

FRI-UW-9819  
December 1998

# **THE 1999 FRI PRESEASON FORECAST OF THE BRISTOL BAY SOCKEYE RUN USING AN ALTERNATIVE APPROACH**

R. HILBORN, D. ROGERS, G. RUGGERONE, AND R. STEEN

**ANNUAL REPORT TO**

**BRISTOL BAY PROCESSORS**

## **PREFACE**

The traditional method for preseason forecasting of Bristol Bay sockeye salmon has clearly failed in the last 2 years, and this may portend a return to lower rates of return. This year, we explored a number of methods for forecasting the run, including the traditional approach, adjusting the forecast by recent deviations from the forecast, and using recruits-per-spawner. The first method is documented in Rogers (1998), and this report describes the second two methods. We then used these three approaches and produced a weighted average to provide our final preseason forecast.

The forecast for the 1999 year is highly uncertain and we wished to express this uncertainty in our forecasting.

## **KEY WORDS**

Alaska, alternative forecasts, Bristol Bay fishery, marine survival, ocean conditions, recruits-per-spawner, sockeye salmon

# The 1999 FRI Preseason Forecast of the Bristol Bay Sockeye Run Using an Alternative Approach

R. HILBORN, D. ROGERS, G. RUGGERONE, AND R. STEEN

## OVERVIEW

The poor returns of sockeye salmon (*Oncorhynchus nerka*) for the Bristol Bay fishery in 1997 and 1998 and the failure of the Fisheries Research Institute (FRI) and Alaska Department of Fish & Game (ADFG) forecasts to predict these poor returns raise the possibility that the forecast methods that have been used with considerable success since the mid-1980s may no longer be reliable. The strongest evidence is for reduced marine survival of the major Kvichak, Naknek, Egegik and Ugashik runs. This poor survival could be due to increased predation pressure during the early ocean life, poorer feeding conditions leading to reduced growth and survival, catastrophic marine mortality events, or high-seas interception.

We have documented three different forecasting approaches—the traditional FRI forecast method done by Rogers, a modification to this method correcting for the overforecasting bias of recent years done by Ruggerone, and a method looking at the time trends in recruits per spawner done by Hilborn and Steen. These methods produce total run forecasts ranging from 18 million to 35 million fish. We are aware of other forecasts by University of Alaska and NMFS staff that run up to about 44 million fish.

If we believe that the poor ocean survival seen in recent years will continue for the fish returning in 1999, our forecast will be at the low end whereas if we believe that the average conditions over the last 20 years or so will prevail, we end up towards the high end.

We adopted a different approach to this year's forecast: rather than deciding on a single methodology, we blended the different approaches using our professional judgment, and have provided the forecast as a range of possible run sizes.

Our method was as follows. After discussion between all of us, Hilborn, Rogers and Ruggerone independently assigned probabilities to the run falling into the categories 10–20 million, 20–30 million, 30–40 million and greater than 40 million.

Table 1 shows how we weighted the different alternatives. Person A assigned the most weight (50%) to a run between 30 and 40 million, while persons B and C assigned the most weight to a run between 20 and 30 million. We all agreed there is a 10% chance of the run being below 20 million, and on average about an 8% chance the run will be greater than 40 million. The expected value of this forecast is 28.8 million total return.

## THE 1999 FORECAST ADJUSTED FOR 1997–98 MARINE SURVIVAL CONDITIONS

G.T. RUGGERONE

### Introduction

Sockeye salmon runs to Bristol Bay were considerably smaller than expected in 1997 and 1998. Several hypotheses have been suggested to explain the small runs, ranging from increased predation on smolts by beluga whales in the Kvichak River to low survival of adults entering Bristol Bay. The hypothesis that is explored here involves changes in marine conditions that might have led to reduced survival of Bristol Bay sockeye salmon. Evidence is presented showing that major changes in the ocean environment have occurred in recent years. One particularly important effect of changing ocean conditions is the small body length of Bristol Bay sockeye salmon returning to the bay during the past 2 years.

TABLE 1. Weighting values for determining Bristol Bay sockeye salmon run forecast.

Range	A	B	C	Average
10-20 M	0.10	0.10	0.10	0.10
20-30 M	0.30	0.70	0.50	0.50
30-40M	0.50	0.15	0.30	0.32
> 40 M	0.10	0.05	0.10	0.08

If ocean conditions led to reduced survival and low returns of sockeye salmon to Bristol Bay in 1997 and 1998, it is possible that low survival may continue into 1999. Most of the 1999 sockeye run would have entered the ocean in 1996 (3-ocean fish) and 1997 (2-ocean fish); these fish may have been exposed to similar environmental conditions as fish returning in 1997 and 1998.

Modified salmon forecasts were developed to show the projected runs in 1999 assuming low survival is consistent with the small runs in 1997 and 1998. The forecasts were based on Rogers' 1999 forecast models for key salmon age groups. However, average forecast errors were used when hindcasting the 1997 and 1998 runs to adjust the 1999 forecast. This adjustment caused the modified 1999 forecast to be considerably lower than the 1999 forecast by Rogers since forecasts during the past 2 years overestimated the run size.

