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THE TIME OF ANNULUS FORMATION IN CHINOOK SALMON CAUGHT IN WASHINGTON COASTAL WATERS

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ABSTRACT

We analyzed a large database (5,066 fish) of information on time of formation of the last ocean annulus on scales collected from coded-wire tagged chinook salmon recovered in Washington State coastal waters from 1988 to 1993. Variation in the time of formation of the last ocean annulus by year, recovery age, behavioral type, recovery season, recovery area, and stock was investigated. The most important finding was that time of annulus formation varied by freshwater age or behavioral type. Chinook salmon that migrated to the ocean in their first year (ocean-type; freshwater age-0.) completed formation of the last ocean annulus in March, and chinook salmon that migrated to the ocean in their second year (stream-type; freshwater age-l.) completed annulus formation in April. Many of the stream-type chinook salmon in the analysis were artificially (hatchery) produced, that is, their natural life history is ocean-type. Inter- and intra-specific differences in time of annulus formation on salmon scales may reflect differences in growth rates, regulated by feeding conditions.

INTRODUCTION

In this paper, we report on the time of annulus formation on the scales of chinook salmon (*Oncorhynchus tshawytscha*) caught in Washington coastal waters. In addition, we address whether the time of annulus formation varies by year, recovery age, behavioral type, recovery season, recovery area, and stock.

The widely spaced bands of circuli on salmon scales are thought to reflect rapid growth in the summer, and the narrowly spaced bands of circuli may represent slow growth in the winter (Bilton and Ludwig 1966). The narrowly spaced band is called the "annual ring" (Semko 1954, Vedensky 1954, Birman 1960). The scale annulus is defined as the last narrowly spaced circulus of the annual ring, preceding the first, more widely spaced circulus referred to as the start of new growth (Bilton and Ludwig 1966).

Chinook salmon are often categorized as ocean-type or stream-type fish. Ocean-type chinook salmon migrate to sea during their first year (age-0.), while stream-type chinook salmon spend more than one year in freshwater before migrating to sea (age-1.; Healey 1991). Ocean-type chinook salmon spend most of their ocean life in coastal waters and return to their natal river during summer and fall (Healey 1991). Contrary to this, stream-type chinook salmon extensively migrate offshore and return to their natal river in the spring and summer (Healey 1991).

Many of the stream-type chinook salmon in our analysis are artificially (hatchery) produced, that is, their natural life history is ocean-type (age-0., fall chinook salmon). Most artificial stream-type stocks probably do not follow the typical "northerly/outside" migration/distribution patterns of natural stream-type stocks. The main reason for releasing yearling fall chinook salmon from Puget Sound hatcheries in Washington is to promote an inside distribution. The genetic origin of many of the hatchery stocks of Puget Sound fall chinook salmon is probably the Green River (Soos Creek) population.

The time of annulus formation for chinook salmon is not yet known, while those for sockeye (*O. nerka*), pink (*O. gorbuscha*), and chum salmon (*O. keta*) were reported (Birman 1960, Bilton and Ludwig 1966). For Aleutian salmon, Birman (1960) concluded that pink salmon completed the annulus in early January, sockeye salmon in March, and chum salmon in April. However, these times are not the same as those reported by other researchers. For salmon caught in the Gulf of Alaska, Bilton and Ludwig (1966) suggested that pink salmon complete the annulus in late December, sockeye salmon in January, and chum salmon in February or March.

METHODS

The scales used in this analysis were collected from coded-wire tagged chinook salmon recovered in Washington State coastal waters from 1988 to 1993. The salmon were caught by hook-and-line in commercial troll and recreational fisheries with various restrictions on fish size. Age was determined by visual reading of freshwater and marine annuli on the scale, and information on the formation of the last annulus was recorded for all scales that could be aged. We also used the coded-wire tag database (PSMFC 1997) to acquire additional stock information. Our data set consists of a large number of records (5,066 records). We show a portion of the data in Appendix 1. The entire data set is archived at the Fisheries Research Institute, University of Washington, and is available by written request to K. Myers. We categorized information on the formation of the last annulus into three groups as follows:

- *Lastan 1: last annulus had not started forming*
- *Lastan 2: last annulus was forming, but there were no widely spaced circuli after the annulus*
- *Lastan 3: last annulus completely formed, and there was at least one widely spaced circulus after the annulus.*

Each record in our data set represents one fish, and consists of stock code, tag code, recovery year, recovery month, recovery area, brood year, release year, recovery age, and Lastan (Appendix 1). The real stock names, which correspond to stock codes, are displayed in Appendix 2. The data set includes 148 stocks. Recoveries were from 13 statistical areas in Washington state coastal waters (Fig. 1).

We calculate the proportions of Lastan 1 and Lastan 2 + 3 in each recovery month. We combine Lastan 2 and 3 because separate analysis led to unreliable sample sizes in the resultant strata. Combining Lastan 2 and 3 did not change our results. Bar plots of the relative proportions of Lastan 1 and Lastan 2 + 3 were used to determine the month in which annulus formation is completed. Scale patterns may differ by year, recovery time, recovery area, recovery age, behavioral type, or stock. To address these effects on the time of annulus formation, we graphically explore our data, and perform ANOVA (analysis of variance) and χ^2 (Chi-square) analyses. In these statistical analyses, the frequencies of Lastan 1 and Lastan 2 + 3 are the dependent variables.

RESULTS

- *Graphical exploration*

The graphical exploration, perhaps, indicates some annual variation (Fig. 2). In April 1990 the annulus was present on all scales, while in other years scales from some fish caught in April did not have an annulus. However, it would be misleading to test the null hypothesis regarding year effect on the time of annulus formation on the basis of only year and month strata. Other factors such as area, age, behavioral type or stock might have caused the annual differences in April scale patterns. Later, we show the statistical results of testing annual variation with stratified data.

The graphical analysis shows a difference in time of annulus formation between subyearling (freshwater age-0.) and yearling (freshwater age-1.) chinook salmon (Fig. 3). In April, the annulus was completely formed in all subyearling chinook salmon, but the annulus had not started to form in some yearling chinook salmon. The sample sizes for April recoveries of age 0.2, age 0.3, age 1.1, and age 1.2 chinook salmon were large enough that this finding is reliable.

When examining the effect of recovery area on the time of annulus formation, we stratified recoveries by area, age, and month. The sample sizes of the stratified groups were greatly reduced, and most were not large enough for statistical testing. In Fig. 4, recoveries are stratified by areas 4 and 5, age 0.2, and month. If we stratified them further by an additional factor such as year or stock, the resultant strata would be meaningless in terms of statistical reliability. Because of this overparameterization, we used only those factors thought be critical, and assumed that the other factors do not affect annulus formation. Therefore, we assumed that the time of annulus formation was not different between the 13 ocean recovery areas (Fig. 1). This assumption is acceptable because the 13 ocean areas are concentrated around the coast of Washington, and time of annulus formation is similar between areas 4 and 5 (Fig. 4).

To examine stock effect, recoveries were stratified by age, month, and stock (Fig. 5). We did not consider recoveries after April because Lastan 1 did not occur after April. Only strata with recoveries greater than or equal to 10 were analyzed. If annual variation is significant, then further stratification by year is necessary. There was no clear difference in the proportions of Lastan 1 or Lastan 2 + 3 between stocks. For example, the proportions of Lastan 1 and Lastan 2 + 3 for Big Soos Creek (stock code 7) and Chilliwack River (stock code 94) stocks looked slightly different from each other (Fig. 5 (A), (B) and (C)), but we could not conclude anything until performing a statistical test.

- *Statistical tests*

The graphical analyses indicated that recovery month, year, and age are factors possibly critical to time of annulus formation. For our statistical tests, we made a contingency table where these three factors were variables and the cell values were frequencies of Lastan 1. For recovery month, we included only January through April because the time of annulus formation was constant during the other months (Fig. 2 - Fig. 4). For recovery age, we used only ages 0.2, 0.3, and 1.2 fish because the numbers of recoveries of the other age groups were not large enough. There were not enough data to allow us to consider stock and area as factors in this analysis. The contingency table consisted of 72 cells (four months x six years x three ages; Appendix Table 3). The results of our ANOVA tests showed that recovery year was insignificant (p-value = 0.383) but recovery age (p-value = 0.003) and month (p-value = 0.000) were highly significant (Table 1). After dropping the recovery year factor, we tested the interaction term of recovery age and month. The interaction term had a significant effect on the frequencies of Lastan 1 (p-value = 0.057, Table 2).

Based on these results, we could not reject the null hypothesis that there was no annual variation in the time of annulus formation but could reject the following two null hypotheses: (1) recovery age did not affect the time of annulus formation, and (2) recovery month did not influence the time of annulus formation. Also, we could reject the null hypothesis that the time of annulus formation between ages was the same regardless of month.

Because year did not significantly affect the time of annulus formation (Table 1), we can ignore this factor when testing for stock effects. Therefore, we stratified recoveries by age, month, and stock (Fig. 5), and tested for stock effects within the age and month strata shown in Fig. 5 (A - E). For these respective five cases, we could not reject the null hypothesis that the time of annulus formation is independent of stock factor (Tables 3 - 7).

DISCUSSION

The time of annulus formation for chinook salmon caught in Washington coastal waters was different by age or behavioral type. The annulus of all subyearling chinook salmon was forming or completely formed before April, while that of some yearling chinook salmon had not started to form during April (Fig. 3). The significant interaction between age and month in an ANOVA test also reflected this (Table 2). This is the most important finding in this report. We could not detect significant effects of year and stock on the time of annulus formation. Insufficient sample sizes (recoveries) prevented us from testing area effects on the time of annulus formation.

Ricker (1962) hypothesized that, for Pacific salmon as a whole, the time of annulus formation should be different between different stocks of each species, and between different life-history types within a single stock. On the basis of our results, we can accept Ricker's hypothesis regarding life-history type, but cannot confirm his hypothesis regarding stock differences.

However, Ricker's definition of stock may have been different than ours. In the past, a critical criterion of determining stock was geographic habitat, but now genetic similarity is also critical. We traced the genetic origins of stocks in Fig. 5, and found some of the stocks had the same genetic origin. "Big Soos Creek (stock code 7)" was a native of Green River, Washington, and was used as one of the brood stocks for "South Sound + Hood Canal (stock code 116)" and "Samish (stock code 119)" stocks (Peck 1993, Fuss and Ashbrook 1995). "Deschutes River (stock code 26)" was also used as one of the brood stocks for "South Sound + Hood Canal" stock (Peck 1993, Fuss and Ashbrook 1995). "Cowlitz River (stock code 24)" originated from mixed stocks (WDF et al. 1993). This genetic similarity may have led to the apparent similarity in the time of annulus formation between stocks (Fig. 5).

