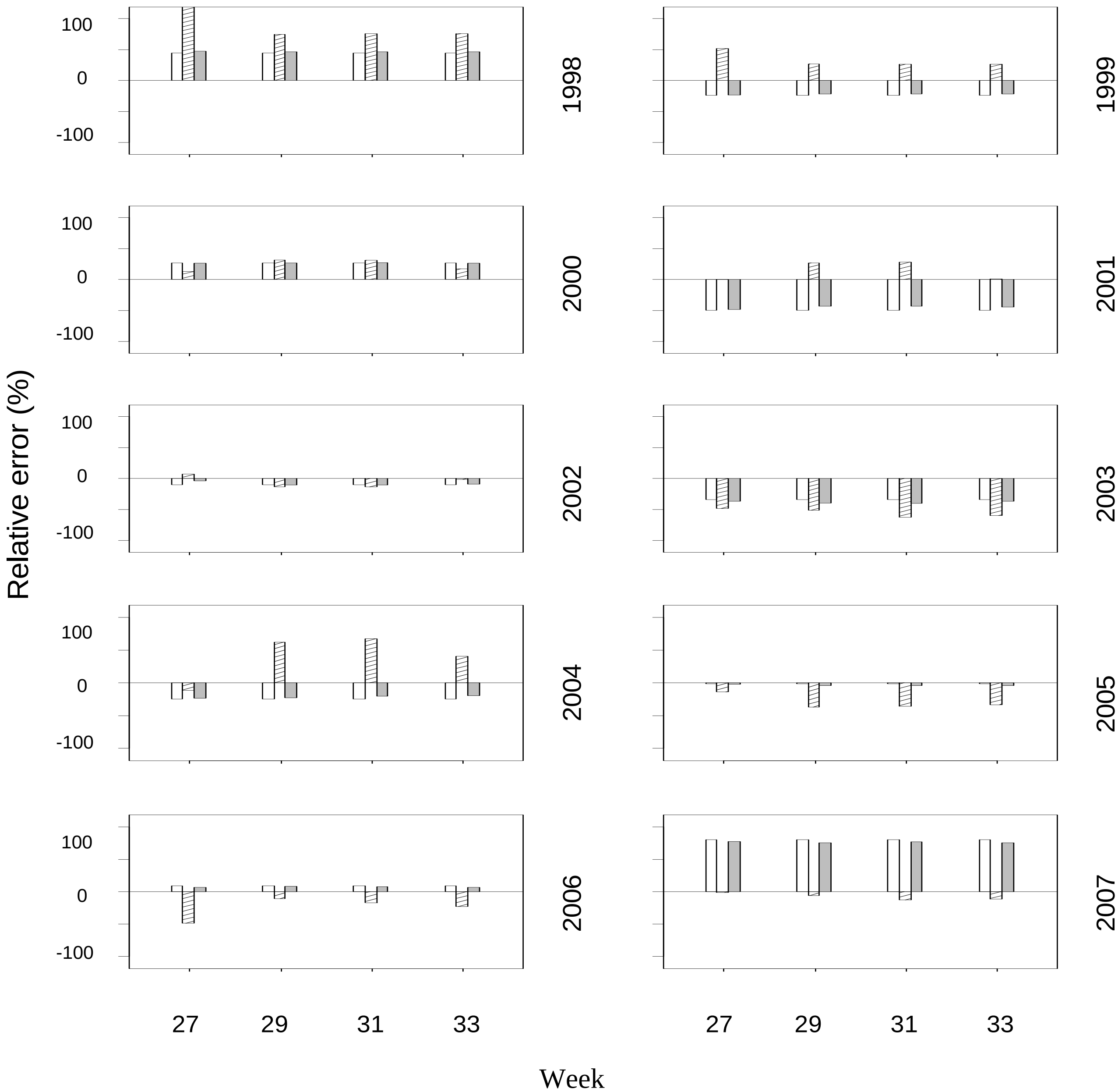

Figure 20. Relative error (%) in preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Mid Columbia River Bright (MCB) runs in 1998 - 2007. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