### Modified 1999 Sockeye Forecast

The modified 1999 forecast is 27.3 million sockeye compared to Rogers' forecast of 35.1 million sockeye salmon (Table 2). The greatest difference occurs in the

TABLE 2. Comparison of Rogers' 1999 Bristol Bay forecast with a forecast based on Rogers' forecast models after making adjustments for errors in the 1997 and 1998 forecasts. Only major age groups and stocks having large error were evaluated.

River System	Run by age group (millions)				Total
	1.2	2.2	1.3	2.3	
<b>Kvichak</b>					
Rogers	5.2	7.4	1.2	0.4	14.2
Modified forecast	3.0	5.4	same	same	10.0
<b>Naknek</b>					
Rogers	0.4	0.8	1.2	0.6	3.0
<b>Branch</b>					
Rogers	0.2	0.2	0.1	0.0	0.5
<b>NAKNEK/KVICHAK DISTRICT</b>					
Rogers	5.8	8.4	2.5	1.0	17.7
Modified forecast	3.6	6.4	2.5	1.0	13.5
<b>Egegik</b>					
Rogers	0.6	4.7	1.1	1.3	7.7
Modified forecast	same	2.4	0.6	0.8	4.4
<b>Ugashik</b>					
Rogers	0.6	1.0	1.0	0.1	2.7
Modified forecast	same	0.7	0.9	same	2.3
<b>Nushagak</b>					
Rogers	2.7	0.2	3.7	0.1	6.7
<b>Togiak</b>					
Rogers	0.1	0	0.2	0	0.3
<b>BRISTOL BAY</b>					
Rogers	9.8	14.3	8.6	2.4	35.1
Modified forecast	7.6	9.6	8.0	2.0	27.3

Kvichak, Egegik, and Ugashik forecasts where the runs are forecasted by the new approach to be 10.0, 4.4, and 2.3 million fish, respectively. The forecast of age 1.2 sockeye returning to the Kvichak in 1999 (which should be a large portion of the 1999 run) is subject to greater error because the historical relationship for this age group is weak. No adjustments were made to the Nushagak District run since the past forecast to this district was reasonably accurate.

### Past Relationships Between Ocean Environment and Salmon Forecasts

Salmon runs to Bristol Bay and other areas of Alaska increased sharply in the late 1970s and remained large. During this transition period from lower to higher runs, salmon forecasts underestimated the runs because they were based on historical data when runs were relatively small. Rogers quickly realized this trend and noted that, around 1980, ocean survival must have increased because data collected in the Wood River Lakes and in Lake Iliamna did not indicate a change in salmon abundance or size. Furthermore, Rogers observed that the larger runs were associated with increased winter sea-surface temperatures (SST) in the Gulf of Alaska.

### Evidence for Recent Ocean Condition Changes

During the 1995–96 winter, SST reached a historical high (since 1965) in the region occupied by salmon below the Aleutian Islands (Fig. 1, Ruggerone 1997). Oceanographers

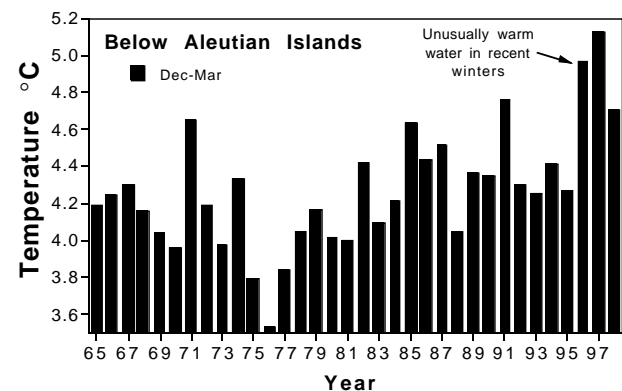


FIGURE 1. Time series of sea surface temperature during winter in the western North Pacific Ocean south of the Aleutian Islands. Temperature was exceptionally warm during the two winters preceding the 1997 El Niño.

suggested the warm waters were related to cumulative effects of El Niño conditions during the early 1990s. Winter SST below the Aleutian Islands increased again in 1996–97, the season preceding the 1997 El Niño event. During the summer of 1997 (El Niño), many dead seabirds were observed from Chignik to False Pass to the Bering Sea. Necropsies by the U.S. Fish and Wildlife Service indicated the birds died from starvation rather than disease; observers noted that smaller die-offs had been observed in the past. Also, widespread blooms of a diatom were noted in the Bering Sea. During winter of 1997–98, SST remained relatively high below the Aleutian Islands. We plan to continue monitoring SST during the 1998–99 winter.

The sockeye salmon forecast models provide evidence that ocean conditions led to unexpectedly small runs in 1997 and 1998. Most age-specific forecast models for Bristol Bay sockeye salmon are based on abundance of smolts and/or abundance of siblings that returned during the previous year (e.g., jacks). The large deviation from the historical relationship during 1997 and 1998 suggests that overall marine survival declined (e.g., smolt-to-adult ratio) or that marine survival during the last year at sea declined (e.g., change in sibling ratio).

