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ANALYSIS OF STOCK-RECRUITMENT DYNAMICS OF BRITISH COLUMBIA SALMON

by

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ABSTRACT

An overview of stock-recruitment dynamics for major B.C. salmon (*Oncorhynchus* spp.) stocks is presented. Stock-recruitment patterns range from linear relationships to "Ricker" type relationships to no relationship at all. However, stocks for which there are accurate escapement estimates generally show patterns expected from stock-recruitment theory. It is concluded that errors in stock definiton, mixed catch allocation, and spawning counts bias optimum escapement estimates downward so that poorly monitored stocks may become severely overexploited without being noticed. Because of poor escapement counts and/or difficulties in separating mixed catches, optimum escapements for many B.C. salmon stocks, which account for about half of the total B.C. production, cannot be estimated. Most stocks for which optimum escapement can be estimated are now being severely depleted. Restoration of these stocks by increasing escapement to optimum levels would increase the total catch by at least 40% of the current yield. Further, experimental management by increasing escapement appears to be the best policy for most of the other stocks.

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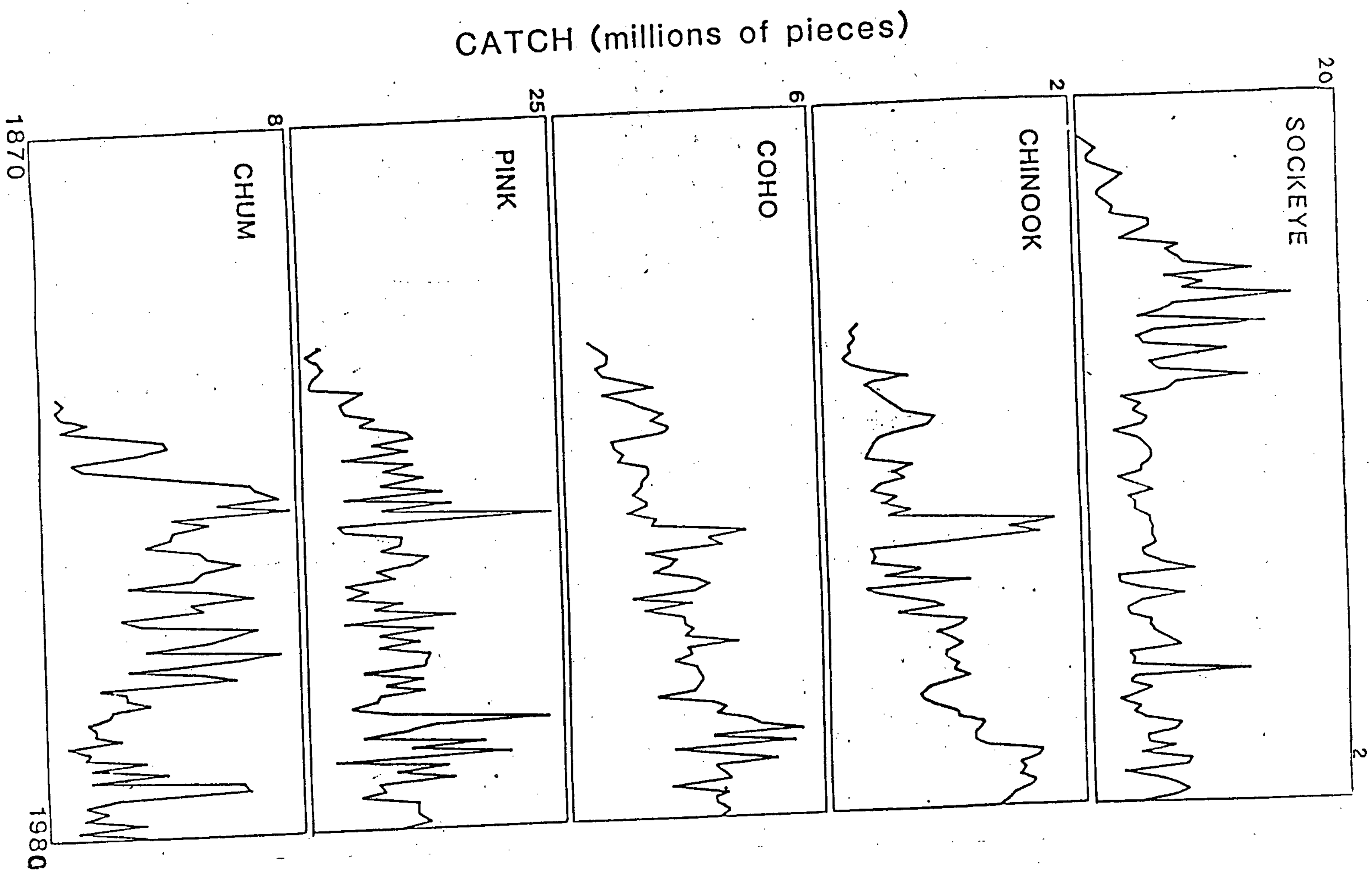
1. INTRODUCTION

The five species of Pacific salmon (*Oncorhynchus* spp.) indigenous to British Columbia have been exploited commercially since the late 1800s. Landings by Canadian fisherman indicate that sockeye (*O. nerka*) and chum (*O. keta*) were much more abundant historically than at the present (Fig. 1). Pink (*O. gorbuscha*) catches have been highly variable due to the two-year cycle of this species and due to fluctuations in population sizes. However no significant trend is apparent in the landings since the early 1900s. Coho (*O. kisutch*) and spring (*O. tshawytscha*) production increased steadily until the early 1970s. Catches of both species have declined recently.

Sockeye production dropped significantly after the Hell's Gate disaster on the Fraser River in 1913 and 1914. Continued heavy exploitation has prevented recovery of these stocks even to this date. It has only recently been recognized that chum is the least productive salmon species in B.C. Its persistent decline is generally believed to be the result of overfishing throughout most of this century. It is difficult to relate coho and spring catches to local productivity. Tagging studies in the 1930s and 1960s (Pritchard 1934, Hollett 1970), and the more recent Coded Wire Tagging Program, show that significant portions of the spring and coho catches in B.C. are from stocks of United States origin. (Riddell pers. Comm).