In addition, the analysis of data other than "Lastan" may lead to the discovery of significant stock effects. For example, some researchers use the maximum number of circuli after the annulus when analyzing salmon scale pattern (Bilton and Ludwig 1966, Sakurai 1996). Our data set did not include this information for fish with more than nine circuli after the last annulus.

The time of annulus formation on the scales of chinook salmon caught in Washington coastal waters is similar to those reported for Aleutian sockeye and chum salmon (Birman 1960).

But it is later than those reported for Aleutian pink salmon and for pink, sockeye and chum salmon caught in the Gulf of Alaska (Birman 1960, Bilton and Ludwig 1966). In Washington waters, subyearling chinook salmon completed the annulus in March, and yearling chinook salmon completed the annulus in April (Fig. 3). We hypothesize that these differences primarily reflect differences in growth rates between species, age groups, maturity groups, and regions (for example, coastal vs. offshore waters). These growth rates may be determined by feeding conditions. To test our hypothesis regarding differences in growth rates, we suggest examining the relationship between fish length and the maximum number of circuli after the annulus. Fish length can be an index of growth rate. Sakurai (1996) found a strong correlation between fish length and fish scale radius, and thus fish length is likely to show a relation with the maximum number of circuli after the annulus.

ACKNOWLEDGMENTS

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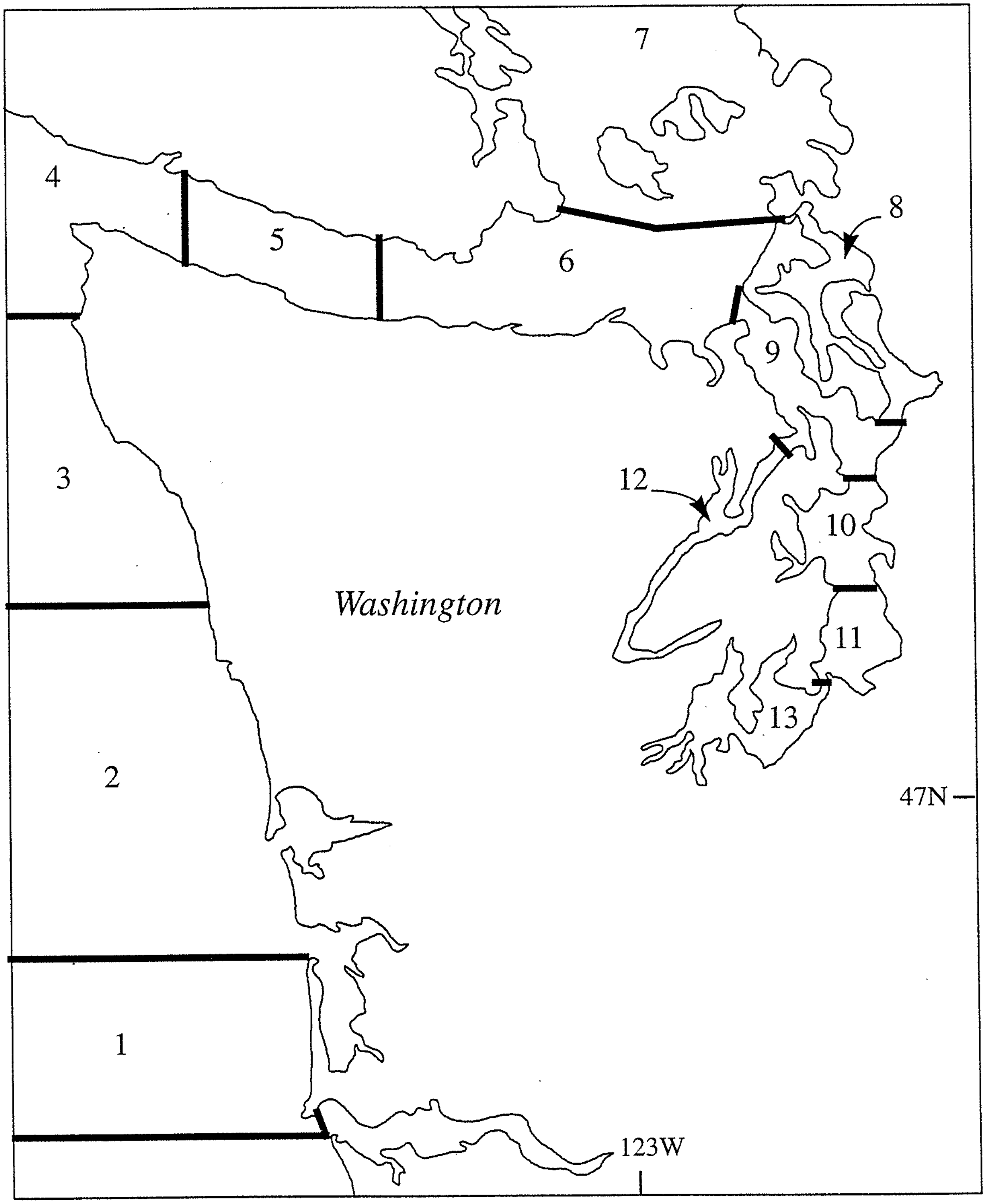

Fig. 1. Thirteen ocean recovery areas in Washington State coastal waters.

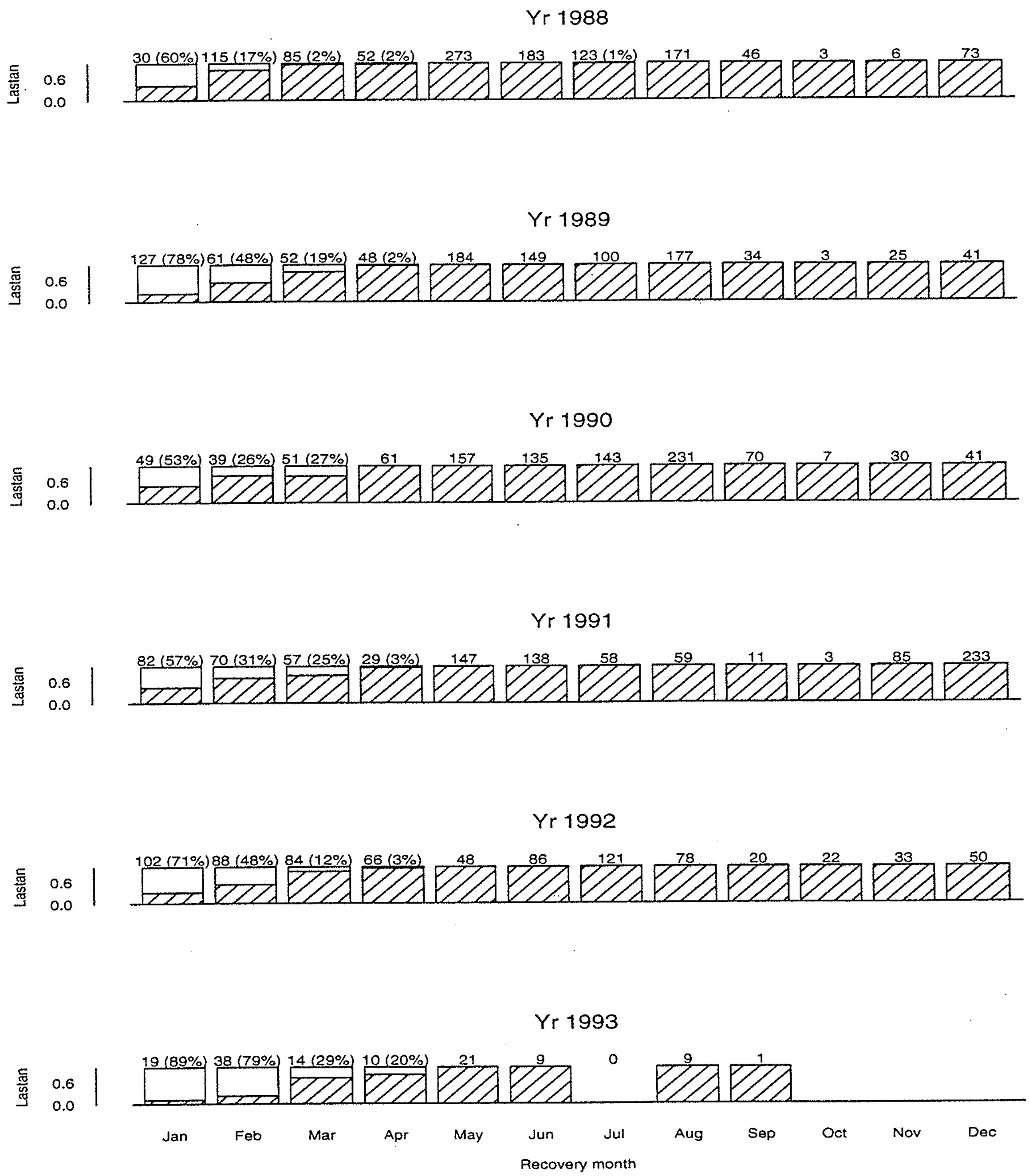

Fig. 2. Annual variation in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by recovery year and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum, and the value in the parentheses is Lastan 1 portion (%) within each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