Rogers and Ruggerone (1993) described the inverse relationship between the length of adult sockeye salmon returning to Bristol Bay and run size. That is, smaller fish of a given age were associated with larger runs. Notably, this relationship differed between two historical periods. Sockeye length was considerably larger at a given run size during 1978–96 compared with 1958–77. Sockeye run size was typically larger during 1978–96 compared with 1958–77.

Multiple regression was used to describe the relationship between sockeye run size and sockeye length during 1958–96 ( $r^2 = 0.80$ ,  $df = 38$ ). The model included three age groups of female salmon (age 1.3, 2.2, and 1.2; partial  $p \leq 0.005$ ) and two time periods (1958–77 and 1978–96, partial  $p < 0.001$ ). The residual values (observed run–predicted run) in 1997 and 1998 were exceptionally large compared to the past 39 years (Figure 2), indicating sockeye length was exceptionally small in relationship to run size.

Figure 3 shows the multiple regression corrected plot of Bristol Bay run size in relationship to length of age 1.3 female sockeye salmon. Salmon length in 1997 and 1998 was exceptionally small compared with lengths during 1977–96 when runs were relatively large. Sockeye length in 1997 was similar to that expected during 1958–77 when runs were relatively small. In 1998, sockeye length was small even when compared with 1958–77 (Figure 3).

In summary, a variety of unusual events have occurred in recent years. The SST have been unusually high during the past three winters and the 1997 El Niño caused unique oceanic conditions during summer 1997 that apparently led to starvation of seabirds. For Bristol Bay, the preseason run forecasts overestimated the runs during the past two years; the length of returning fish was exceptionally small. These data suggest the ocean environment changed in recent years and may have influenced the unexpectedly small runs.

The key question is whether the apparently poor ocean conditions will continue to influence Bristol Bay runs into 1999. Since most fish returning to the bay in 1999 were at sea since 1996 and 1997, it appears likely that the 1999 return may be influenced by poor ocean conditions.

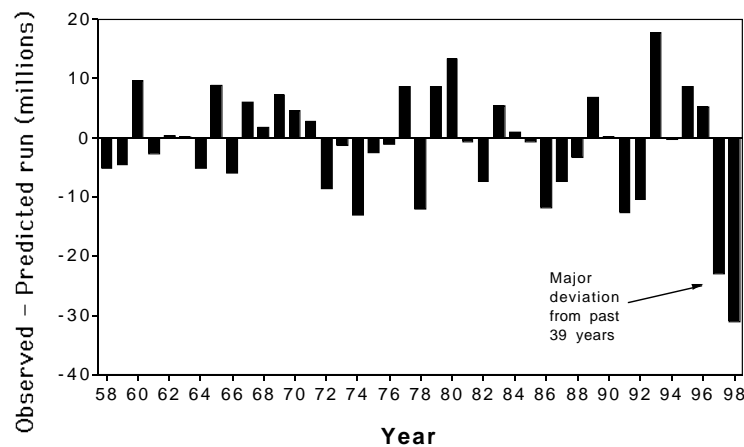


FIGURE 2. Annual error in Bristol Bay run-size prediction based on adult length multiple regression. This graph highlights the major deviation that occurred in 1997 and 1998, indicating conditions changed in the ocean.

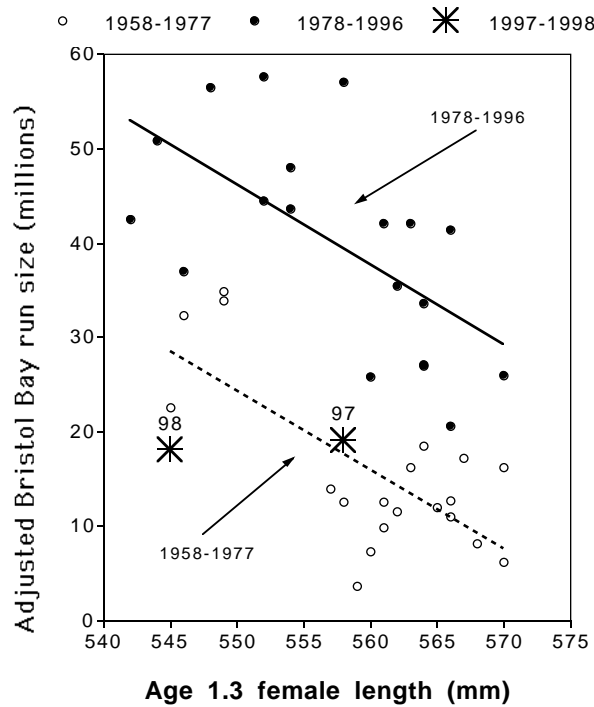


FIGURE 3. Relationship between Bristol Bay run size and length of female sockeye salmon based on multiple regression model, 1958–96. Graph highlights different relationships between salmon run and salmon length during early period when runs were relatively small and the recent period when runs were relatively great. Run and size in 1997 and 1998 are extreme outliers for this 39-year period of record.