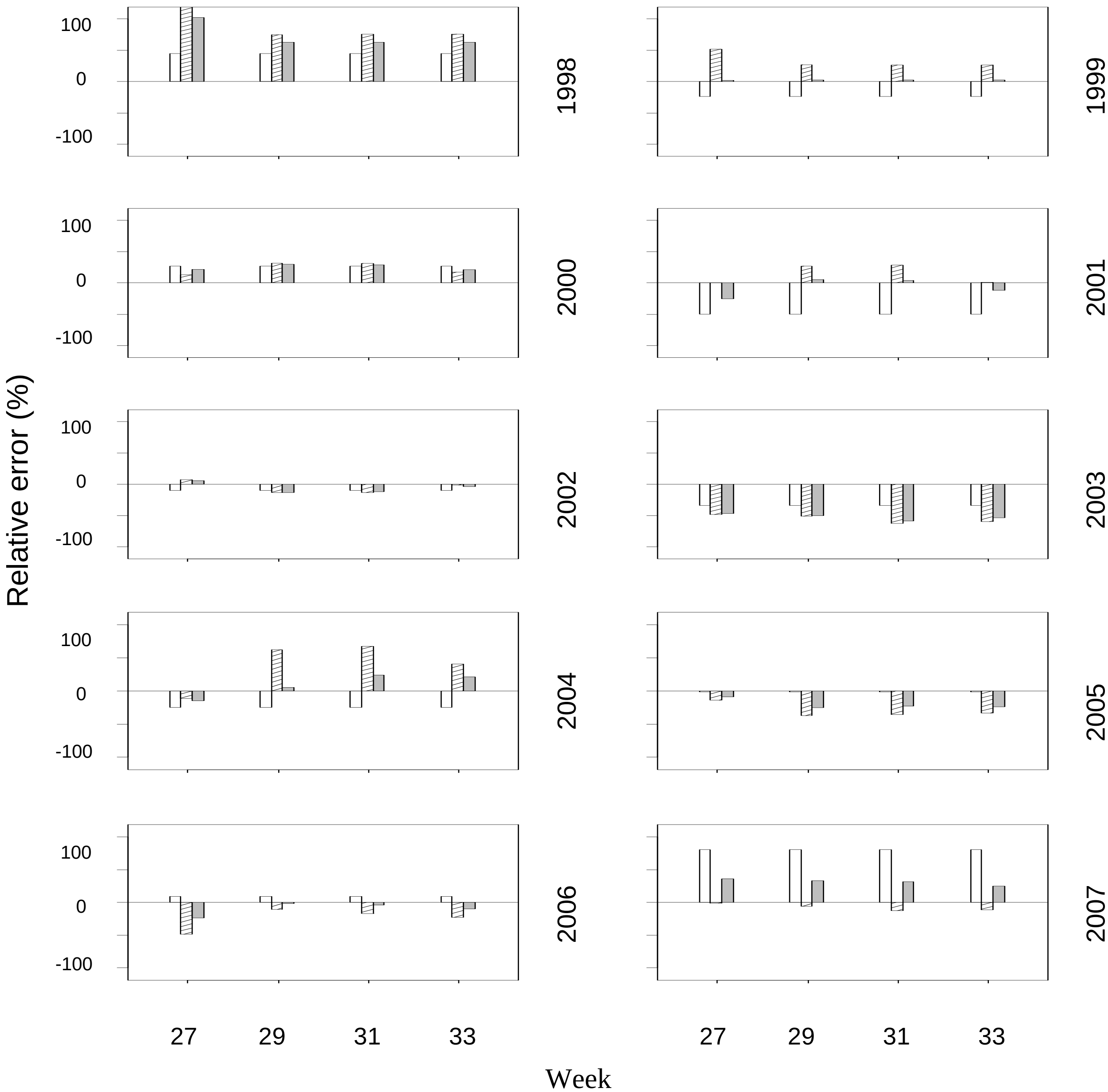

Figure 21. Relative error (%) in modified preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Mid Columbia River Bright (MCB) runs in 1998 – 2007, where modified preseason forecasts were made by inflating the distribution by five times the standard deviation (SD) of the original preseason forecast distributions. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

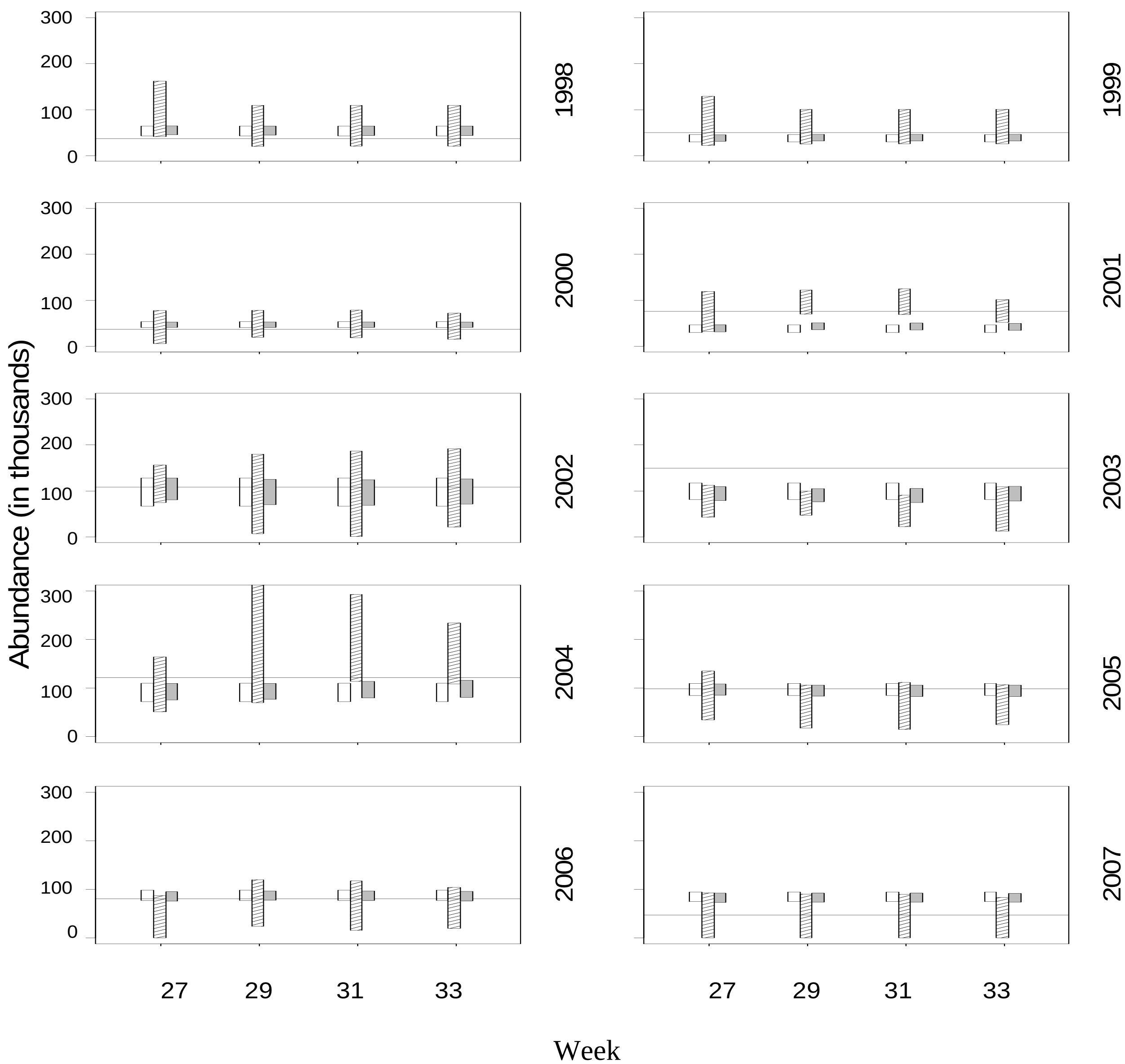

Figure 22. Comparison of preseason forecasts (blank bar), in-season forecasts (shaded bar), and blended forecasts (grey bar) of Mid Columbia River Bright (MCB) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Preseason forecasts are used whose variances are not inflated.