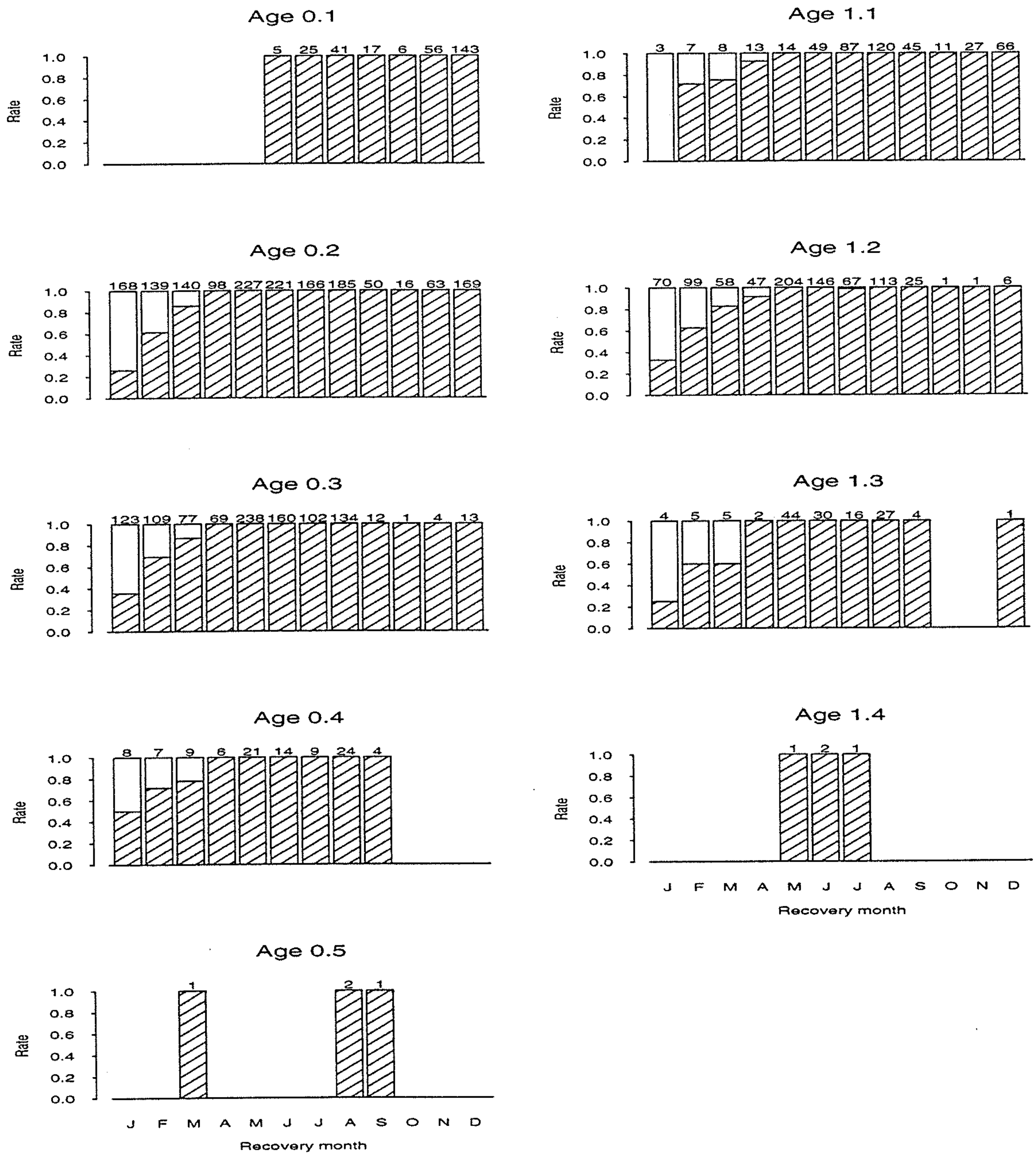

Fig. 3. Age variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by recovery age and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

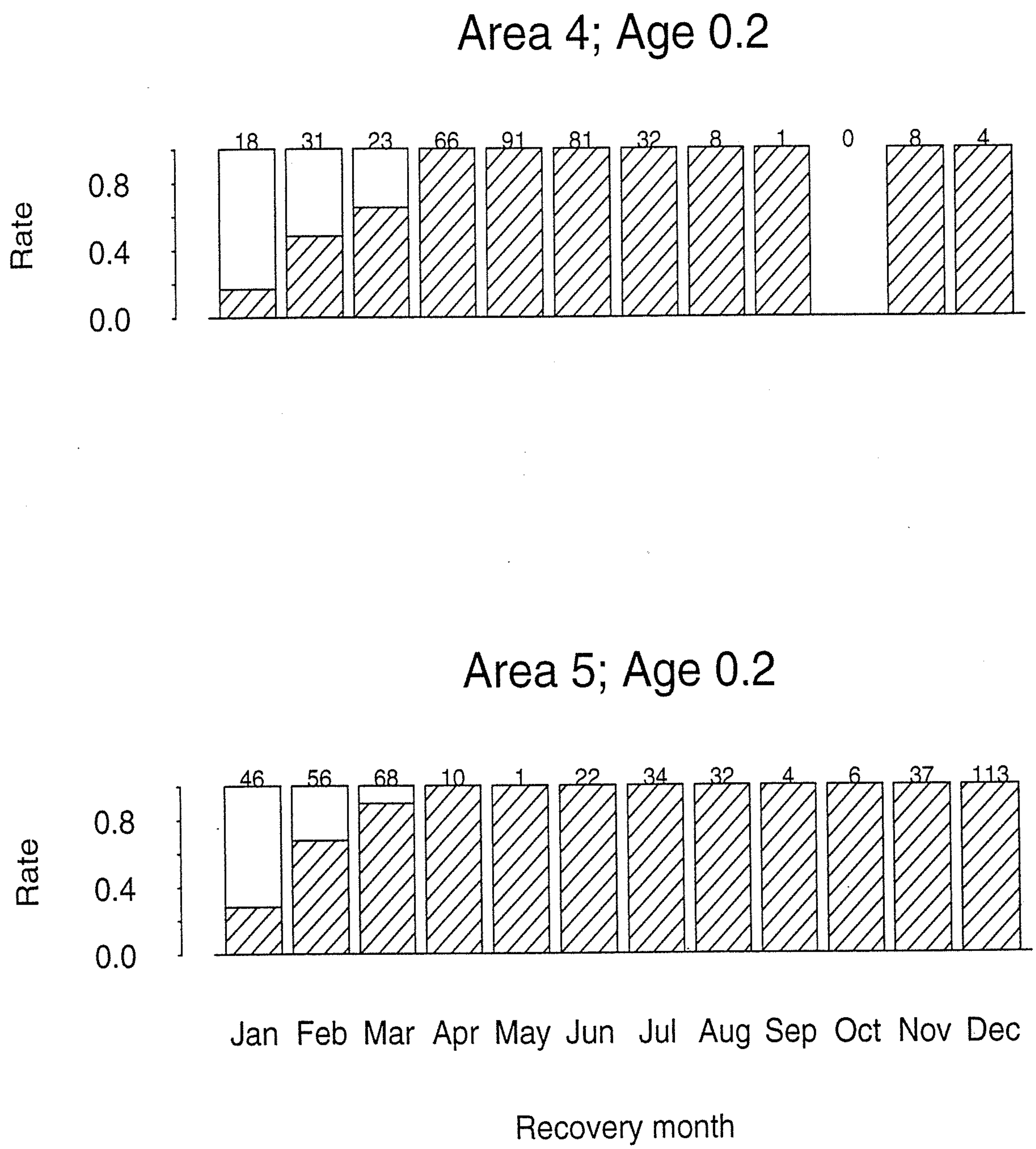

Fig. 4. Area variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by area, age, and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

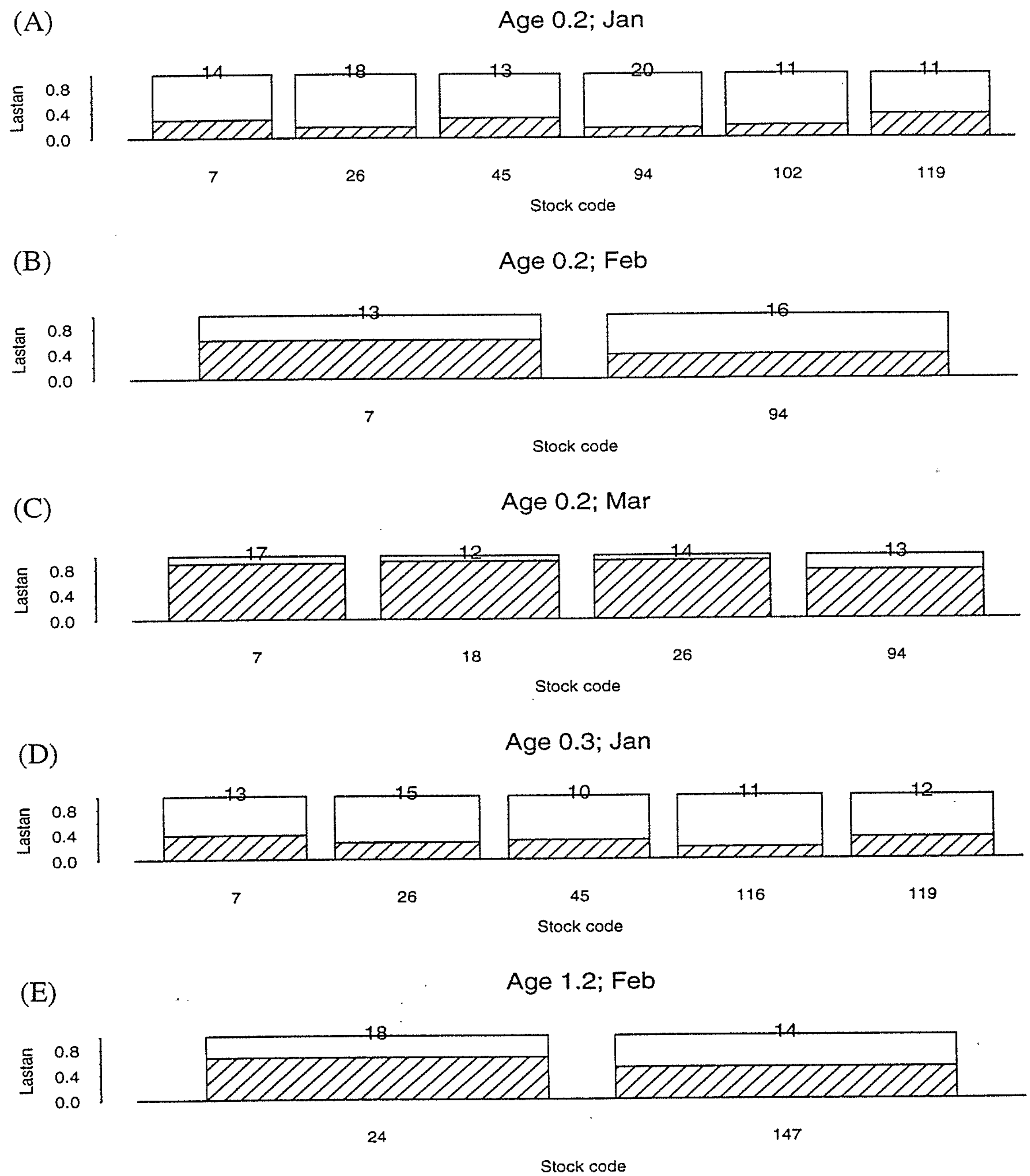

Fig. 5. Stock variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by stock, age, and month. We show only strata with recoveries greater than or equal to 10. Stocks corresponding to the codes are listed in Appendix Table 2. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

TABLE 1. ANOVA of recovery age, recovery month (recmo) and recovery year (recyr). Contingency table data used for this ANOVA are shown in Appendix Table 3.