**Cautionary Note**

The modified forecast of 27.3 million sockeye salmon returning to Bristol Bay in 1999 was based on the premise that poor ocean conditions led to unexpectedly small runs in 1997 and 1998 and will similarly affect the 1999 run. However, we do not yet have evidence that ocean conditions remain unfavorable at present. Furthermore, we cannot explain why some sockeye runs were productive in 1998 (e.g., Kodiak) whereas others (Bristol Bay and Upper Cook Inlet) were not. Nor can we explain why pink (*O. gorbuscha*) salmon runs were abundant in Kodiak, Prince William Sound, and Southeast Alaska during 1998. However, biological evidence from Upper Cook Inlet during 1997 and 1998 (fry-to-adult survival) suggests marine rather than freshwater survival led to the unexpectedly low runs there (K. Tarbox, ADFG, pers. comm.). Given the uncertainty associated with the changing ocean environment as described above, the key to the 1999 sockeye salmon season will be to apply a cautionary approach.

**FORECASTING USING RECRUITS PER SPAWNER**

R. HILBORN AND R. STEEN

An alternative approach to predicting the 1999 return to Bristol Bay is to look at the trends in recruits per spawner by system and by age of return. The recruits per spawner for each age of return is simply defined as

$$Y_{s,a,y} = \frac{R_{s,a,y}}{S_{s,y}}$$

where R = total return by system (s), age (a) and brood year (y),

S = number spawning by system and brood year, and

Y = recruits per spawner by system, age and year.

Tables 3-10 and Figures 4-11 provide tabular and graphic data on recruits-per-spawner for each system and age, respectively.

We see a pattern of very poor recruits per spawner for recent years from the major systems of Kvichak/Naknek, Egegik and Ugashik. The Nushagak/Wood river system stands out as not showing a similar decline in recruits per spawner.

If we assume that 1999 will be like recent years, then we expect poor recruits per spawner—however, if we believe that the average conditions affecting survival will prevail, we obviously expect a considerably larger return.

TABLE 3. Recruits-per-spawner for the Kvichak system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
74	1.39	0.44	3.70	0.16
75	0.42	0.09	2.14	0.04
76	2.56	0.39	1.95	0.12
77	1.36	0.63	0.13	0.07
78	0.40	0.26	0.30	0.19
79	1.57	0.19	1.52	0.29
80	0.16	0.09	0.45	0.02
81	0.44	0.13	0.52	0.09
82	0.39	0.46	0.44	0.12
83	2.35	0.83	0.32	0.15
84	0.23	0.18	1.56	0.23
85	0.14	0.17	1.81	0.21
86	0.56	0.89	1.14	1.04
87	0.67	0.39	0.70	0.11
88	0.60	0.58	0.99	0.13
89	0.24	0.19	2.22	0.39
90	0.21	0.16	2.94	0.17
91	0.62	0.29	0.16	0.04
92	0.09	0.04	0.11	0.03
93	0.20	0.21	0.15	
94	0.21			

TABLE 4. Recruits-per-spawner for the Naknek system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	0.43	1.41	0.27	0.78
82	0.25	0.63	0.15	0.32
83	0.28	0.62	0.35	0.45
84	0.42	0.70	0.83	1.22
85	0.50	1.79	0.69	1.37
86	1.01	3.26	0.64	1.19
87	0.39	1.11	0.57	2.64
88	0.34	0.73	0.59	0.46
89	0.40	0.76	0.96	0.52
90	0.29	0.58	0.72	0.58
91	0.19	1.37	0.10	0.09
92	0.19	0.32	0.16	0.18
93	0.21	0.75	0.28	
94	0.51			

TABLE 5. Recruits-per-spawner for the Egegik system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	0.75	1.38	4.71	1.99
82	0.98	1.74	1.69	1.54
83	2.18	3.41	3.84	3.30
84	0.50	0.79	5.27	4.05
85	0.49	1.21	3.79	1.11
86	1.53	3.12	3.30	3.66
87	0.68	3.42	6.62	8.45
88	0.25	0.89	6.36	3.40
89	0.37	0.27	3.71	2.43
90	0.18	0.38	4.24	2.11
91	0.48	1.39	1.08	0.90
92	0.16	0.54	2.31	1.44
93	0.30	0.35	0.55	
94	0.19			

TABLE 6. Recruits-per-spawner for the Ugashik system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	1.14	1.89	1.65	0.68
82	0.35	0.59	0.50	0.62
83	0.60	0.34	0.59	0.30
84	0.36	0.44	2.82	0.56
85	0.49	0.69	0.95	0.46
86	0.48	2.38	1.83	1.63
87	1.21	2.31	2.66	3.37
88	0.70	1.05	3.17	3.41
89	0.39	0.22	1.45	0.55
90	0.47	0.92	3.05	1.62
91	0.78	1.24	0.23	0.12
92	0.08	0.25	0.41	0.34
93	0.17	0.23	0.16	
94	0.30			

TABLE 7. Recruits-per-spawner for the Wood River Lakes system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	0.49	0.93	0.07	0.07
82	0.51	0.92	0.13	0.02
83	1.40	0.90	0.01	0.05
84	0.52	1.32	0.03	0.02
85	1.18	1.46	0.03	0.01
86	1.41	2.37	0.09	0.07
87	1.01	0.55	0.07	0.07
88	1.83	1.60	0.10	0.03
89	1.82	1.53	0.01	0.03
90	1.01	1.07	0.26	0.15
91	2.18	2.09	0.04	0.06
92	1.80	1.24	0.07	0.04
93	1.42	0.83	0.11	
94	1.88			

### Predicting Total Return Using Recruits per Spawner

We can calculate a running average recruits-per-spawner for each system by simply averaging over some  $n$  previous years.

$$\bar{Y}_{s,a,1999-a} = \frac{1}{n} \sum_{y=1999-n-a}^{1999-a} Y_{s,a,1999}$$

Note that here we use  $a$  to denote the combined freshwater and marine age.