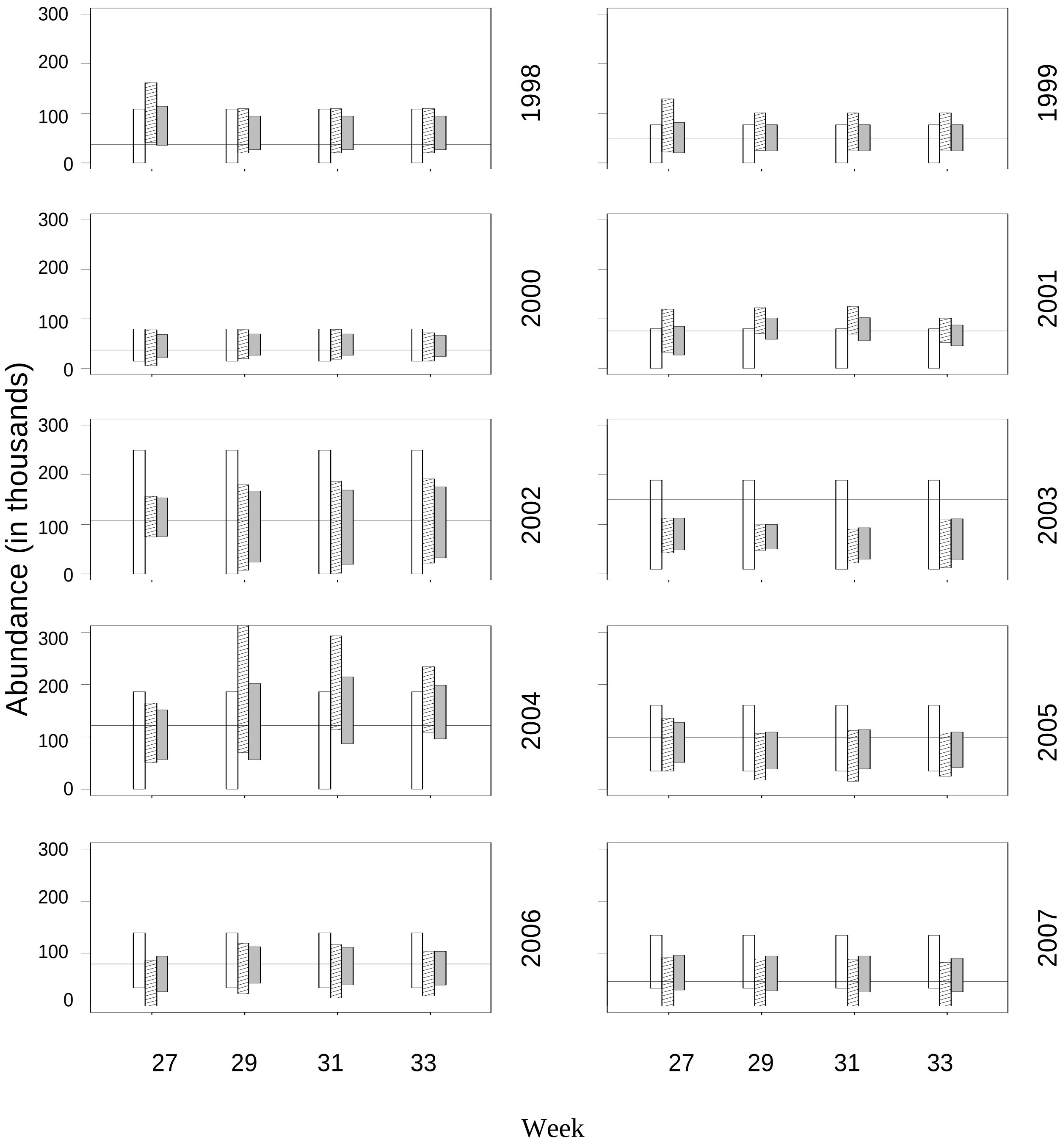

Figure 23. Comparison of modified preseason forecasts (blank bar), in-season forecasts (shaded bar), and blended forecasts (grey bar) of Mid Columbia River Bright (MCB) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Modified preseason forecasts are used whose variances are inflated by multiplying their standard deviation by five.