Source	Df	Sum of Sq	Mean Sq	F Value	p-value
age	2	78.25	39.13	6.22	0.003
recmo	3	233.83	77.94	12.40	0.000
recyr	5	33.83	6.77	1.08	0.383
Residuals	61	383.58	6.29		

TABLE 2. ANOVA of final linear model, where the dependent variable is frequency of Lastan 1 and the independent variables are recovery age and month (recmo).

Source	Df	Sum of Sq	Mean Sq	F Value	p-value
age	2	78.25	39.13	6.85	0.002
recmo	3	233.83	77.94	13.65	0.000
age*recmo	6	74.75	12.46	2.18	0.057
Residuals	60	342.67	5.71		

TABLE 3. Contingency table for age 0.2 chinook salmon recoveries in January (Fig. 5 (A)) to test independence between stock and Lastan frequency. $\chi^2 = 3.073$ with df=5 (p-value= 0.689). Stock names are listed in Appendix Table 2.

Stock code	*7*	*26*	*45*	*94*	*102*	*119*
Lastan 1	10	15	9	17	9	7
Lastan 2 & 3	4	3	4	3	2	4

TABLE 4. Contingency table for age 0.2 chinook salmon recovered in February (Fig. 5 (B)) to test independence between stock and Lastan frequency. $\chi^2 = 1.660$ with df=1 (p-value=0.198). Stock names are listed in Appendix Table 2.

Stock code	*7*	*94*
Lastan 1	5	10
Lastan 2 & 3	8	6

TABLE 5. Contingency table for age 0.2 chinook salmon recovered in March (Fig. 5 (C)) to test independence between stock and Lastan frequency. $\chi^2 = 1.896$ with df=3 (p-value=0.594). Stock names are listed in Appendix Table 2.

Stock code	*7*	*18*	*26*	*94*
Lastan 1	2	1	1	3
Lastan 2 & 3	15	11	13	10

TABLE 6. Contingency table within age 0.3 chinook salmon recovered in January (Fig. 5 (D)) to test independence between stock and Lastan frequency. $\chi^2 = 1.323$ with df=4 (p-value=0.857). Stock names are listed in Appendix Table 2.

Stock code	*7*	*26*	*45*	*116*	*119*
Lastan 1	8	11	7	9	8
Lastan 2 & 3	5	4	3	2	4

TABLE 7. Contingency table within age 1.2 chinook salmon recovered in February (Fig. 5 (E)) to test independence between stock and Lastan frequency. $\chi^2 = 0.907$ with df=1 (p-value=0.341). Stock names are listed in Appendix Table 2.

Stock code	*24*	*147*
Lastan 1	6	7
Lastan 2 & 3	12	7

Appendix Table 1. An example of data format.

No	Stockcd	Tagcd	Recyr	Recmo	Recare	Bryr	Relyr	Recag	Lastan
1	1	052542	92	6	5	90	91	0.1	3
2	2	064826	89	7	2	86	87	0.2	3
3	2	064830	89	6	2	86	87	0.2	3
4	2	065405	88	6	2	85	86	1.2	3
5	2	065405	88	5	2	85	86	0.2	3
6	2	065405	88	5	3	85	86	0.2	3
7	2	065405	88	2	5	85	86	0.2	1
8	2	065405	88	3	5	85	86	na	3
9	2	065406	88	5	2	85	86	0.2	3
10	2	065406	89	5	2	85	86	0.3	3
11	2	065406	89	5	2	85	86	0.3	3
12	2	065406	88	2	6	85	86	0.2	1
13	2	065406	88	4	5	85	86	0.2	2
14	2	065407	90	5	4	86	87	0.3	2
15	2	065407	90	6	4	86	87	0.3	3
16	2	065409	90	7	2	87	88	0.2	3
17	2	065411	90	8	1	87	88	0.2	3
18	2	065415	91	8	1	88	89	0.2	3
19	2	065453	88	5	2	84	85	0.3	3
20	2	065453	88	5	3	84	85	0.3	3
21	3	621632	89	9	5	84	85	0.4	3
22	3	621634	88	8	3	84	85	1.3	3
23	3	623142	88	5	2	84	85	0.3	3
24	4	H60702	88	8	4	85	86	0.2	3
25	4	H60704	88	6	2	85	86	0.2	3
26	4	H60704	88	5	4	85	86	0.2	3
27	4	H60705	88	5	3	85	86	0.2	3
28	4	H60705	89	6	2	85	86	0.3	3
29	5	073319	90	6	1	86	87	0.3	3
30	5	073319	89	5	2	86	87	0.2	3
31	5	073319	89	3	5	86	87	0.2	3
32	5	073319	89	5	2	86	87	0.2	3
33	5	073817	89	5	4	86	87	0.2	3
34	5	073817	89	5	1	86	87	0.2	3
35	5	074007	90	6	3	87	88	0.2	3
36	5	074250	92	1	6	89	90	1.2	1
37	5	074250	91	11	5	89	90	0.1	3
38	5	074251	90	5	4	86	87	0.3	2
39	5	074251	90	8	6	86	87	0.3	3
40	5	074251	89	4	4	86	87	0.2	3
41	5	074251	89	4	4	86	87	0.2	3
42	5	074251	89	5	2	86	87	0.2	3
43	5	074253	90	8	2	86	87	0.3	3
44	5	074253	89	2	6	86	87	0.2	1
45	5	074255	92	4	4	89	90	0.2	3
46	5	074255	92	2	5	89	90	0.2	1
47	5	074255	91	11	5	89	90	1.1	3
48	5	074256	92	5	4	89	90	0.2	3
49	5	074256	92	3	5	89	90	0.2	3
50	5	074256	91	12	5	89	90	0.1	3
51	5	074259	92	3	5	89	90	0.2	3
52	5	074259	91	12	5	89	90	0.1	3
53	5	074261	92	7	5	89	90	0.2	3
54	5	074335	91	5	2	88	89	0.2	3
55	5	074335	91	6	2	88	89	0.2	3
56	5	074335	92	2	5	88	89	0.3	1
57	5	074335	91	5	4	88	89	0.2	3
58	5	074336	91	5	4	88	89	na	3
59	5	074336	92	5	4	88	89	0.3	3
60	5	074336	91	1	5	88	89	0.2	2
61	5	074337	91	5	1	88	89	0.2	3
62	5	074337	91	5	2	88	89	0.2	3
63	5	074407	92	8	1	90	91	na	4
64	5	074452	90	7	1	86	87	0.3	3
65	5	074452	89	5	2	86	87	0.2	3
66	5	074452	89	6	2	86	87	0.2	3
67	5	074452	88	12	5	86	87	0.1	3
68	5	074456	88	12	6	86	87	0.1	3
69	5	074459	89	6	2	86	87	0.2	3
70	5	074521	91	6	4	88	89	0.2	3
71	5	074559	90	6	4	87	88	0.2	3
72	5	074560	90	6	4	87	88	0.2	3
73	5	074560	90	8	1	87	88	0.2	3
74	5	074561	90	5	2	87	88	0.2	3

Appendix Table 2. Stock names corresponding to stock codes. *Notice that stock code 20 is shared by WA and OR.