We can then calculate the total expected return to a system by summing over all brood years and age classes that

will return in 1999—that is brood year 1993 returning as 2.3 fish, 1994 brood year returning as either 2.2 or 1.3 fish, and the 1995 brood year returning as 1.2 fish. For each age of return, we multiply the number of spawners times the average recruits per spawner.

The anticipated return to each system was based on how many years running average we used (Table 11, Figures 12-20).

### Discussion

Using recruits per spawner is a crude approach to run forecasting that ignores much of the basic biological data

TABLE 8. Recruits-per-spawner for the Igushik system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	0.25	1.41	0.00	0.08
82	0.12	1.14	0.02	0.02
83	0.83	1.83	0.06	0.17
84	0.16	3.32	0.26	0.16
85	2.43	4.29	0.38	0.38
86	0.74	7.10	0.10	0.10
87	0.94	3.35	0.06	0.18
88	1.12	6.00	0.24	0.24
89	1.04	2.28	0.13	0.11
90	0.43	3.68	0.49	0.41
91	0.41	1.72	0.00	0.03
92	0.13	0.42	0.03	0.06
93	0.29	0.71	0.05	
94	0.53			

TABLE 9. Recruits-per-spawner for the Nushagak system.

Brood year	Age at return		
	0.3	1.2	1.3
81	0.12	0.16	1.42
82	0.55	0.27	1.42
83	1.43	0.28	1.55
84	0.37	0.20	0.93
85	0.98	0.12	1.18
86	0.84	0.11	0.68
87	2.36	0.10	1.33
88	1.08	0.44	2.90
89	0.94	0.24	1.32
90	1.12	0.06	0.36
91	0.26	0.34	1.98
92	0.70	0.31	0.84
93	0.04	0.08	0.94
94	0.08	0.16	

TABLE 10. Recruits-per-spawner for the Togiak system.

Brood year	Age at return			
	1.2	1.3	2.2	2.3
81	0.16	0.77	0.03	0.06
82	0.38	0.83	0.03	0.07
83	1.33	4.33	0.05	0.10
84	0.13	0.73	0.00	0.13
85	0.20	1.40	0.27	0.53
86	0.40	2.20	0.40	0.55
87	0.68	1.89	0.11	0.29
88	0.35	1.26	0.10	0.16
89	1.20	3.10	0.10	0.40
90	0.53	2.26	0.37	0.21
91	0.64	1.50	0.11	0.11
92	0.25	0.55	0.15	0.15
93	0.32	1.32	0.05	0.16
94	0.24	1.06	0.18	

collected by FRI and ADF&G in freshwater, including growth, smolt counts, and sibling returns. However we have obviously seen dramatic changes in recent years that indicate the possibility that we have entered a regime of poor ocean survival. If we believe this regime will also affect the 1999 return then relatively poor returns in 1999 are likely, whereas if we believe that the average survivals over the past 20 years will prevail, then we expect a much bigger return.

There is no way to know for sure what to expect in 1999. There are certainly signs that major changes have taken place in the ocean, but no firm evidence that any form of major regime shift has occurred.

## REFERENCES

- Rogers, D.E. and G.T. Ruggerone. 1993. Factors affecting the marine growth of Bristol Bay sockeye salmon. *Fish. Res.* 18:89-103.
- Rogers, DE. 1998. Forecasts of the 1999 sockeye salmon runs to Bristol Bay using traditional FRI methodology. Univ. Washington School of Fisheries, *Fish. Res. Inst. FRI-UW-9818*. Seattle.
- Ruggerone, G.T. 1997. Preseason forecast of sockeye salmon run timing in Bristol Bay, Alaska, 1997. Prepared for Bristol Bay salmon processors and the University of Washington by Natural Resources Consultants, Seattle.

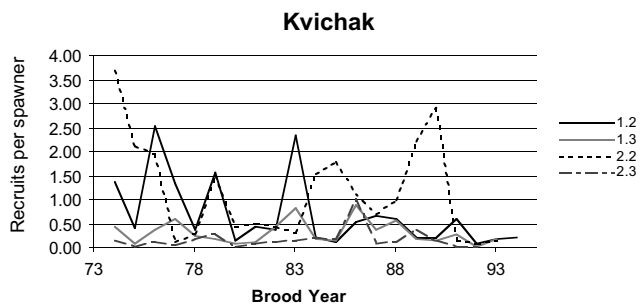


FIGURE 4. Recruits-per-spawner for the Kvichak system.