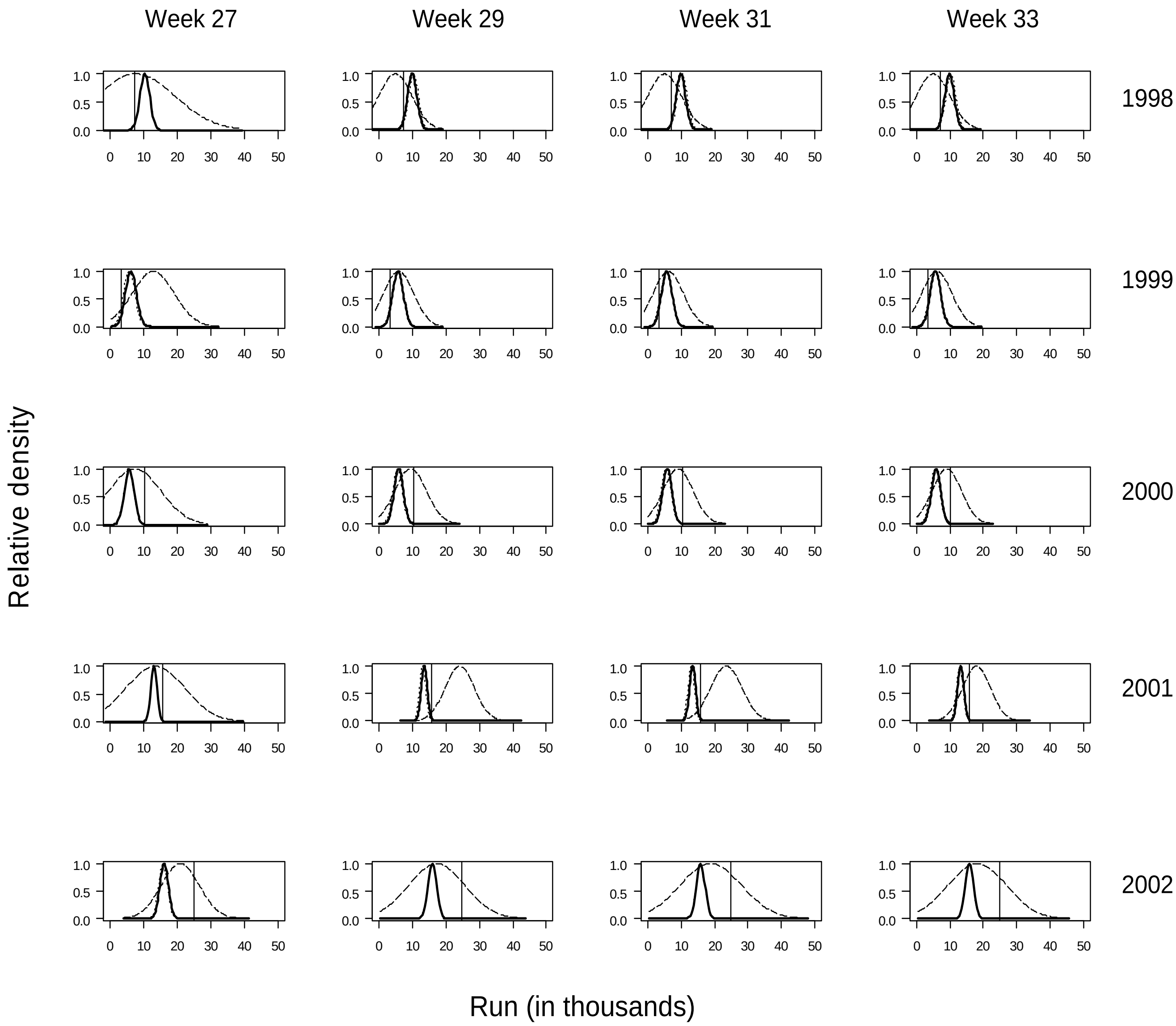

Figure 24. In-season (broken line) and preseason (dot line) forecasts of Lower River Wild (LRW) return sizes at ages 3-5 in 1998 - 2002, and the integrated forecasts (solid line). Vertical line indicates actual return size.

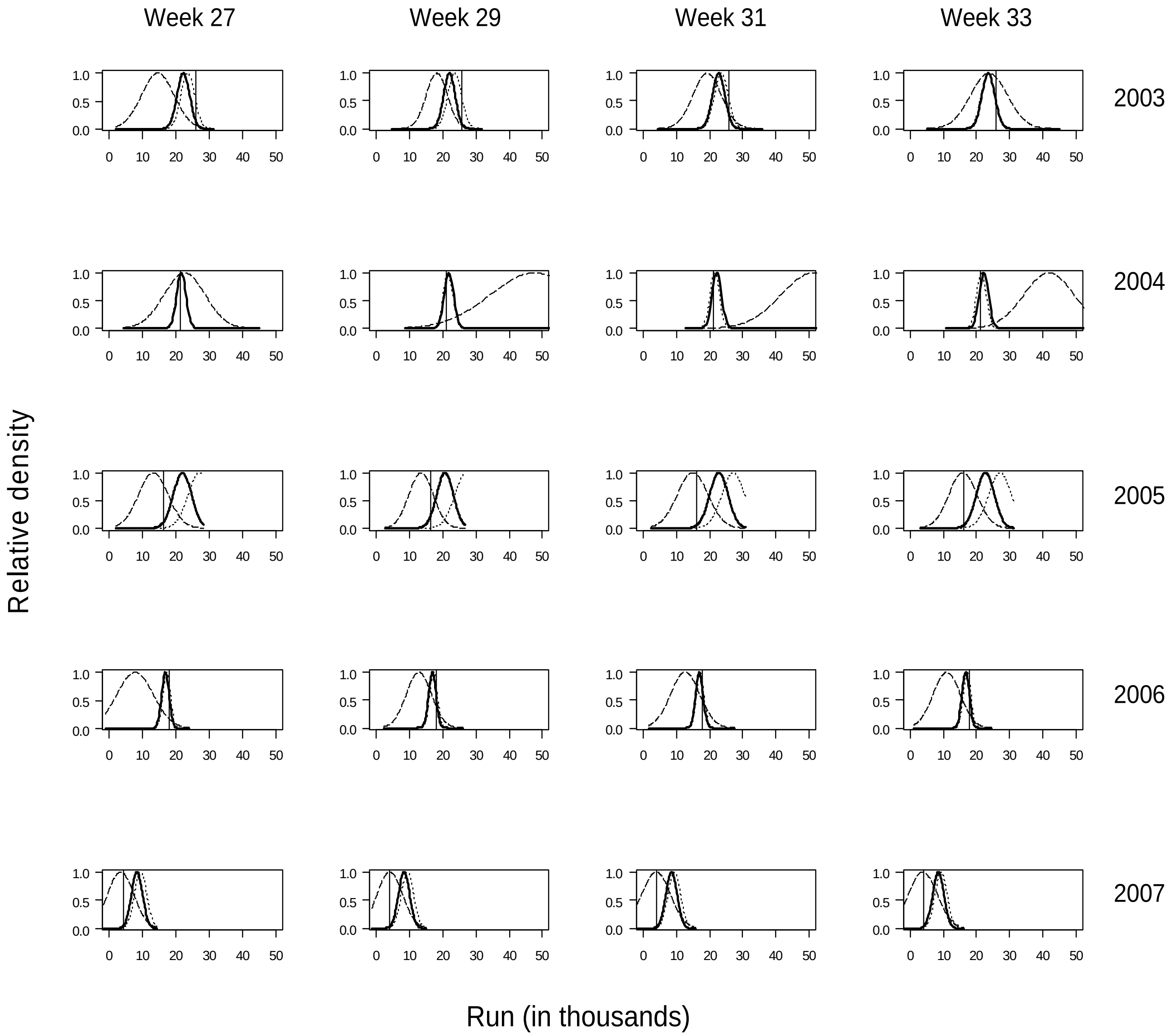

Figure 25. In-season (broken line) and preseason (dot line) forecasts of Lower River Wild (LRW) return sizes at ages 3-5 in 2003 - 2007, and the integrated forecasts (solid line). Vertical line indicates actual return size.