Because of the anadromous nature of Pacific salmon, concerns have been voiced since as early as 1909 (Babcock 1909) that a "sufficient" number of spawning adults must be allowed to

FIGURE 1. The history of Canadian Salmon catches since 1870 (millions of fish). Key trends to note are the drop in sockeye production following the Fraser Hells Gate disaster in 1912, growth in chinook and coho yields since 1960, and the long term decline in chum production. (from Walters et.al.1982)



pass through the fishery. Restrictions on fishing time, location and gear have been in effect since the late 1800s to limit catches on major salmon producing streams in B.C. However, what constitutes "sufficient" escapement remains rather uncertain even to the present.

Before the 1950s, there was great uncertainty about the production potential of the stocks, and no clear concensus about the information needed to improve understanding. Catch, escapement and other biological data were collected only sporadically, and were seldom analysed systematically. The effect and extent of habitat degradation on production were largely unknown. Without quantitative measures of "sufficient" escapement, management actions were largely compromises between fishermen's demand for larger catches on one hand and biologists' desire for larger escapements on the other.

Since the 1950s, more precise quantitative models have been used extensively for salmon management. Ricker(1954) proposed the "stock-recruitment model" from which the level of escapement that will produce the maximum sustained yield (MSY) can be calculated. Unfortunately, fitting the "Ricker curve" to data is not straight-forward. Tanaka (1962) suggested different ways to fit the curve and argued about the proper data to include. Ricker and Smith (1975) suggested that old data may not be relevant to current management because conditions may have changed due to environmental deterioration, selection by the fishery, and extinction of substocks. Concerns have also been raised about the possibility of interaction between different year classes (Ward and Larkin 1964, Larkin 1971, Ricker 1962), and about possible multiple equilibria (Neave 1954, Perterman 1977) in some salmon populations. More recently, Walters and Ludwig (1981) and Ludwig and Walters (1981) concluded that measurement errors commonly found in escapement estimates tend to bias the stock-recruitment relationship so as to promote severe overexploitation.

Another problem is to determine what constitutes a unit stock. It is well recognised that salmon runs to large river systems (e.g. Fraser, Skeena) are made up of many substocks, which may have overlapping run timings and different sustained harvest rates (Larkin and McDonald 1968). But these substocks are often harvested jointly in a common fishery and the mixed catches can seldom be separated accurately. Recently the Department of Fisheries and Oceans has been moving fishing areas away from river mouths to avoid overfishing of some local stocks by the increasingly efficient fleet(Anderson 1980). Similarly the troll fleet, which operates where all North American stocks mix , has been encouraged to take advantage of the American enhancement production of coho and spring. The result is that it is now almost impossible to measure the contribution of any single stock very accurately. Ricker (1973) warned that if stocks of unequal productivity are harvested together, the optimal exploitation rate can be exceeded without being noticed. Furthermore the stock-recruitment relationship of the mixture behaves differently during the expansion phase of the fishery than when fishing pressure is relaxed. Rehabilitation of the stocks to optimum levels by increasing overall escapement may take several generations.

Since the advent of computers, more complex models have been proposed for fisheries management (Paulik and Greenough 1966, Southward 1968, Walters 1969, Parrish (ed.) 1973) ,and for ecological optimization in general (Patten (ed.) 1971, Holling (ed.) 1980). Unfortunately most of these models are used to predict optimal policies at equilibrium. Allen (1973) and Walters(1975) argued that by following such policies,the fishery might be brought to an equilibrium that is neither truly optimum nor productive of information necessary to determine the true optimum. Harvest strategy curves or "control laws" have been developed to specify optimum harvest rates for non-equilibrium situations as well as dealing with uncertainty associated with various estimates (Huang et. al 1976, Walters and Hilborn 1976, Silvert 1978, Walters 1981, Ludwig and Walters 1981).

By the late 1970s, quantitative techniques for estimating the "desired" escapement that would produce the maximum biological sustained yield were well established. However, Gordon(1954), Crutchfield and Pontecorro (1969) and Roedel (ed.) (1975) noted that maximum sustained biological yield is rarely the optimum policy for most fisheries because of social and economic objectives. Unfortunately, very little effort has been spent to determine what the actual goals are for management. Keeney (1977) and Hilborn and Walters (1977) used multiattribute utility analysis to investigate the differing goals of salmon management, but the results are rather subjective and depend greatly on individual preferences and/or biases.

Much time and effort have been spent in the past 30 years to monitor B.C. salmon catch and escapement. Yet few attempts have been made to systematically study the stock-recruitment problem. Because of the above problems and the presence of large sampling errors, most researchers and biologists shy away from using the data to estimate "optimum" escapements. With little or no help from researchers, some managers resolve this difficult problem by defining "desired" or "optimum" escapement very simplistically (for example, the largest escapement since 1950 that has produced an equal or higher subsequent escapement). Some settle for the preservation of the status quo without questioning what the current condition of the stocks is. Others simply react to whatever political pressure is on hand regardless of the consequences to the stocks.

The Salmonid Enhancement Program (MacLeod 1977) is creating increased fishing rates on natural stocks, and the impact of enhancement for the coast as a whole has not been examined. It is quite probable that the enhancement program will result in as much loss of wild production as is added by enhancement activities. Thus there is a critical need to examine natural productivity for the coast as whole. Accumulated historical data have never been pulled together to provide an overview of patterns and trends, or analysed carefully and consistently for stock-recruitment patterns.

The purpose of this thesis is to provide a general account of the natural stock-recruitment dynamics for all major manageable stocks of salmon along the B.C. coast, and to estimate optimal policies that would produce maximum expected yields under different assumptions about biological uncertainities. Such policies may not necessarily be the most desirable nor achievable in practice, but should serve as a standard of comparison with other policies that take into account richer sets of objectives and constraints. Chapter 2 outlines methods for estimating spawning stocks and catches associated with these stocks from mixed fisheries. Chapter 3 presents methods and results from stock-recruitment analysis. Chapter 4 describes methods and results of estimating optimal policies under different assumptions of biological uncertainties. Finally chapter 5 discusses the major findings and conclusions of this study.