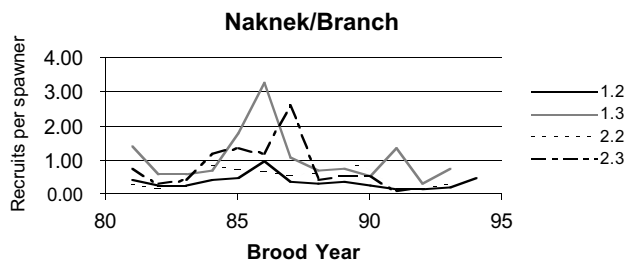


FIGURE 5. Recruits-per-spawner for the Naknek system.

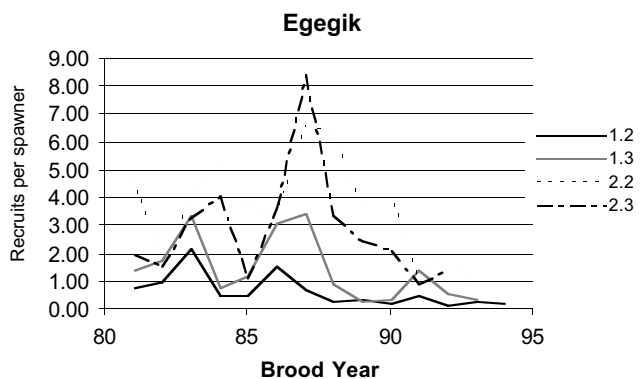


FIGURE 6. Recruits-per-spawner for the Egegik system.

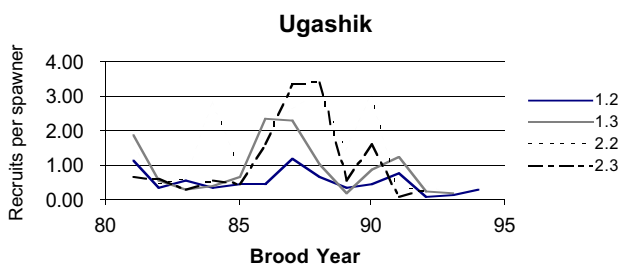


FIGURE 7. Recruits-per-spawner for the Ugashik system.

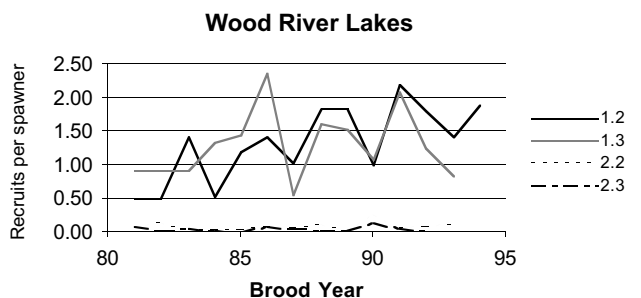


FIGURE 8. Recruits-per-spawner for the Wood River Lakes system.

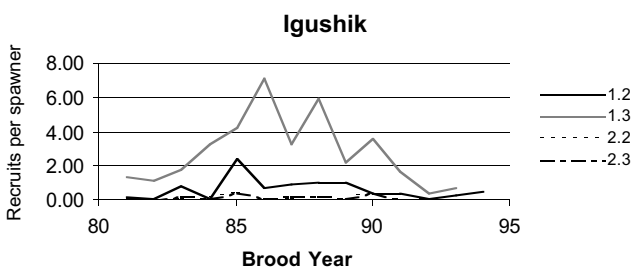


FIGURE 9. Recruits-per-spawner for the Igushik system.

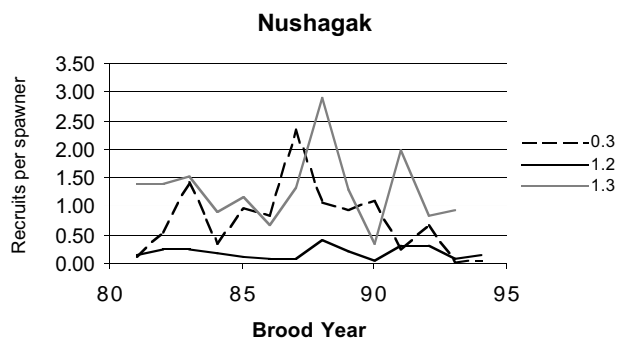


FIGURE 10. Recruits-per-spawner for the Nushagak system.

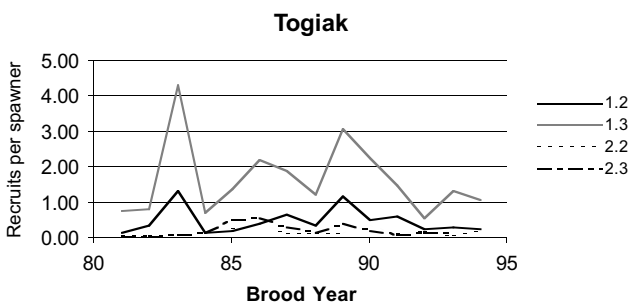


FIGURE 11. Recruits-per-spawner for the Togiak system.