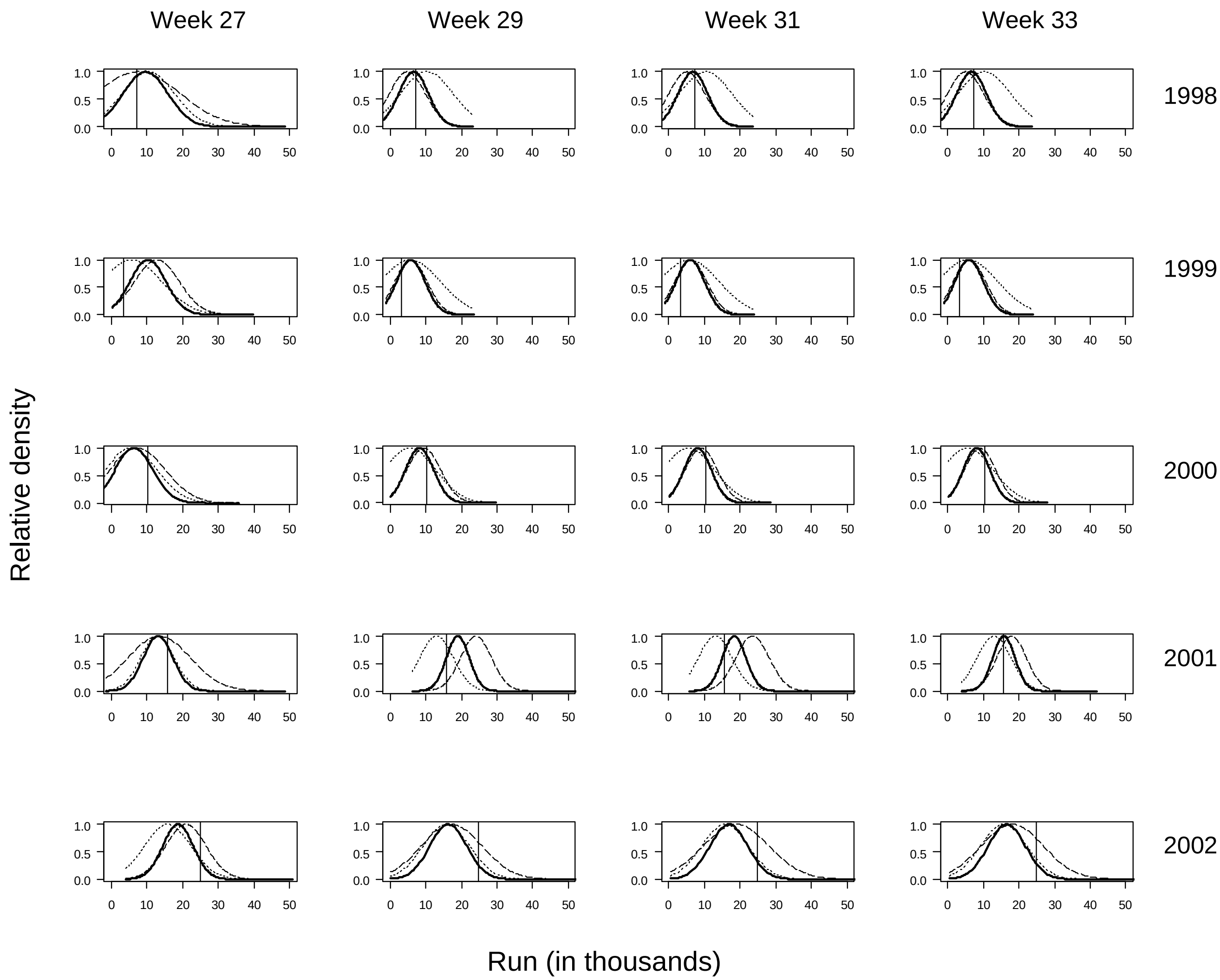

Figure 26. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Lower River Wild (LRW) return sizes at ages 3 - 5 in 1998 - 2002 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size.