Stockcd	Stock	State
1	ABERNATHY CR 25.0297	WA
2	AMERICAN RIVER	CA
3	ANADROMOUS	OR
4	BATTLE CREEK	CA
5	BIG CREEK	OR
6	BIG QUILCENE 17.0012	WA
7	BIG SOOS CR 09.0072	WA
8	BONNEVILLE	OR
9	CHAMBERS BASIN MIXED	WA
10	CHETCO R	OR
11	CHIWAWA R 45.0759	WA
12	CLACKAMAS R	OR
13	CLACKAMAS R EARLY	OR
14	CLARK CR 03.1421	WA
15	CLARK CR + SUIATTLE	WA
16	COLE RIVERS	OR
17	COLEMAN NFH	CA
18	COLUMBIA (N BONNEVL)	WA
19	COLUMBIA R - GENERAL	WA
20*	COLUMBIA R BRIGHTS	WA
20*	COLUMBIA R BRIGHTS	OR
21	COLUMBIA R UPRIVER S	OR
22	COOS R - PUBLIC	OR
23	COQUILLE R	OR
24	COWLITZ R 26.0002	WA
25	DESCHUTES R	OR
26	DESCHUTES R 13.0028	WA
27	DESCHUTES X HOOD CNL	WA
28	DUNGENESS R 18.0018	WA
29	EAGLE CR NFH (CLACKA	OR
30	ELK R (ELK R HT)	OR
31	ELOCHOMAN + KALAMA R	WA
32	ELOCHOMAN R 25.0236	WA
33	ELWHA R 18.0272	WA
34	FEATHER RIVER	CA
35	FINCH CR 16.0222	WA
36	FORK CR 24.0356	WA
37	G.ADAMS/FINCH/MCKERN	WA
38	GARRISON SPRINGS STK	WA
39	GEORGE ADAMS (PURDY)	WA
40	GLENWOOD SPRINGS	WA
41	GRAYS R 25.0093	WA
42	GRAYS R +ELOCHOMAN R	WA
43	GREEN R + ISSAQUAH	WA
44	GREEN R +TULALIP BAY	WA
45	GROVERS CR 15.0299	WA
46	HANFORD REACH STOCK	WA
47	HOKO R 19.0148	WA
48	HOLLOW TREE CREEK	CA
49	HOOD CANAL MIXED	WA
50	HUMPTULIPS R 22.0004	WA
51	ISSAQUAH CR 08.0178	WA
52	KALAMA C+GREEN+MCALL	WA
53	KALAMA CR 11.0017	WA
54	KALAMA CR & GREEN R	WA
55	KALAMA R 27.0002	WA
56	KENDALL CR 01.0406	WA
57	KLAMATH RIVER	CA
58	KLICKITAT R 30.0002	WA
59	LEWIS R 27.0168	WA
60	LOOKINGGLASS CR	OR
61	LOWER ELWHA 18.0274	WA
62	LTL WHITE SALMON-NFH	WA
63	LYONS FERRY HATCHERY	WA
64	M WILLAMETTE R	OR
65	MAY CR + WALLACE CR	WA
66	MCALLISTER CR11.0324	WA
67	MCKENZIE R	OR
68	MERCED RIVER	CA
69	MINTER CR 15.0048	WA
70	MIXED COLUMBIA	WA
71	N SANTIAM R	OR
72	NASELLE R +WILLAPA R	WA
73	NEMAH R + WILLAPA R	WA
74	NOOKSACK -SF 01.0246	WA
75	NOOKSACK+SAMISH MIX	WA
76	OAF	OR
77	PISTOL R AND TRIBS	OR
78	PORTAGE BAY STOCK UW	WA
79	PRIEST RAPIDS (36)	WA
80	QUEETS R 21.0016	WA
81	QUILLAYUTE +BIG SOOS	WA
82	QUILLAYUTE R 20.0096	WA
83	QUINAULT R 21.0398	WA
84	ROGUE R	OR
85	S-B.QUAL+L.QUAL+CAPL	BC
86	S-BAEZAEKO RIVER	BC
87	S-BIG QUALICUM RIVER	BC
88	S-BONAPARTE RIVER	BC
89	S-BOWRON RIVER	BC
90	S-CAPILANO RIVER	BC
91	S-CARIBOO R UPPER	BC
92	S-CHEMAINUS RIVER	BC
93	S-CHILKO RIVER	BC
94	S-CHILLIWACK RIVER	BC
95	S-CLEARWATER R UPR/B	BC
96	S-COLDWATER RIVER	BC
97	S-COWICHAN RIVER	BC
98	S-DEADMAN RIVER	BC
99	S-DOME CREEK	BC
100	S-EAGLE RIVER	BC
101	S-FINN CREEK	BC
102	S-HARRIS + CHEHALIS	BC
103	S-HARRISON RIVER	BC
104	S-HIRSCH CREEK	BC
105	S-NANAIMO RIVER	BC
106	S-NICOLA RIVER	BC
107	S-QUESNEL RIVER	BC
108	S-RAFT RIVER/BC	BC
109	S-ROBERTSON CREEK	BC
110	S-SHUSWAP R. MIDDLE	BC
111	S-THOMPSON R NORTH	BC
112	S-WEST ROAD RIVER	BC
113	S-WILLOW RIVER	BC
114	S PUGET SOUND STOCKS	WA
115	S SANTIAM R	OR
116	S SOUND + HOOD CANAL	WA
117	S.FK. SALMON SU. CH.	ID
118	SALMON R	OR
119	SAMISH (FRIDAY CR)	WA
120	SAN JOAQ.R, AB BROAD	CA
121	SANDY R (SANDY HT)	OR
122	SKAGIT R 03.0176	WA
123	SKAGIT TRIBUTARIES	WA
124	SKOOKUM CR 01.0273	WA
125	SNAKE +PRIEST RAPIDS	WA
126	SNAKE R-LOWR 33.0002	WA
127	SNAKE RIVER FALL CH.	ID
128	SNOHOMISH R 07.0012	WA
129	SOLEDUCK R 20.0096	WA
130	SOOES R 20.0015	WA
131	SPRING CR 29.0159	WA
132	STILLAGUAMISH R	WA
133	STILLAGUAMISH R -NF	WA
134	SUIATTLE R 03.0710	WA
135	TANNER CR	OR
136	TOUTLE (TYPE-S)STOCK	WA
137	TRASK R (TRASK HT)	OR
138	TRINITY RIVER	CA
139	TULE STOCK -COLUMBIA	WA
140	UMPQUA R(ROCK CR HT)	OR
141	VOIGHT CR 10.0414	WA
142	WALLACE R 07.0940	WA
143	WASHINGTON BRIGHTS	OR
144	WASHOUGAL R 28.0159	WA
145	WELLS DAM (47)	WA
146	WENATCHEE R 45.0030	WA
147	WHITE R 10.0031	WA
148	WIND R 29.0023	WA

Appendix Table 3. Three-way contingency table where three variables (recovery age, month, and year) are tested. Dependent variable is Lastan 1 frequency (Freq).

Rec age	Rec month	Rec year	Freq	Rec age	Rec month	Rec year	Freq
0.2	1	88	1	0.3	3	92	0
0.2	1	89	14	0.3	3	93	0
0.2	1	90	3	0.3	4	88	0
0.2	1	91	14	0.3	4	89	0
0.2	1	92	8	0.3	4	90	0
0.2	1	93	8	0.3	4	91	0
0.2	2	88	4	0.3	4	92	0
0.2	2	89	5	0.3	4	93	0
0.2	2	90	1	1.2	1	88	0
0.2	2	91	11	1.2	1	89	5
0.2	2	92	6	1.2	1	90	3
0.2	2	93	7	1.2	1	91	1
0.2	3	88	1	1.2	1	92	1
0.2	3	89	4	1.2	1	93	2
0.2	3	90	2	1.2	2	88	9
0.2	3	91	3	1.2	2	89	2
0.2	3	92	3	1.2	2	90	0
0.2	3	93	2	1.2	2	91	0
0.2	4	88	0	1.2	2	92	1
0.2	4	89	0	1.2	2	93	5
0.2	4	90	0	1.2	3	88	1
0.2	4	91	0	1.2	3	89	1
0.2	4	92	0	1.2	3	90	3
0.2	4	93	0	1.2	3	91	1
0.3	1	88	1	1.2	3	92	0
0.3	1	89	5	1.2	3	93	1
0.3	1	90	6	1.2	4	88	0
0.3	1	91	6	1.2	4	89	1
0.3	1	92	7	1.2	4	90	0
0.3	1	93	2	1.2	4	91	0
0.3	2	88	1	1.2	4	92	1
0.3	2	89	3	1.2	4	93	2
0.3	2	90	4				
0.3	2	91	2				
0.3	2	92	2				
0.3	2	93	4				
0.3	3	88	0				
0.3	3	89	3				
0.3	3	90	3				
0.3	3	91	0				

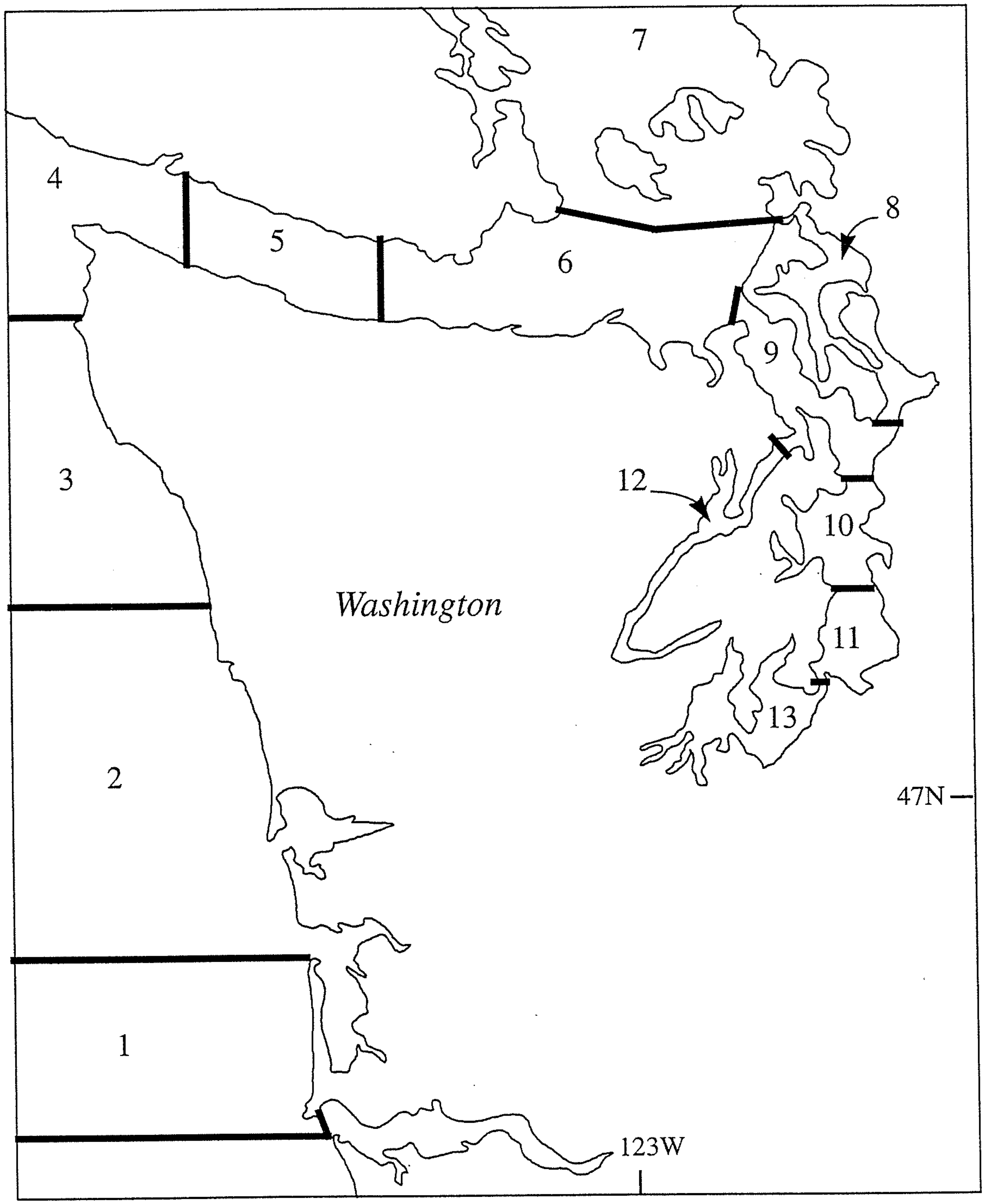

Fig. 1. Thirteen ocean recovery areas in Washington State coastal waters.