TABLE 11. Anticipated return to each system based on number of years running average.

n years	Kvichak	Egegik	Naknek	Ugashik	Wood	Igushik	Nush/Nuy	Togiak	Baywide
1	5.2	2.83	2.25	1.29	4.22	0.62	0.55	0.27	17.2
2	4.3	3.80	1.63	1.19	4.15	0.48	0.51	0.30	16.3
3	4.6	3.88	2.09	2.12	4.76	0.66	0.77	0.27	19.2
4	11.9	4.69	2.35	3.11	4.88	1.02	0.66	0.33	28.9
5	14.1	5.43	2.58	3.93	4.66	1.09	0.73	0.38	32.9
6	14.4	7.60	3.31	4.91	4.77	1.47	0.91	0.46	37.8
7	15.1	8.53	3.49	5.44	4.61	1.56	0.94	0.45	40.1
8	16.2	8.35	3.98	5.60	4.68	1.85	0.95	0.47	42.1
9	17.0	8.44	4.26	5.33	4.64	1.92	0.94	0.48	43.0
10	17.0	8.84	4.20	5.26	4.55	2.01	0.93	0.46	43.2
11	16.5	8.88	4.04	4.99	4.33	1.91	0.93	0.44	42.1
12	17.8	8.65	3.93	4.82	4.28	1.83	0.95	0.49	42.7
13	17.1	8.60	4.16	4.81	4.33	1.82	0.95	0.50	42.3
14	16.6	8.46	4.33	4.77	4.46	1.82	0.94	0.51	41.9

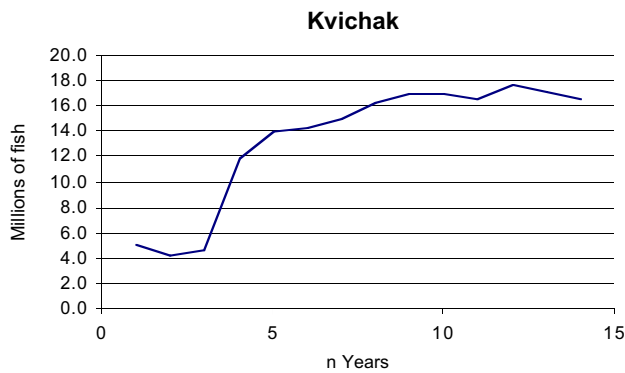


FIGURE 12. Anticipated return to Kvichak based on number of years running average.

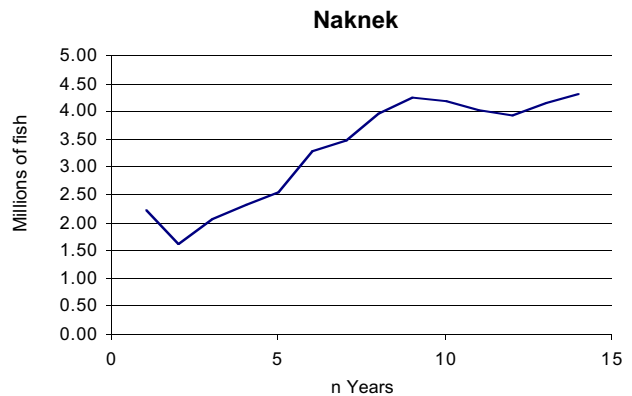


FIGURE 13. Anticipated return to Naknek based on number of years running average.

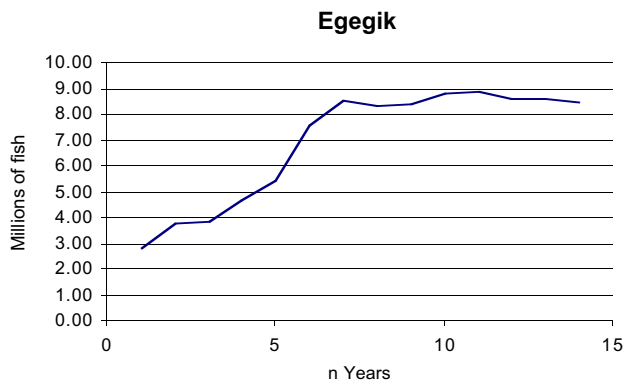


FIGURE 14. Anticipated return to Egegik based on number of years running average.

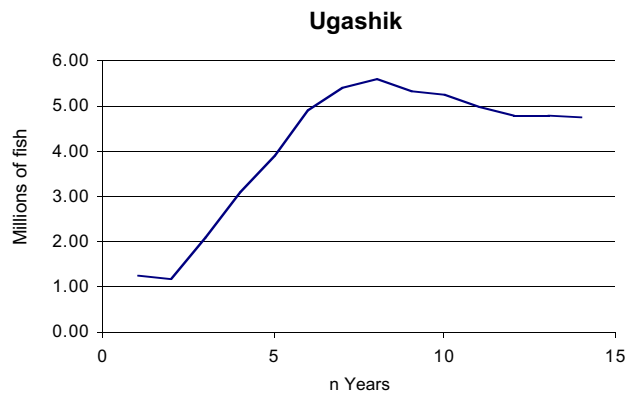


FIGURE 15. Anticipated return to Ugashik based on number of years running average.