2. ESTIMATION OF SPAWNING STOCK AND RECRUITMENT

Despite the fact that Pacific salmon (Oncorhynchus spp.) is one of the most studied genera of fish in the world, much uncertainty still surrounds many important relationships essential to sound management practice. Sound population studies require many years of data collection, which involves tremendous manpower, equipment and financial support. The Department of Fisheries and Oceans has not been prepared to make such investments systematically over the vast geographical area covered by this study. Consequently, much of the data used in this thesis came from published and unpublished bits and pieces of information recorded during the past twenty-five years by many fisheries officers, technicians , biologists and researchers of the Department of Fisheries and Oceans. Frequent changes of personnel, equipment and methods used undoubedly render the error structure of these data extremely difficult to estimate. Some possible sources of error and attempts to deal with them will be discussed in this chapter.

2.1 Sources of Data

Since 1951, reliable records of commercial catches of the five species of Pacific salmon native to British Columbia have been reported annually by the Fisheries and Marine Service (B.C. Catch Statistics, Department of Fisheries and Oceans, Pacific region). For most streams, escapements to spawning grounds have also been estimated since 1948 by fisheries officers and reported on form bc16 of the Department of Fisheries and Oceans. These spawning files are currently being organized and published as spawning catalogues for each statistical area (Department of Fisheries and Oceans Data Reports). Most of the escapement estimates used in this study were obtained from these spawning catalogues where published, or by summing the fisheries officers' estimates of individual spawning streams to obtain statistical area totals. Data for Fraser river sockeye and pink stocks were obtained from annual reports of the International Pacific Salmon Fisheries Commission. Age composition of sockeye, chum and spring salmon catches from 1957 to 1972 were from the series of publications by Bilton et. al. (1965-1973), while earlier and later data were obtained from various district management biologists. Coho and spring sports catch estimates were obtained from the Annual B.C. Sports Catch Statistics Reports with more recent estimates from Argue et. al. (1977). Catch statistics for Washington state and Columbia river coho and spring were from I.N.P.F.C. Statistical yearbooks (1967-78), and escapements were from Korn 1977 and Holland 1977 with updated data from Riddell (pers. Comm.). The methods, considerations and assumptions used in various estimates (e.g. stock definition) are discussed in more detail in the following sections.

2.2 Stock Definition

One of the most fundamental requirements for the successful management of a fishery resource is to define what constitutes a unit stock. Ideally, a unit stock can be defined as "a single, interbreeding population". In nature, however, it is usually the exception rather than the rule that such an ideal exists.

For Pacific salmon, a unit stock is usually referred to as a species of salmon inhabiting a particular stream (Larkin 1970). But because of their strong homing tendency, a species of salmon utilizing a stream may be divided into numerous semi-discrete "sub-stocks" which, to a large extent, do not participate in a common gene pool (e.g. various Fraser river sockeye stocks). Also straying among streams is common (Merrell 1962, Simon 1972, and recent reinvasion of pink above Hells gate in the Fraser). Thus the definition of a unit stock becomes rather arbitrary even in a strictly biological sense.

In practice both biological, political and economic considerations have to be taken into account for delimiting certain groups of salmon as management units or manageable stocks. Within the political boundaries of the British Columbia coast , different species of salmon from different origins are harvested jointly in many places (e.g. Johnstone Strait). Because of the high mobility of the fleet and the year to year fluctuations in the abundance of fish and their routes of migration ,the problem of allocating these catches correctly to their streams of origin is very difficult. Unless the mixed catches can be separated with some confidence, all the streams contributing a significant portion of their production to these fisheries should be treated as a single unit for assessment purposes (Gulland 1969). Any claim for a more detailed breakdown into substock units would simply be misleading.