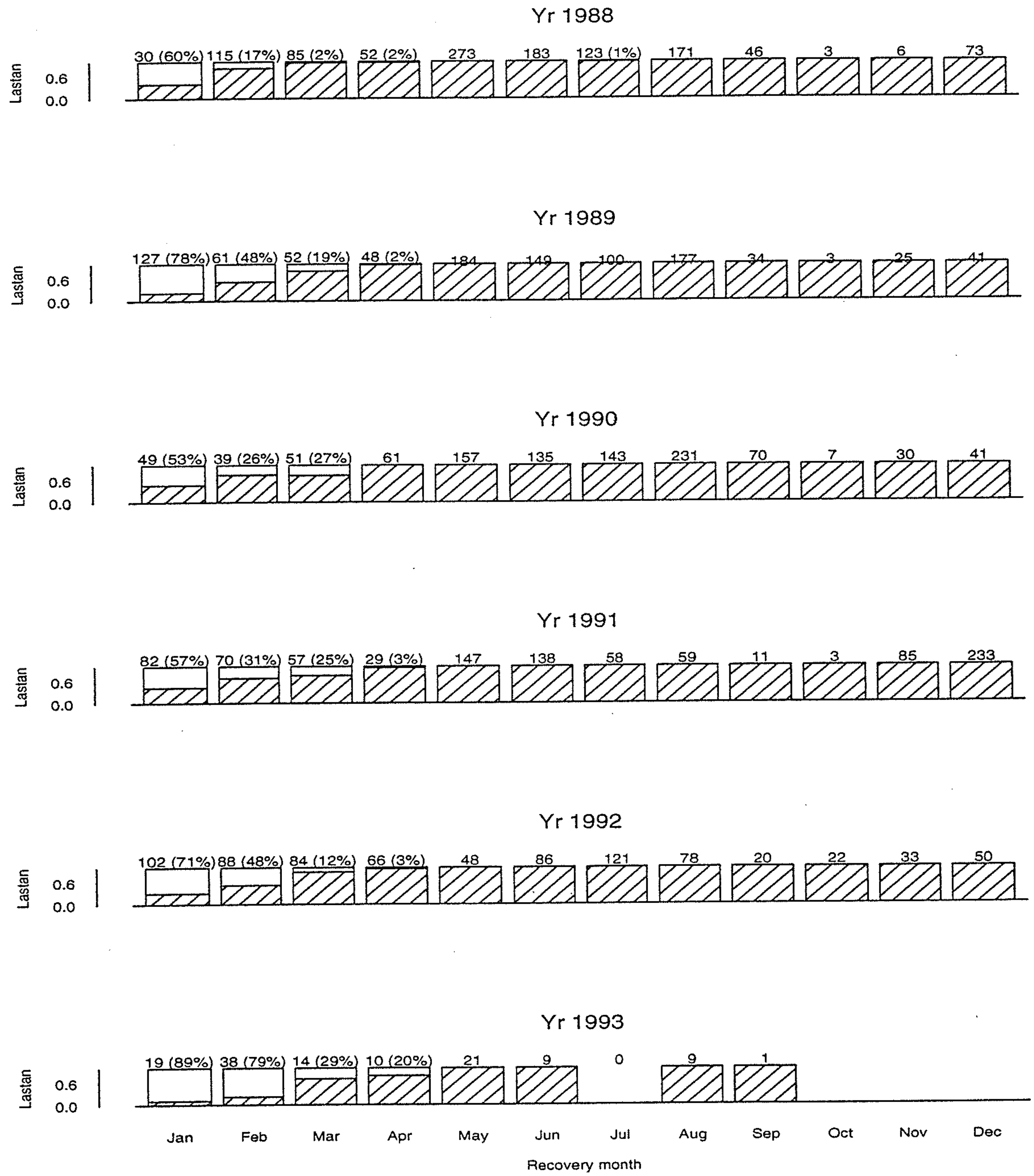

Fig. 2. Yearly variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by recovery year and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum, and the value in the parentheses is Lastan 1 portion (%) within each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

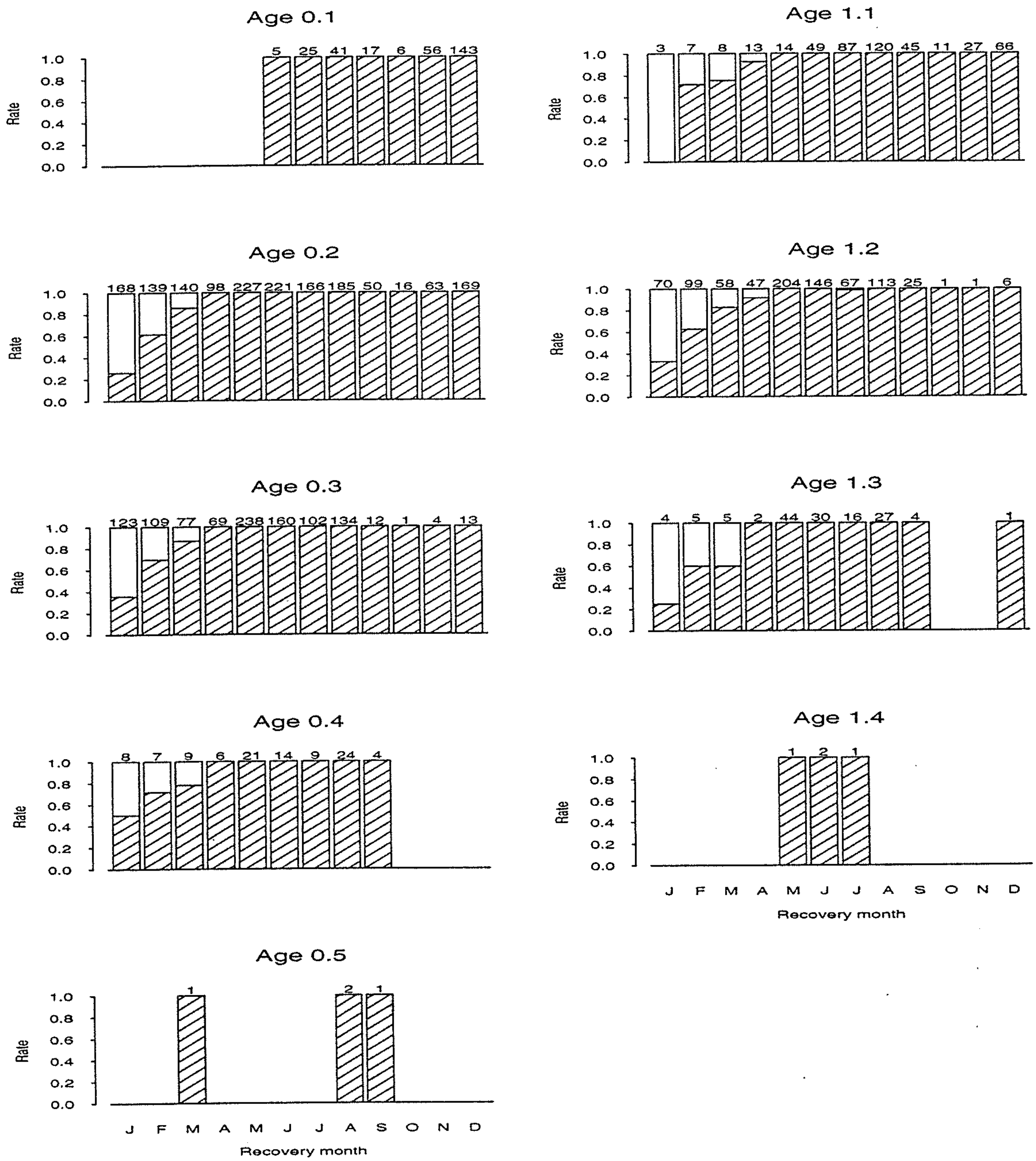

Fig. 3. Age variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by recovery age and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

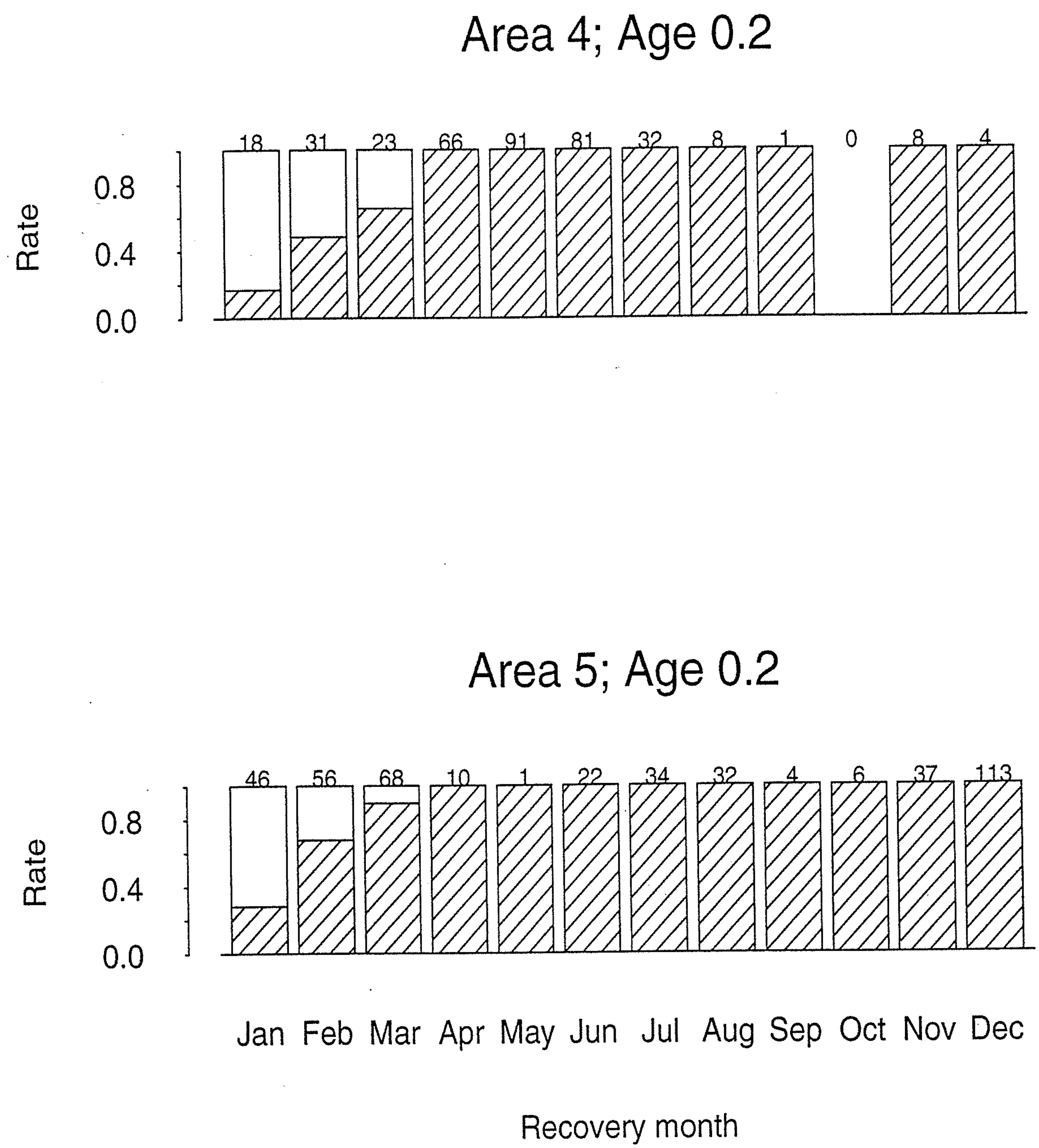

Fig. 4. Area variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by area, age, and month. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