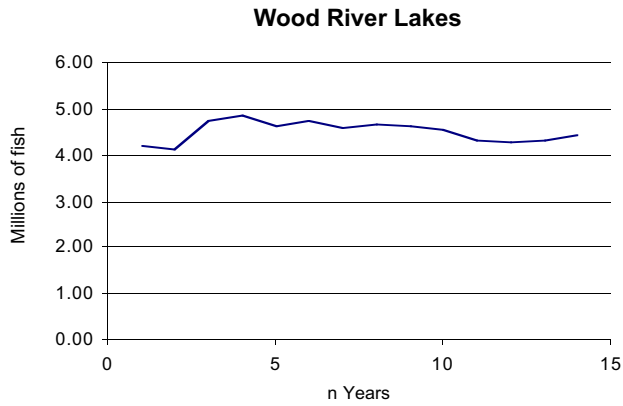


FIGURE 16. Anticipated return to Wood River Lakes based on number of years running average.

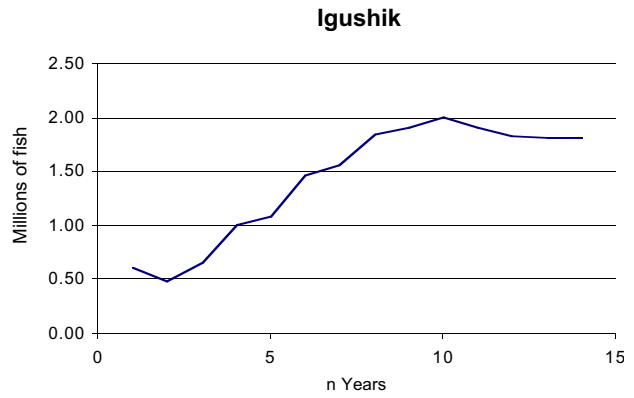


FIGURE 17. Anticipated return to Igushik based on number of years running average.

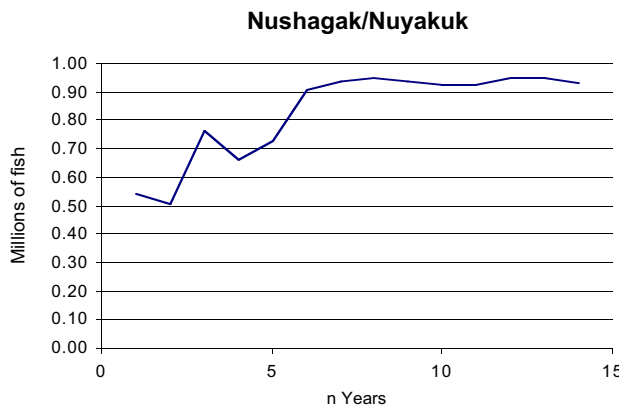


FIGURE 18. Anticipated return to Nushagak based on number of years running average.

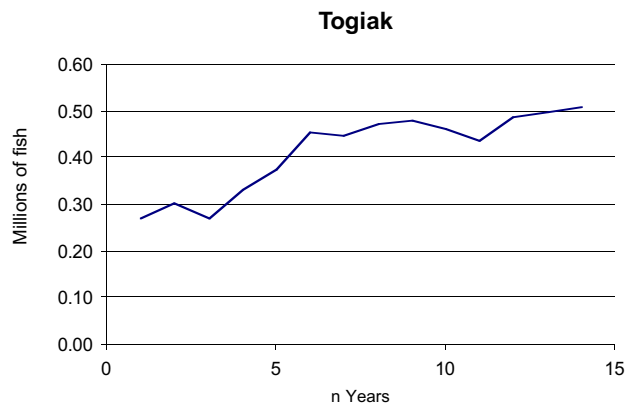


FIGURE 19. Anticipated return to based Togiak on number of years running average.

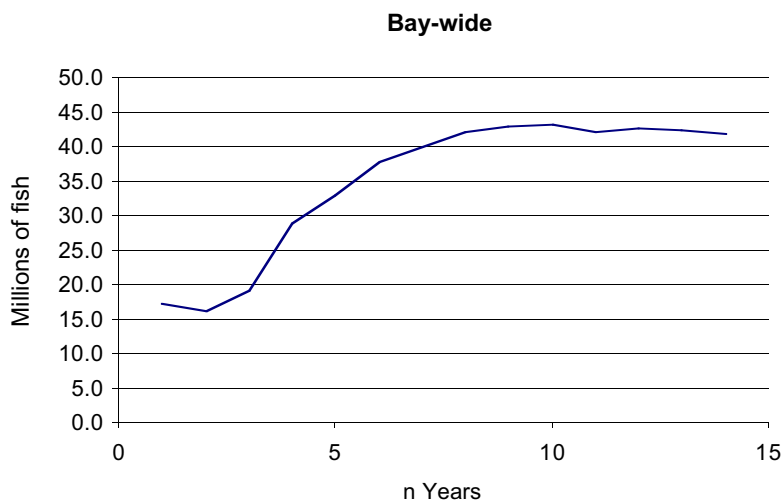


FIGURE 20. Anticipated returns to Bristol Bay collectively, based on number of years running average.