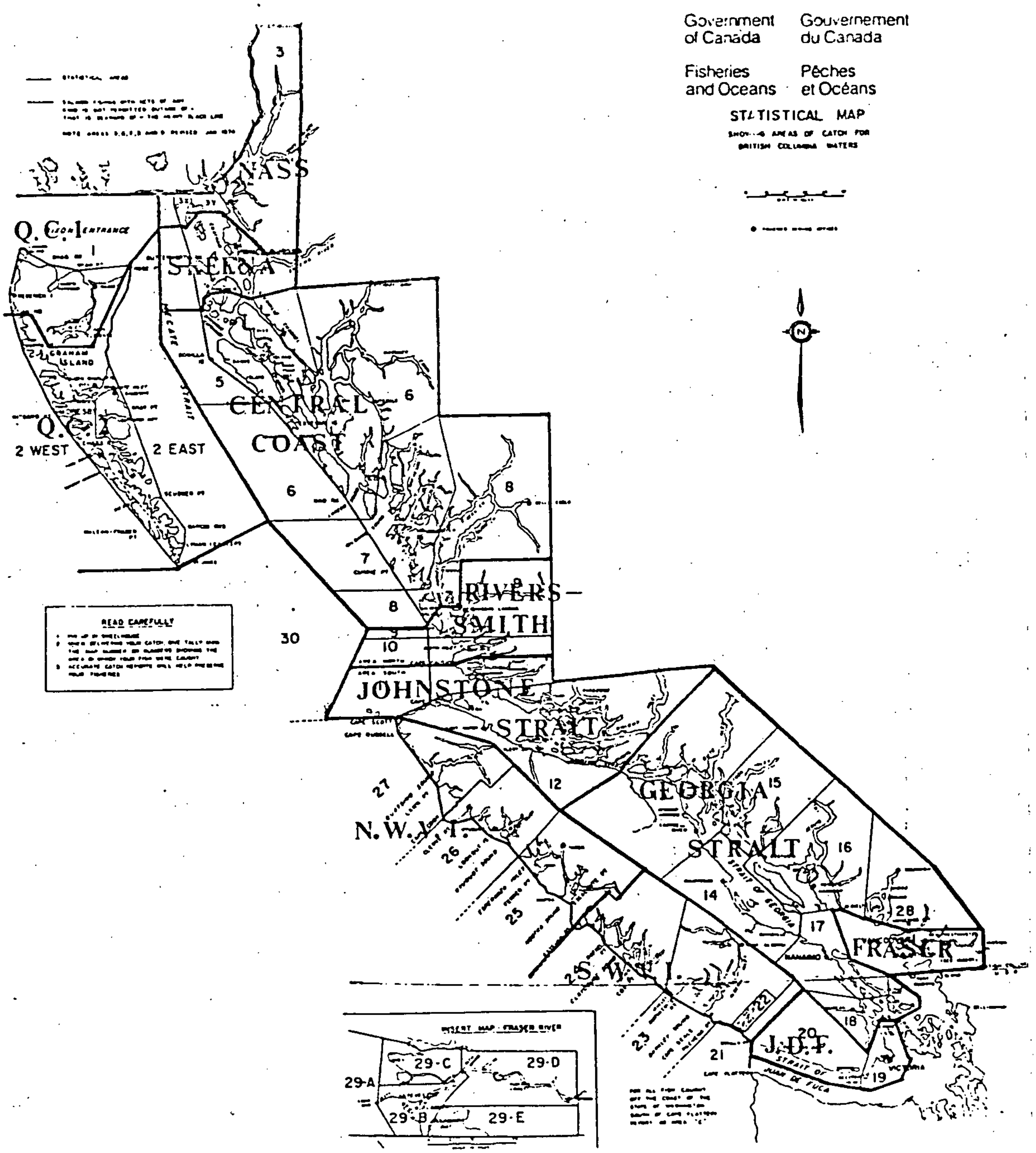
With the above considerations in mind, and after considerable discussion with salmon management biologists of the Department of Fisheries and Oceans (D. Anderson, A.W. Argue, F. Fraser, K. Petrie, D. Schutz, E. Zyblut), twelve "production areas" were delimited along the British Columbia coast (fig. 2). Table 1 lists these "production areas" and corresponding statistical areas used for reporting by the Department of Fisheries and Oceans. Within each production area , sockeye, coho, chum, chinook, odd year pink and even year pink salmon were considered as separate production stocks. Obviously, as knowledge of various aspects of salmon biology improves, future definitions of production units may be substantially more refined.

2.3 Estimation of Spawners

As in other populations, many factors have to be taken into account in designing methods to census a spawning population of salmon. Because of the importance of errors in spawning estimates for the final stock-recruitment analysis to be detailed in the next chapter, several methods commonly used to enumerate spawning populations of salmon stocks in British Columbia are reviewed below so as to provide a feeling for the likely magnitude of errors involved.

A common method is to make several visual appraisals of a spawning population from airplanes, counting towers or on foot. Estimates may be obtained by counting the numbers of live or dead salmon present then extrapolating to the total population

Fig. 2. "Production units" and corresponding statistical areas.


Government of Canada
Gouvernement du Canada
Fisheries and Oceans
Pêches et Océans
STATISTICAL MAP
NASS
Q.C.I.
SKEENA
CENTRAL COAST
Q.C.I.
2 WEST
2 EAST
RIVERS
SMITH
JOHNSTONE
STRAIT
GEORGIA
STRAIT
N.W.V.I.
S.W.V.I.
FRASER
J.D.F.
READ CAREFULLY
INSERT MAP - FRASER RIVER
29-A
29-B
29-C
29-D
29-E
1
3
5
6
6
7
8
8
9
10
12
14
15
16
17
18
19
20
21
22
23
25
26
27
28
30

PRODUCTION AREA		STATISTICAL AREA
1. Queen Charlotte 1 ...	(Q.C.1)	1
2. Queen Charlotte 2 ...	(Q.C.2)	2
3. Nass	(Nass)	3
4. Skeena	(Skeena)	4
5. Central Coast	(C.C.)	5,6,7,8
6. Rivers-Smith	(R-S)	9,10
7. Johnstone Strait	(J.S.)	11,12,13
8. Georgia Strait	(G.S.)	14,15,16,17,18,28
9. Fraser River	(Fraser)	29
10. Juan de Fuca Strait .	(J.F.S.)	19,20
11. S.W. Vancouver Island	(SWVI)	21,22,23,24
12. N.W. Vancouver Island	(NWVI)	25,26,27

Table 1 : Production areas and corresponding statistical areas.

from these samples. The extrapolation is usually not done systematically; just an index is provided by the observer, giving his overall impression of abundance. These estimates (or indexes) depend greatly on the observer's subjective judgement and experience. Undoubtedly such estimates are affected by fluctuations of the physical characteristics of the streams, the intervals of inspection, experience of the observer, the run timing and stream life of the fish, and many other undetermined factors. In a rare case when the accuracy of foot survey was put to a direct test, the discrepancy was found to be around 50% - the estimates from foot survey were only half of the actual total (Brett 1952). Variations of +- 50% were also found in aerial surveys, and different observers made inconsistent counts among different streams (Bevan 1961). Discussions with fishery officers and biologists during recent workshops for the Pearse Commission on Pacific Fisheries Policy (Walters, pers. Comm.) have revealed some even more dramatic examples, where visual survey estimates have differed by up to an order of magnitude from estimates based on more systematic procedures such as fence counts and mark-recapture trials.

While visual counts generally underestimate spawning populations, tagging and recovery procedures tend to overestimate (Brett 1961 ,Vernon et al 1964). For Harrison river sockeye, fairly precise estimates could be obtained only by tagging very close to the spawning grounds. As the distance between tagging to recovery increased, the calculated population also increased. And at some distance, the error became so large that the estimates were useless by any criterion (Schaeffer

1951). The theory, assumptions, advantages and drawbacks of enumerating a population by mark and recapture methods have been well studied and can be obtained from Howard(1948), Vernon et al (1964), Schaeffer(1951) and Ricker(1975).