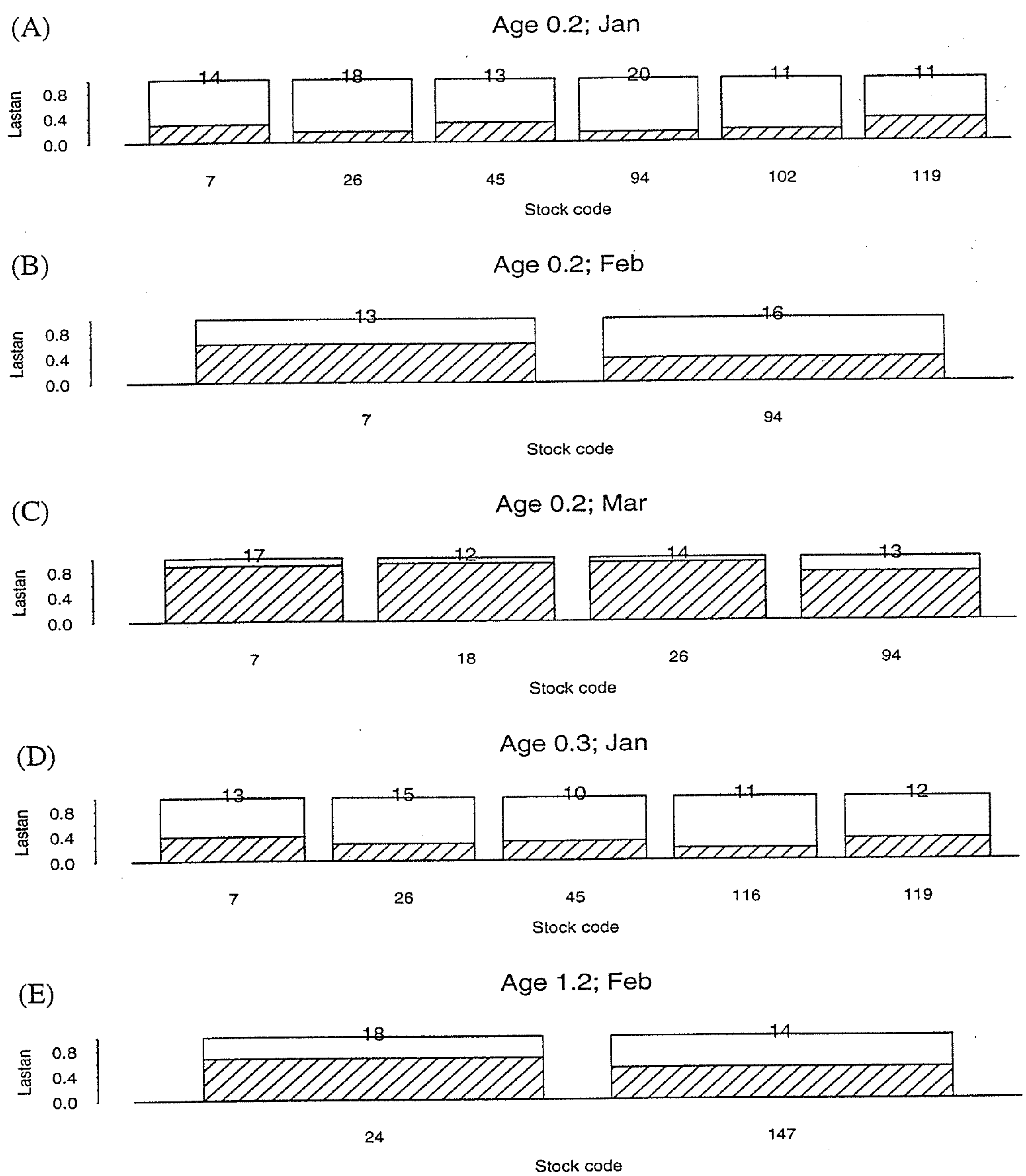

Fig. 5. Stock variability in time of annulus formation in chinook salmon recovered in Washington coastal waters. Recoveries are stratified by stock, age, and month. We show only strata with recoveries greater than or equal to 10. Stocks corresponding to the codes are listed in Appendix Table 2. Blank part indicates the portion of Lastan 1 and shaded area is the portion of Lastan 2 + 3. The number at the top of each bar represents the number of recoveries in each stratum.

☐ Lastan 1 = last annulus had not started forming.

▨ Lastan 2 + 3 = last annulus forming or completely formed.

TABLE 1. ANOVA of recovery age, recovery month and recovery year. Contingency table data used for this ANOVA are shown in Appendix Table 3.

Source	Df	Sum of Sq	Mean Sq	F Value	p-value
age	2	78.25	39.13	6.22	0.003
recmo	3	233.83	77.94	12.40	0.000
recyr	5	33.83	6.77	1.08	0.383
Residuals	61	383.58	6.29		

TABLE 2. ANOVA of final linear model, where the dependent variable is frequency of Lastan 1 and independent variables are recovery age and month.

Source	Df	Sum of Sq	Mean Sq	F Value	p-value
age	2	78.25	39.13	6.85	0.002
recmo	3	233.83	77.94	13.65	0.000
age*recmo	6	74.75	12.46	2.18	0.057
Residuals	60	342.67	5.71		

TABLE 3. Contingency table for age 0.2 chinook salmon recoveries in January (Fig. 5 (A)) to test independence between stock and Lastan frequency. $\chi^2 = 3.073$ with df=5 (p-value= 0.689).

Stock code	*7*	*26*	*45*	*94*	*102*	*119*
Lastan 1	10	15	9	17	9	7
Lastan 2 & 3	4	3	4	3	2	4

TABLE 4. Contingency table for age 0.2 chinook salmon recovered in February (Fig. 5 (B)) to test independence between stock and Lastan frequency. $\chi^2 = 1.660$ with df=1 (p-value=0.198).

Stock code	*7*	*94*
Lastan 1	5	10
Lastan 2 & 3	8	6

TABLE 5. Contingency table for age 0.2 chinook salmon recovered in March (Fig. 5 (C)) to test independence between stock and Lastan frequency. $\chi^2 = 1.896$ with df=3 (p-value=0.594).

Stock code	*7*	*18*	*26*	*94*
Lastan 1	2	1	1	3
Lastan 2 & 3	15	11	13	10

TABLE 6. Contingency table within age 0.3 chinook salmon recovered in January (Fig. 5 (D)) to test independence between stock and Lastan frequency. $\chi^2 = 1.323$ with df=4 (p-value=0.857).

Stock code	*7*	*26*	*45*	*116*	*119*
Lastan 1	8	11	7	9	8
Lastan 2 & 3	5	4	3	2	4

TABLE 7. Contingency table within age 1.2 chinook salmon recovered in February (Fig. 5 (E)) to test independence between stock and Lastan frequency. $\chi^2 = 0.907$ with df=1 (p-value=0.341).

Stock code	*24*	*147*
Lastan 1	6	7
Lastan 2 & 3	12	7

Appendix Table 1. An example of data format.

No	Stock cd	Tagcd	Recyr	Recmo	Recare	Bryr	Relyr	Recag	Lastan
1	1	052542	92	6	5	90	91	0.1	3
2	2	064826	89	7	2	86	87	0.2	3
3	2	064830	89	6	2	86	87	0.2	3
4	2	065405	88	6	2	85	86	1.2	3
5	2	065405	88	5	2	85	86	0.2	3
6	2	065405	88	5	3	85	86	0.2	3
7	2	065405	88	2	5	85	86	0.2	1
8	2	065405	88	3	5	85	86	na	3
9	2	065406	88	5	2	85	86	0.2	3
10	2	065406	89	5	2	85	86	0.3	3
11	2	065406	89	5	2	85	86	0.3	3
12	2	065406	88	2	6	85	86	0.2	1
13	2	065406	88	4	5	85	86	0.2	2
14	2	065407	90	5	4	86	87	0.3	2
15	2	065407	90	6	4	86	87	0.3	3
16	2	065409	90	7	2	87	88	0.2	3
17	2	065411	90	8	1	87	88	0.2	3
18	2	065415	91	8	1	88	89	0.2	3
19	2	065453	88	5	2	84	85	0.3	3
20	2	065453	88	5	3	84	85	0.3	3
21	3	621632	89	9	5	84	85	0.4	3
22	3	621634	88	8	3	84	85	1.3	3
23	3	623142	88	5	2	84	85	0.3	3
24	4	H60702	88	8	4	85	86	0.2	3
25	4	H60704	88	6	2	85	86	0.2	3
26	4	H60704	88	5	4	85	86	0.2	3
27	4	H60705	88	5	3	85	86	0.2	3
28	4	H60705	89	6	2	85	86	0.3	3
29	5	073319	90	6	1	86	87	0.3	3
30	5	073319	89	5	2	86	87	0.2	3
31	5	073319	89	3	5	86	87	0.2	3
32	5	073319	89	5	2	86	87	0.2	3
33	5	073817	89	5	4	86	87	0.2	3
34	5	073817	89	5	1	86	87	0.2	3
35	5	074007	90	6	3	87	88	0.2	3
36	5	074250	92	1	6	89	90	1.2	1
37	5	074250	91	11	5	89	90	0.1	3
38	5	074251	90	5	4	86	87	0.3	2
39	5	074251	90	8	6	86	87	0.3	3
40	5	074251	89	4	4	86	87	0.2	3
41	5	074251	89	4	4	86	87	0.2	3
42	5	074251	89	5	2	86	87	0.2	3
43	5	074253	90	8	2	86	87	0.3	3
44	5	074253	89	2	6	86	87	0.2	1
45	5	074255	92	4	4	89	90	0.2	3
46	5	074255	92	2	5	89	90	0.2	1
47	5	074255	91	11	5	89	90	1.1	3
48	5	074256	92	5	4	89	90	0.2	3
49	5	074256	92	3	5	89	90	0.2	3
50	5	074256	91	12	5	89	90	0.1	3
51	5	074259	92	3	5	89	90	0.2	3
52	5	074259	91	12	5	89	90	0.1	3
53	5	074261	92	7	5	89	90	0.2	3
54	5	074335	91	5	2	88	89	0.2	3
55	5	074335	91	6	2	88	89	0.2	3
56	5	074335	92	2	5	88	89	0.3	1
57	5	074335	91	5	4	88	89	0.2	3
58	5	074336	91	5	4	88	89	na	3
59	5	074336	92	5	4	88	89	0.3	3
60	5	074336	91	1	5	88	89	0.2	2
61	5	074337	91	5	1	88	89	0.2	3
62	5	074337	91	5	2	88	89	0.2	3
63	5	074407	92	8	1	90	91	na	4
64	5	074452	90	7	1	86	87	0.3	3
65	5	074452	89	5	2	86	87	0.2	3
66	5	074452	89	6	2	86	87	0.2	3
67	5	074452	88	12	5	86	87	0.1	3
68	5	074456	88	12	6	86	87	0.1	3
69	5	074459	89	6	2	86	87	0.2	3
70	5	074521	91	6	4	88	89	0.2	3
71	5	074559	90	6	4	87	88	0.2	3
72	5	074560	90	6	4	87	88	0.2	3
73	5	074560	90	8	1	87	88	0.2	3
74	5	074561	90	5	2	87	88	0.2	3

Appendix Table 2. Stock names corresponding to stock codes. *Notice that stock code 20 is shared by WA and OR.