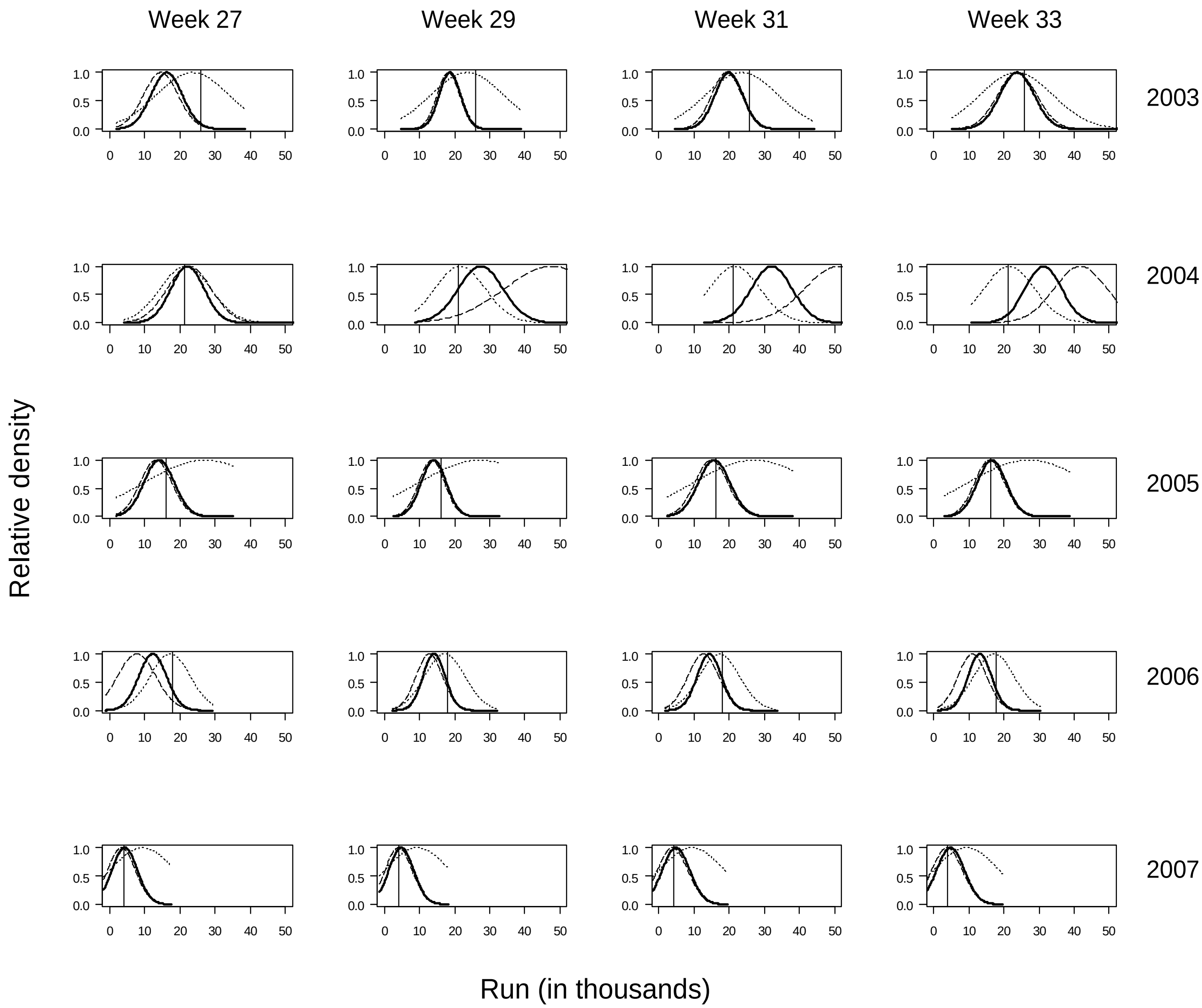

Figure 27. Comparison of in-season (broken line), modified preseason (dot line), and integrated (solid line) forecasts of Lower River Wild (LRW) return sizes at ages 3 - 5 in 2003 - 2007 where the modified preseason is made by inflating its distribution by five times the standard deviation (SD) of the original preseason forecast distribution. Vertical line indicates actual return size.

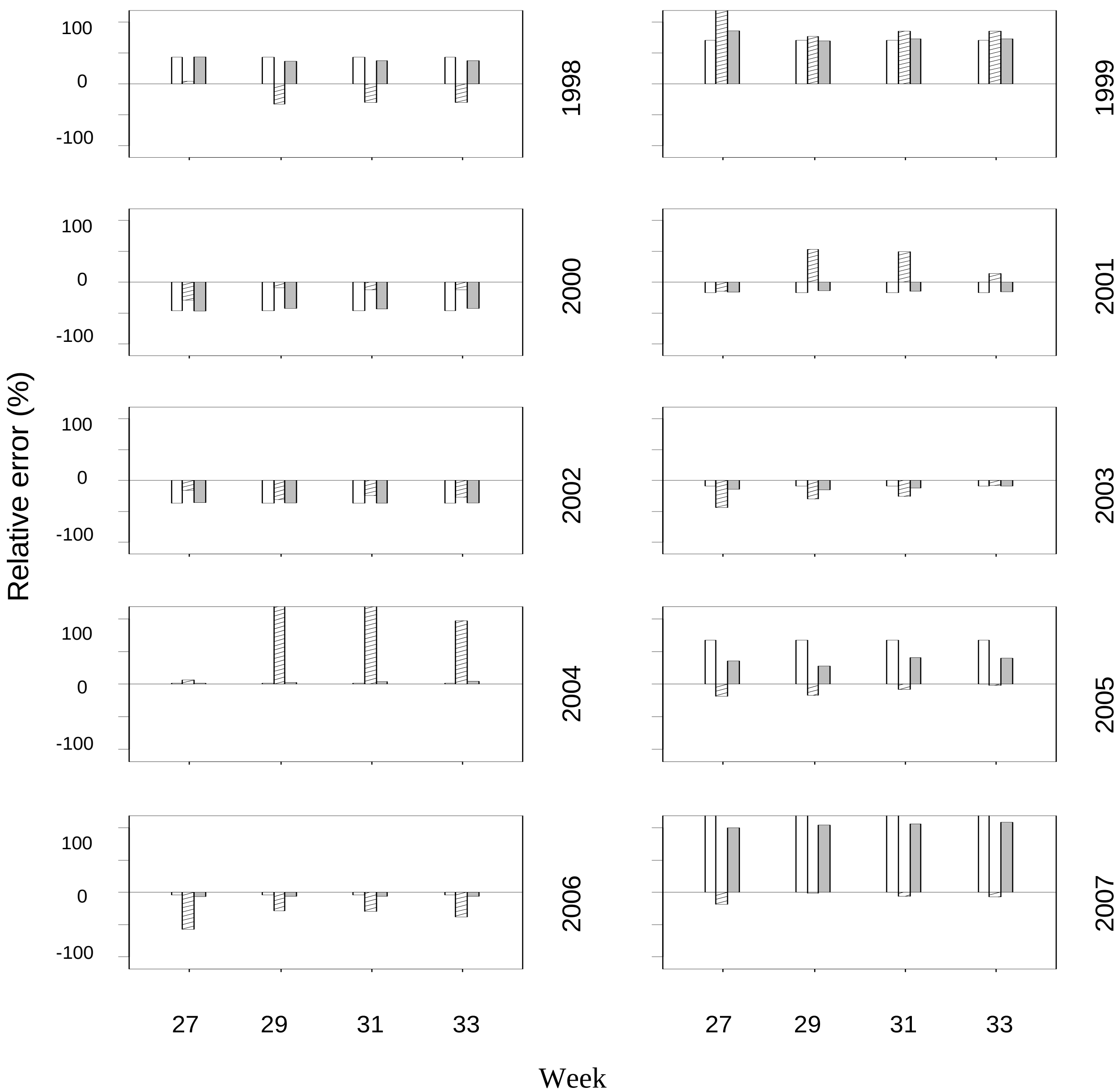

Figure 28. Relative error (%) in preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Lower River Wild (LRW) runs in 1998 - 2007. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