Test fishing conducted just upstream of commercial fisheries supplies rapid information on escapement strength in a few systems. A small, but unknown, percentage of escapement is intercepted and catch per standardized effort provides an index of abundance. These indexes have been used to estimate total escapements but frequently suffer from lack of consistency from year to year. Relatively good estimates, within 15% of the actual escapement, were obtained this way for the Skeena river sockeye from 1956 to 1963. But these estimates became more erratic and errors of +- 40% have occurred in some years since 1964 (Vroom 1971). Many factors could have caused the inconsistency, and no mechanism has yet been identified to correct some of the existing error (Kadowaki, pers.comm.). Gatto and Rinaldi (1979) presented a procedure to estimate the annual run and escapement of a population of salmon. This method requires that the population be sampled at two diffent parts of its migration route every day by some form of test fishing. The reliability of this method has yet to be tested vigorously under field conditions.

Echo sounding is one of the newer techniques for fish stock assessment and its potential is quite promising (Anon. 1980, Drew 1980). As with other newer methods (electronic counters, aerial photography etc.) it will take many years of field trials for its credibility to be established. Some descriptions of using sonar equipment to enumerate spawning populations of salmon are discussed by Wood and Mason (1971) and Vroom (1971).

In rare circumstances when the exploitation rate of a salmon stock can be estimated with confidence, the escapement can be calculated if the catch is known. The average instantanous rate of fishing per boat is computed from detailed recent data. Assuming that fishing regulations and catching power of the fleet have not changed, exploitation rates for past years can be estimated if past fishing efforts are recorded (e.g. Shepard and Withler 1958). Escapements for early years can be calculated simply as catch*((1/exploitation rate)-1). However, with the rapid improvement of fishing technology in the past 20 years, this method cannot be widely employed today.

Finally the most accurate method is to erect a barrier below the spawning area and count the spawners as they pass through a gate in the fence. However , in most situations, the accuracy gained this way can seldom justify the cost of construction and maintenance of the counting fence, even if conflicts with other user groups can be kept to a minimum. Therefore usually parts (samples) of the population can be counted or manipulated to provide estimates of the total numbers present. While procedures have been developed to calculate confidence limits for these estimates, (Chapman 1948, Cochran 1963), the degree to which their assumptions have been violated is very difficult to evaluate.

2.4 Estimation of Recruitment

In most fisheries literature, recruitment is defined as the number of fish reproduced by a breeding population, and surviving to become vulnerable to the fishing gears in use. For Pacific salmon (except coho and spring), recruitment occurs just prior to spawning. Thus the recruitment from a given brood stock can be estimated if the age structure ,escapement and corresponding catches are known.

Because most salmon fisheries in B.C. are conducted in areas where many stocks mix, one of the major problems of recruitment estimation is the correct allocation of these mixed catches to their production areas. Besides the problems associated with the basic catch statistics (Campbell, unpublished report), the actual numbers of fish caught in an area do not necessarily indicate the relative abundance of recruits produced from that area. The migration routes of various stocks change from year to year. For example, table 2 shows that the percentage of Fraser river sockeye migrating through Johnstone Strait has varied from 3 percent to 57 percent since 1954. Even when the migration routes used are fairly consistent (e.g. Table 3), the run timing, gear distribution and opening patterns vary from year to year. Since the current management scheme allows and sometimes even promotes capturing fish destined to another area, (e.g. Johnstone Strait fishery to take Fraser pink and sockeye), the problem of allocating the catches back to their streams (or areas) of origin is difficult indeed.

Three methods are commonly used to estimate historical

YEAR	PERCENTAGE	YEAR	PERCENTAGE
1954	2.5	1967	25.0
1955	9.0	1968	18.0
1956	9.5	1969	16.0
1957	19.0	1970	24.0
1958	35.0	1971	11.0
1959	14.0	1972	34.0
1960	18.0	1973	10.0
1961	16.5	1974	21.0
1962	11.0	1975	10.0
1963	10.5	1976	19.0
1964	10.0	1977	12.0
1965	10.0	1978	57.0
1966	24.5	1979	30.0

Table 2 : Percentage of Fraser River sockeye adults that returned via Johnstone Strait (I.P.S.F.C. pers.comm.)

YEAR	PERCENTAGE
1957	26.0
1959	33.0
1961	25.0
1963	32.0
1965	28.0
1967	25.0
1969	39.0
1971	22.0
1973	29.0
1975	25.0
1977	23.0
1979	23.0

Table 3 : Percentage of Fraser River pink adults that returned via Johnstone Strait (I.P.S.F.C. pers.comm.)

stock contributions to mixed catches. The first method is to allocate fixed proportions (over time) of the mixed catch to the contributing production areas. Catch allocation tables have been generated for this purpose from preliminary coded wire tagging studies and the experiences of six members of the Department of Fisheries and Oceans - D.Anderson, A.W.Argue, M.Farwell, K.Petrie, D.Shutz and E.Zyblut (Staley, pers.comm.). For each of the production areas (as defined in table 1), the biologists were asked to estimate the percentage of fish produced in that area but caught in another catch area (as defined in table 4) for each species along the coast. Tables 5 to 10 show the estimated proportion of fish caught in a harvest area which are produced from the appropiate production area (for example, row 1 of column 4 of table 5 reads 79.7 which means of the sockeye catches in the north coast, 79.7% are produced from the Skeena). Unfortunately, this allocation method ignores the fact that production from different stocks fluctuates from year to year.