Stock cd	Stock	State
1	ABERNATHY CR 25.0297	WA
2	AMERICAN RIVER	CA
3	ANADROMOUS	OR
4	BATTLE CREEK	CA
5	BIG CREEK	OR
6	BIG QUILCENE 17.0012	WA
7	BIG SOOS CR 09.0072	WA
8	BONNEVILLE	OR
9	CHAMBERS BASIN MIXED	WA
10	CHETCO R	OR
11	CHIWAWA R 45.0759	WA
12	CLACKAMAS R	OR
13	CLACKAMAS R EARLY	OR
14	CLARK CR 03.1421	WA
15	CLARK CR + SUIATTLE	WA
16	COLE RIVERS	OR
17	COLEMAN NFH	CA
18	COLUMBIA (N BONNEVL)	WA
19	COLUMBIA R - GENERAL	WA
20*	COLUMBIA R BRIGHTS	WA
20*	COLUMBIA R BRIGHTS	OR
21	COLUMBIA R UPRIVER S	OR
22	COOS R - PUBLIC	OR
23	COQUILLE R	OR
24	COWLITZ R 26.0002	WA
25	DESCHUTES R	OR
26	DESCHUTES R 13.0028	WA
27	DESCHUTES X HOOD CNL	WA
28	DUNGENESS R 18.0018	WA
29	EAGLE CR NFH (CLACKA	OR
30	ELK R (ELK R HT)	OR
31	ELOCHOMAN + KALAMA R	WA
32	ELOCHOMAN R 25.0236	WA
33	ELWHA R 18.0272	WA
34	FEATHER RIVER	CA
35	FINCH CR 16.0222	WA
36	FORK CR 24.0356	WA
37	G.ADAMS/FINCH/MCKERN	WA
38	GARRISON SPRINGS STK	WA
39	GEORGE ADAMS (PURDY)	WA
40	GLENWOOD SPRINGS	WA
41	GRAYS R 25.0093	WA
42	GRAYS R +ELOCHOMAN R	WA
43	GREEN R + ISSAQUAH	WA
44	GREEN R +TULALIP BAY	WA
45	GROVERS CR 15.0299	WA
46	HANFORD REACH STOCK	WA
47	HOKO R 19.0148	WA
48	HOLLOW TREE CREEK	CA
49	HOOD CANAL MIXED	WA
50	HUMPTULIPS R 22.0004	WA
51	ISSAQUAH CR 08.0178	WA
52	KALAMA C+GREEN+MCALL	WA
53	KALAMA CR 11.0017	WA
54	KALAMA CR & GREEN R	WA
55	KALAMA R 27.0002	WA
56	KENDALL CR 01.0406	WA
57	KLAMATH RIVER	CA
58	KLICKITAT R 30.0002	WA
59	LEWIS R 27.0168	WA
60	LOOKINGGLASS CR	OR
61	LOWER ELWHA 18.0274	WA
62	LTL WHITE SALMON-NFH	WA
63	LYONS FERRY HATCHERY	WA
64	M WILLAMETTE R	OR
65	MAY CR + WALLACE CR	WA
66	MCALLISTER CR11.0324	WA
67	MCKENZIE R	OR
68	MERCED RIVER	CA
69	MINTER CR 15.0048	WA
70	MIXED COLUMBIA	WA
71	N SANTIAM R	OR

Appendix Table 2. continued.

72	NASELLE R +WILLAPA R	WA
73	NEMAH R + WILLAPA R	WA
74	NOOKSACK -SF 01.0246	WA
75	NOOKSACK+SAMISH MIX	WA
76	OAF	OR
77	PISTOL R AND TRIBS	OR
78	PORTAGE BAY STOCK UW	WA
79	PRIEST RAPIDS (36)	WA
80	QUEETS R 21.0016	WA
81	QUILLAYUTE +BIG SOOS	WA
82	QUILLAYUTE R 20.0096	WA
83	QUINAULT R 21.0398	WA
84	ROGUE R	OR
85	S-B.QUAL+L.QUAL+CAPL	BC
86	S-BAEZAEKO RIVER	BC
87	S-BIG QUALICUM RIVER	BC
88	S-BONAPARTE RIVER	BC
89	S-BOWRON RIVER	BC
90	S-CAPILANO RIVER	BC
91	S-CARIBOO R UPPER	BC
92	S-CHEMAINUS RIVER	BC
93	S-CHILKO RIVER	BC
94	S-CHILLIWACK RIVER	BC
95	S-CLEARWATER R UPR/B	BC
96	S-COLDWATER RIVER	BC
97	S-COWICHAN RIVER	BC
98	S-DEADMAN RIVER	BC
99	S-DOME CREEK	BC
100	S-EAGLE RIVER	BC
101	S-FINN CREEK	BC
102	S-HARRIS + CHEHALIS	BC
103	S-HARRISON RIVER	BC
104	S-HIRSCH CREEK	BC
105	S-NANAIMO RIVER	BC
106	S-NICOLA RIVER	BC
107	S-QUESNEL RIVER	BC
108	S-RAFT RIVER/BC	BC
109	S-ROBERTSON CREEK	BC
110	S-SHUSWAP R. MIDDLE	BC
111	S-THOMPSON R NORTH	BC
112	S-WEST ROAD RIVER	BC
113	S-WILLOW RIVER	BC
114	S PUGET SOUND STOCKS	WA
115	S SANTIAM R	OR
116	S SOUND + HOOD CANAL	WA
117	S.FK. SALMON SU. CH.	ID
118	SALMON R	OR
119	SAMISH (FRIDAY CR)	WA
120	SAN JOAQ.R, AB BROAD	CA
121	SANDY R (SANDY HT)	~~?~~ OR
122	SKAGIT R 03.0176	WA
123	SKAGIT TRIBUTARIES	WA
124	SKOOKUM CR 01.0273	WA
125	SNAKE +PRIEST RAPIDS	WA
126	SNAKE R-LOWR 33.0002	WA
127	SNAKE RIVER FALL CH.	ID
128	SNOHOMISH R 07.0012	WA
129	SOLEDUCK R 20.0096	WA
130	SOOES R 20.0015	WA
131	SPRING CR 29.0159	WA
132	STILLAGUAMISH R	WA
133	STILLAGUAMISH R -NF	WA
134	SUIATTLE R 03.0710	WA
135	TANNER CR	OR
136	TOUTLE (TYPE-S)STOCK	~~?~~ WA
137	TRASK R (TRASK HT)	OR
138	TRINITY RIVER	CA
139	TULE STOCK -COLUMBIA	WA
140	UMPQUA R(ROCK CR HT)	OR
141	VOIGHT CR 10.0414	WA
142	WALLACE R 07.0940	WA
143	WASHINGTON BRIGHTS	OR
144	WASHOUGAL R 28.0159	WA

Appendix Table 2. continued.

145	WELLS DAM (47)	WA
146	WENATCHEE R 45.0030	WA
147	WHITE R 10.0031	WA
148	WIND R 29.0023	WA

Appendix Table 3. Three-way contingency table where three variables of recovery age, month, and year are tested. Dependent variable is Lastan 1 frequency (Freq.).

Rec age	Rec month	Rec year	Freq.
0.2	1	88	1
0.2	1	89	14
0.2	1	90	3
0.2	1	91	14
0.2	1	92	8
0.2	1	93	8
0.2	2	88	4
0.2	2	89	5
0.2	2	90	1
0.2	2	91	11
0.2	2	92	6
0.2	2	93	7
0.2	3	88	1
0.2	3	89	4
0.2	3	90	2
0.2	3	91	3
0.2	3	92	3
0.2	3	93	2
0.2	4	88	0
0.2	4	89	0
0.2	4	90	0
0.2	4	91	0
0.2	4	92	0
0.2	4	93	0
0.3	1	88	1
0.3	1	89	5
0.3	1	90	6
0.3	1	91	6
0.3	1	92	7
0.3	1	93	2
0.3	2	88	1
0.3	2	89	3
0.3	2	90	4
0.3	2	91	2
0.3	2	92	2
0.3	2	93	4
0.3	3	88	0
0.3	3	89	3
0.3	3	90	3
0.3	3	91	0

Appendix Table 3. continued.

Rec age	Rec month	Rec year	Freq.
0.3	3	92	0
0.3	3	93	0
0.3	4	88	0
0.3	4	89	0
0.3	4	90	0
0.3	4	91	0
0.3	4	92	0
0.3	4	93	0
1.2	1	88	0
1.2	1	89	5
1.2	1	90	3
1.2	1	91	1
1.2	1	92	1
1.2	1	93	2
1.2	2	88	9
1.2	2	89	2
1.2	2	90	0
1.2	2	91	0
1.2	2	92	1
1.2	2	93	5
1.2	3	88	1
1.2	3	89	1
1.2	3	90	3
1.2	3	91	1
1.2	3	92	0
1.2	3	93	1
1.2	4	88	0
1.2	4	89	1
1.2	4	90	0
1.2	4	91	0
1.2	4	92	1
1.2	4	93	2