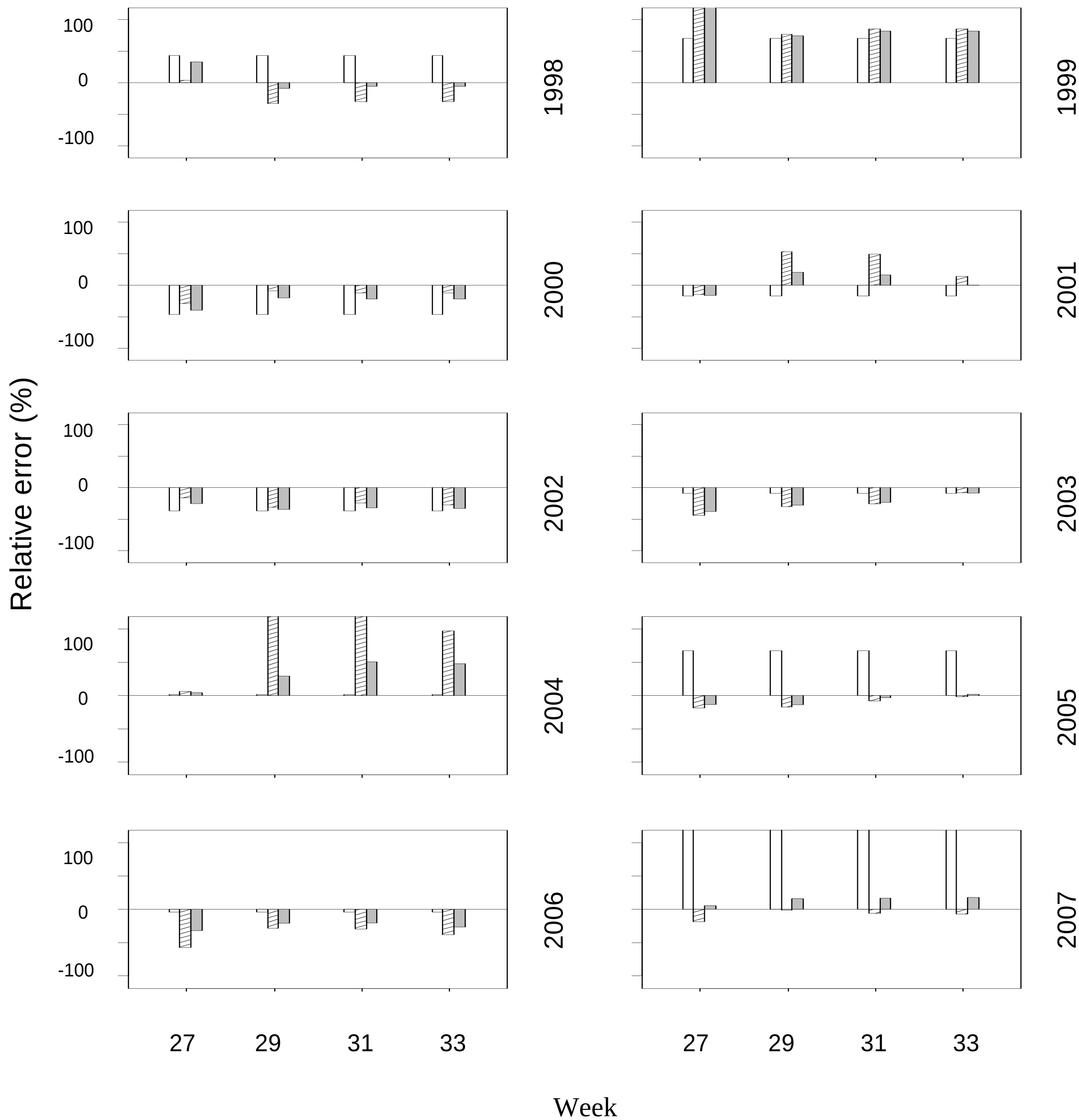

Figure 29. Relative error (%) in modified preseason (blank bar), in-season (shaded bar), and integrated (grey bar) forecasts of Lower River Wild (LRW) runs in 1998 – 2007, where modified preseason forecasts were made by inflating the distribution by five times the standard deviation (SD) of the original preseason forecast distributions. Positive values in relative error indicate over-forecasts whereas negative values mean under-forecasts.