Under most circumstances, separating mixed catches by fixed proportion allocation tends to bias the parameters of the final stock-recruitment analysis, as demonstrated by the following simple simulation model. "Actual" stock-recruitment data for two severely overexploited stocks, each having independent environmental effects and different productivities were generated from the equation

$$R_{t+1} = S_t e^{\alpha + u_{t+1}} \qquad (2.4.1)$$

where S_t is the spawning stock at generation t, R_{t+1} is the

HARVEST AREA		STATISTICAL AREA
Alaska	(AL)	S.W. Alaska
North Coast	(NC)	1,2,3,4,5
Central Coast	(CC)	6,7,8,9,10
Johnstone Strait	(JS)	11,12,13
Georgia Strait	(GS)	14,15,16,17,18,28
Fraser River	(FR)	29
Juan de Fuca Strait ..	(JFS)	19,20
S.W. Vancouver Island	(SWVI)	21,22,23,24
N.W. Vancouver Island	(NWVI)	25,26,27

Table 4 : Harvest areas and corresponding statistical areas.

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	0.0	0.0	68.2	30.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NC	0.4	0.3	16.6	79.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CC	0.0	0.0	0.0	0.0	21.0	79.0	0.0	0.0	0.0	0.0	0.0	0.0
JS	0.0	0.0	0.0	0.0	0.0	0.0	12.0	1.0	87.0	0.0	0.0	0.0
GS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.0	0.0	47.0	0.0
NWVI	0.0	0.0	0.0	0.0	0.0	17.5	0.0	0.0	82.5	0.0	0.0	0.0

Table 5 : Percentage allocation of harvest to production areas (sockeye).

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	4.0	10.0	70.0	15.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NC	6.6	48.0	27.7	9.7	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CC	0.0	0.0	0.0	0.0	93.7	6.3	0.0	0.0	0.0	0.0	0.0	0.0
JS	0.0	0.0	0.0	0.0	0.0	0.0	21.8	48.9	29.3	0.0	0.0	0.0
GS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
NWVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Table 6 : Percentage allocation of harvest to production areas (chum).

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	18.5	10.8	23.0	25.7	21.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0
NC	18.3	15.0	18.2	20.4	23.7	0.6	0.3	1.2	0.0	0.0	1.0	1.3
CC	0.0	4.7	0.0	0.0	49.7	2.6	9.0	21.5	1.0	0.0	6.5	5.0
JS	0.0	0.0	0.0	0.0	7.7	1.3	43.7	45.5	1.8	0.0	0.0	0.0
GS	0.0	0.0	0.0	0.0	0.0	0.0	1.6	85.6	12.8	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.0	17.0	16.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.3	2.1	18.6	3.7	13.5	55.9	5.9
NWVI	0.0	0.0	0.0	0.0	3.2	0.9	10.8	17.8	1.4	6.3	35.8	23.8

Table 7 : Percentage allocation of harvest to production areas (coho).

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	0.0	0.0	12.3	15.6	7.4	2.8	4.3	4.9	23.6	0.0	20.4	7.9
NC	0.0	0.0	17.5	22.2	9.7	3.8	4.1	5.2	25.6	0.0	8.4	3.5
CC	0.0	0.0	0.0	0.0	10.8	6.5	15.1	7.4	41.2	0.0	13.7	5.1
JS	0.0	0.0	0.0	0.0	0.0	0.0	18.2	21.5	58.0	0.0	0.0	3.2
GS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.6	78.6	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0	57.6	0.0	35.4	0.8
NWVI	0.0	0.0	0.0	0.0	0.0	2.1	27.0	5.2	26.3	0.0	26.5	12.1

Table 8 : Percentage allocation of harvest to production areas (spring).

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NC	0.7	0.0	20.8	68.3	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CC	0.0	0.0	0.0	0.0	91.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0
JS	0.0	0.0	0.0	0.0	0.0	0.0	32.0	0.0	68.0	0.0	0.0	0.0
GS	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	94.0	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	98.0	0.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	97.0	0.0	0.0	0.0
NWVI	0.0	0.0	0 0	0.0	0.0	0.0	4.2	0.0	95.8	0.0	0.0	0.0

Table 9 : Percentage allocation of harvest to production areas (odd year pink).

PRODUCTION AREA

HARVEST AREA	Q.C.1	Q.C.2	NASS	SK	CC	RS	JS	GS	FR	JFS	SWVI	NWVI
AL	0.0	0.0	100.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NC	3.2	25.3	19.1	36.4	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CC	0.0	0.0	0.0	0.0	89.7	10.3	0.0	0.0	0.0	0.0	0.0	0.0
JS	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
GS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JFS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
NWVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

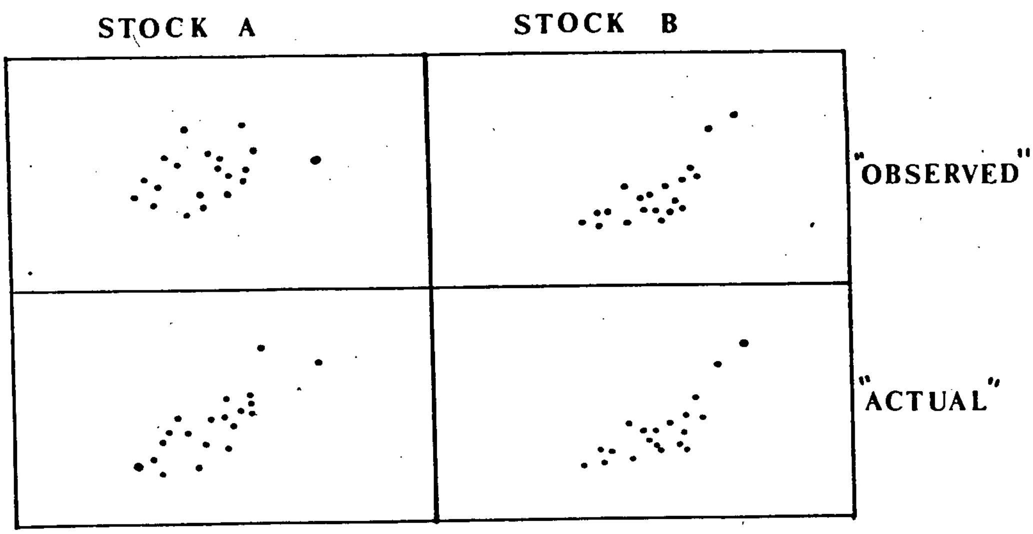
Table 10 : Percentage allocation of harvest to production areas (even year pink).

resulting recruits from S_t , α is a production parameter and μ_{t+1} is a random environmental factor, normally distributed with mean 0.0 and variance σ_u^2 . Recruitments for both stocks were subject to the same exploitation rate by a common fishery. The spawning populations were further regulated by terminal fisheries to vary around fixed escapement goals which were liable to "management errors" of about +-45%. Fixed proportions of the mixed catch were then allocated to each stock according to their relative stock sizes at the beginning of a simulation run. "Observed" recruitment, Y_t ,for stock i at year t would be the sum of the allocated catch, terminal catch and spawning population of that stock at year t. With the environmental factor (σ_u^2) fixed at 0.1, many simulation cases were examined by varying each of the parameters: initial stock sizes, productivities, and total exploitation rate.