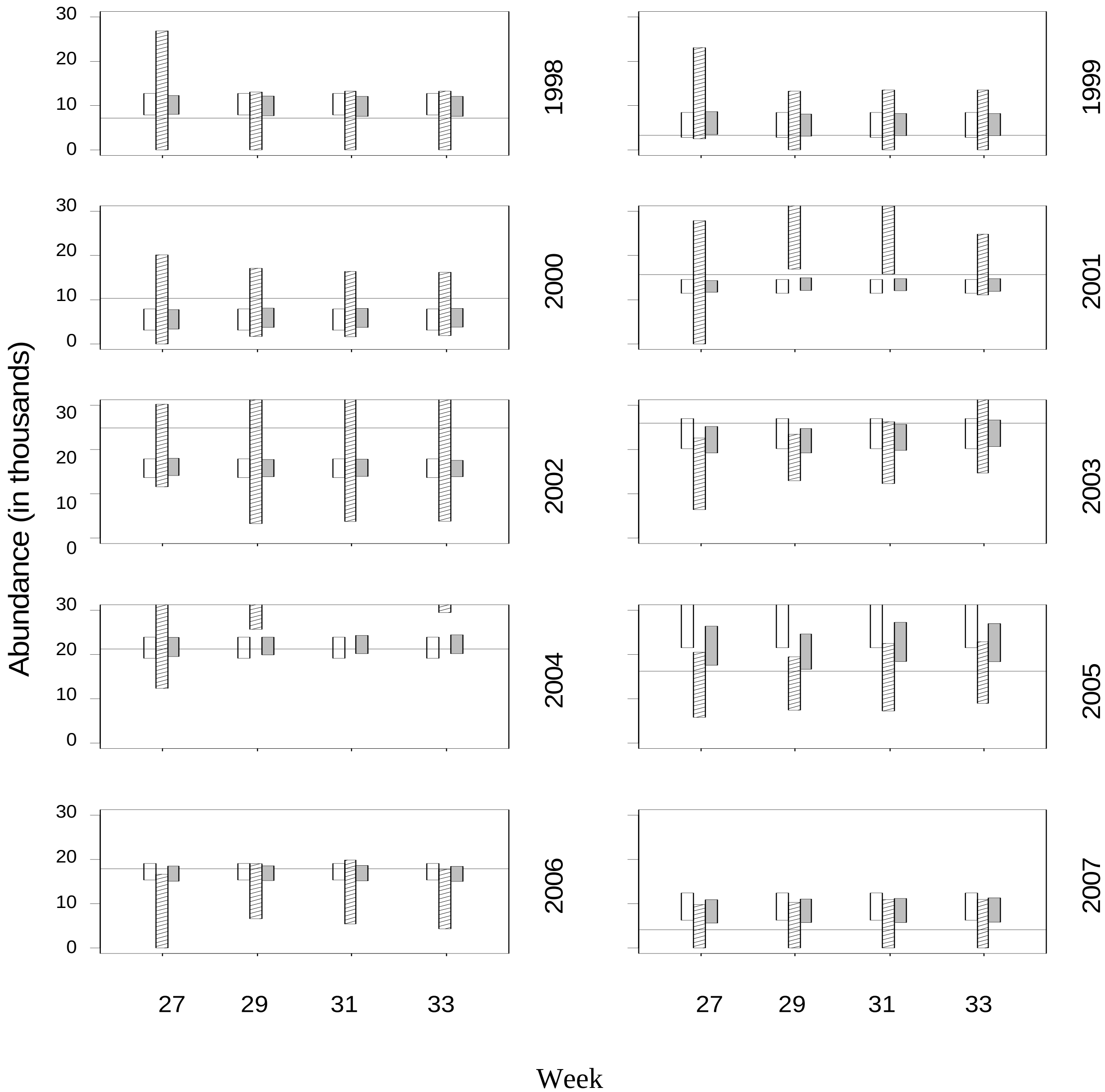

Figure 30. Comparison of preseason forecasts (blank bar), in-season forecasts (shaded bar), and blended forecasts (grey bar) of Lower River Wild (LRW) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Preseason forecasts are used whose variances are not inflated.

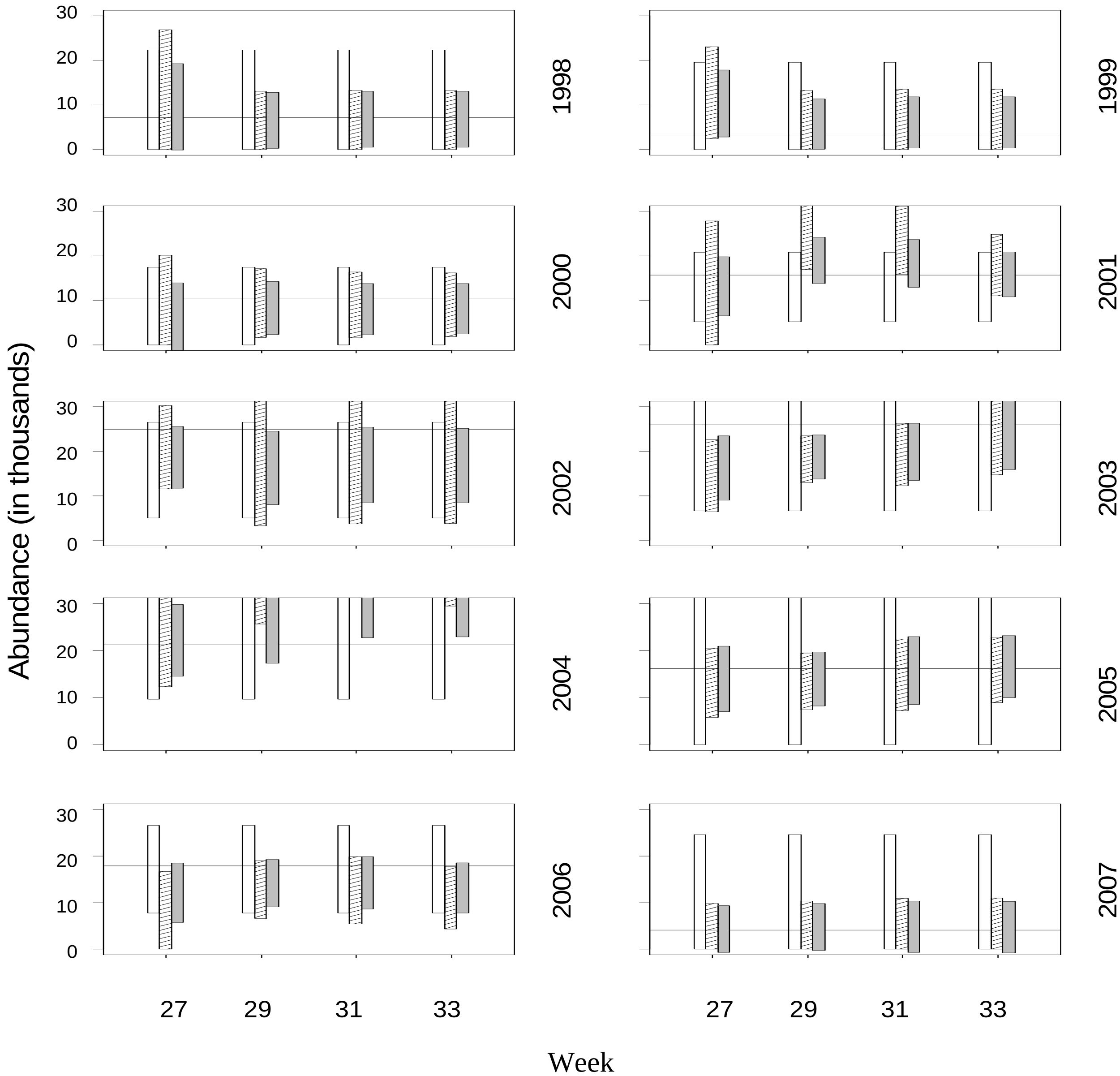

Figure 31. Comparison of preseason forecasts (blank bar), in-season forecasts (middle shaded bar), and blended forecasts (right grey bar) of Lower River Wild (LRW) runs in 1998-2007. Horizontal line in each panel is the actual run size that happened in the corresponding year. Preseason forecasts are used whose variances are inflated by multiplying their standard deviation by 5.