By varying the initial stock sizes alone, significant curvature of the "observed" stock-recruitment data became apparent when one stock was about three times or bigger than the other stock. Only the smaller stocks were affected in most cases as shown for a typical case in figure 3. Stock B was five times as big as stock A. Both stocks have the same productivity (α =1) and were exploited at 50% by the common fishery.

It was more difficult to find visual distortion as the other parameters were also varied. The general conclusion is that smaller stocks are affected significantly more than larger stocks as long as the total exploitation rates are less than or equal to the maximum equilibrium exploitation rate, 1-exp(-α), of the less productive stock. Otherwise both the smaller stock

Fig. 3. "Actual" and "observed" stock-recruitment data points using fixed allocation method to separate mixed catches.


STOCK A
STOCK B
"OBSERVED"
"ACTUAL"

and the less productive stock (can be either stock) will be affected. This can be explained by the fact that the less productive stock is being systematically exploited towards extinction but is treated as though it contributes the same proportion to the common fishery as it did at the beginning of the fishery.

An intuitive explanation of the above outcome is that independent random series tend to show a correlation coefficient of -.707 (Eberhardt 1970) which, in this case, suggests that "smaller than average" spawning populations in one stock are more likely to be accompanied by "larger than average" spawning populations from the other stock and vice versa. The effect of this is more apparent when many stocks are mixed together. Despite varying contributions from each individual stock, the total recruitment of all stocks can remain fairly constant from year to year due to simple "averaging". Therefore to allocate a fixed portion of the total recruitment (in mixed catches) to a stock tends to bias the estimated recruitment upwards when the spawning population is low, but bias it downwards when the spawning population is high. Furthermore, smaller stocks are more sensitive to this form of bias because stock-recruitment data are expressed in absolute numbers rather than proportions.

To correct for possible biases of this kind, a second method is to use a back calculation technique to separate mixed cathes. If we assume every stock that migrates through a mixed area is equally vulnerable to the fishing gears, and that the spawning estimates among the stocks are consistent, we can estimate the proportion of catch arising from each particular stock by the method first articulated clearly by Johnson (1975). Equal vulnerability implies that all stocks are subject to the same overall exploitation rate in fishery j , which is

$$u_j = \frac{\text{total catch}}{\text{total catch} + \text{total "escapement"}},$$

where total escapement includes catches taken in later fisheries (hence the need for back calculation from the last fishery to which a stock is subjected). Since the catch C_{ij} of stock i is U_j times the recruitment (catch plus escapement) of stock i to fishery j, so $E_{ij} = (1-U_j)(C_{ij} + E_{ij})$, we can solve for catch of stock i given escapement E_{ij} as

$$C_{ij} = \frac{E_{ij}}{1-U_j} - E_{ij} = \frac{U_j}{1-U_j} E_{ij} \qquad (2.4.2)$$

The calculation becomes somewhat more complicated for south coast stocks with split migration routes. The method is most easily understood by example, as for south coast (Fraser river, Georgia Strait, Johnstone Strait) chums. The proportion of Fraser river chum salmon caught in Georgia Strait in a given year would be:

$$P_{11} = \frac{(S_1 + C_{11})U_1}{(S_1 + C_{11})U_1 + S_2} \qquad (2.4.3)$$

where S_1 is the number of Fraser chum spawners, S_2 is the number of Georgia Strait chum spawners, C_{11} is the number of chums caught in the Fraser estuary , U_1 the proportion of Fraser chum that migrated through the northern route in that year, and P_{11} the proportion of chum caught in Georgia Strait that belong to the Fraser. Then the proportion of Fraser chum caught (earlier) in Johnstone Strait would be:

$$P_{12} = \frac{(S_1 + C_{11})U_1 + C_{12}}{(S_1 + C_{11})U_1 + (S_2 + C_{22})U_2 + S_3} \qquad (2.4.4)$$

where S_1, S_2, C_{11}, U_1 and P_{11} are the same as before, S_3 is the number of Johnstone Strait chum spawners, C_{12} is the number of Fraser chum caught in Georgia Strait, C_{22} is the Georgia Strait chum catch in Georgia Strait, U_2 is the proportion of Georgia Strait chum migrating through the northern route, and P_{12} is the proportion of chum caught in Johnstone Strait that came from the Fraser.

The mixed catches in Georgia Strait can be separated simply by :

$$C_{12} = P_{11} * TC_2$$

$$C_{22} = TC_2 - C_{12}$$

where TC_2 is the total catch of chum in Georgia Strait. The mixed catches in Johnstone Strait can then be separated accordingly.

These calculations are very straight-forward if the proportion of a stock migrating through each route remains fairly consistent from year to year. Otherwise, estimates of the proportion that went through a given area have to be obtained annually. Mixed catches of chum in Georgia Strait and Johnstone Strait are separated by assuming 100% of the maturing fish migrate through Johnstone Strait. Sockeye and pink catches in the same areas are separated similary by using the percentage of northern approach of Fraser fish estimated by I.P.S.F.C. (table 2 & 3). All sockeye and pink catches in Juan de Fuca Strait (Canadian side) and troll caught sockeye in the west coast of Vancouver Island are assumed to be Fraser fish. I.P.S.F.C. estimates of Fraser sockeye and pink caught in U.S.A. are also included. With the exception of coho and spring, other stocks have negligible (or unknown) mixed fishing and the catch statistics reported by the Department of Fisheries for each stock are assumed to be produced by that stock respectively.

Tagging studies in the early 1960s and the more recent Coded Wire Tagging Program revealed that all the stocks of chinook and coho are exploited extensively by mixed fisheries (mainly by trolling gear) all over the coast. Since the variations of their migration routes or the extent to which different stocks mix are vaguely known, the above method cannot be applied for separating these mixed catches. However it is generally believed that these two species are exploited by trolling gear mainly at their rearing areas, while net fisheries generally catch maturing fish close to their spawning areas. If we assume that fairly consistent proportions of different stocks rear in the same residence areas every year, that all resident fish are equally vulnerable to fishing, and that all stocks are subject to similar overall exploitation rates, then a modified version of the back calculation method can be used to separate the mixed catches by trolling gear. Tables 12 to 16 show the proportion of different age groups of coho and spring rearing in different residence areas (table 11) (Staley, pers. Comm.). For either species, the mixed troll catch at different ages from a

RESIDENCE AREA	STATISTICAL AREA
Alaska	S.W. Alaska
North Coast	1-10
Georgia Strait	11-20,28,29
W. Vancouver Island	21-27
Washington	Washington Coast

Table 11 : Residence areas and corresponding statistical areas.

PRODUCTION AREA	RESIDENCE AREA AL	NC	GS	WVI	WASH
AL	.95	.05	0	0	0
Q.C.1	.85	.15	0	0	0
Q.C.2	-	-	-	-	-
Nass	.70	.30	0	0	0
Skeena	.60	.40	0	0	0
C.C.	.40	.60	0	0	0
R-S	.20	.80	0	0	0
J.S.	.10	.40	.4	.10	0
G.S.	0	.20	.8	0	0
Fraser	0	.10	.7	.15	.05
J.F.S.	-	-	-	-	-
S.W.V.I.	.05	.40	.05	.50	0
N.W.V.I.	.10	.45	.05	.40	0
Puget S.	0	.05	.20	.15	.60
W/O Coast	0	.10	0	.40	.50

Table 12 : Proportion of total stock rearing in each residence area by production area (spring age 2).

PRODUCTION AREA	RESIDENCE AREA AL	NC	GS	WVI	WASH
AL	.95	.05	0	0	0
Q.C.1	.90	.10	0	0	0
Q.C.2	-	-	-	-	-
Nass	.75	.25	0	0	0
Skeena	.70	.30	0	0	0
C.C.	.50	.50	0	0	0
R-S	.30	.70	0	0	0
J.S.	.20	.55	.20	.05	0
G.S.	.05	.25	.65	.05	0
Fraser	.05	.20	.60	.10	.05
J.F.S.	-	-	-	-	-
S.W.V.I.	.15	.45	0	.40	0
N.W.V.I.	.20	.50	0	.30	0
Puget S.	.05	.05	.30	.20	.40
W/O Coast	.15	.15	0	.35	.35

Table 13 : Proportion of total stock rearing in each residence area by production area (spring age 3).

PRODUCTION AREA		RESIDENCE AREA AL	NC	GS	WVI	WASH
	AL	1.00	0	0	0	0
	Q.C.1	1.00	0	0	0	0
	Q.C.2	-	-	-	-	-
	Nass	.90	.10	0	0	0
	Skeena	.90	.10	0	0	0
	C.C.	.70	.30	0	0	0
	R-S	.50	.50	0	0	0
	J.S.	.35	.55	.10	0	0
	G.S.	.15	.50	.30	.05	0
	Fraser	.15	.35	.40	.10	0
	J.F.S.	-	-	-	-	-
	S.W.V.I.	.35	.35	0	.30	0
	N.W.V.I.	.40	.40	0	.20	0
	Puget S.	.10	.20	.35	.15	.20
	W/O Coast	.20	.35	0	.30	.15

Table 14 : Proportion of total stock rearing in each residence area by production area (spring age 4 & 5).

		RESIDENCE AREA				
		AL	NC	GS	WVI	WASH
P						
R	AL	1.00	0	0	0	0
O	Q.C.1	.20	.80	0	0	0
D	Q.C.2	.20	.80	0	0	0
U	Nass	.20	.80	0	0	0
C	Skeena	.20	.80	0	0	0
T	C.C.	.05	.90	0	.05	0
I	R-S	0	.90	0	.10	0
O	J.S.	0	.20	.70	.10	0
N	G.S.	0	.05	.75	.20	0
	Fraser	0	0	.60	.30	.10
	J.F.S.	0	0	.60	.30	.10
A	S.W.V.I.	0	.05	0	.85	.10
R	N.W.V.I.	0	.10	0	.85	.05
E	Puget S.	0	0	.10	.30	.60
A	W/O Coast	0	0	0	.15	.85

Table 15 : Proportion of total stock rearing in each residence area by production area (coho age 2).

		RESIDENCE AREA				
		AL	NC	GS	WVI	WASH
P						
R	AL	.90	.10	0	0	0
O	Q.C.1	.40	.60	0	0	0
D	Q.C.2	.40	.60	0	0	0
U	Nass	.50	.50	0	0	0
C	Skeena	.50	.50	0	0	0
T	C.C.	.10	.80	0	.10	0
I	R-S	0	.90	0	.10	0
O	J.S.	0	.30	.70	.20	0
N	G.S.	0	.15	.75	.25	.10
	Fraser	0	.05	.60	.30	.25
	J.F.S.	0	.05	.60	.30	.25
A	S.W.V.I.	0	.10	0	.75	.15
R	N.W.V.I.	0	.15	0	.75	.10
E	Puget S.	0	0	.10	.45	.50
A	W/O Coast	0	0	0	.20	.80

Table 16 : Proportion of total stock rearing in each residence area by production area (coho age 3).

residence area in any year can be separated as:

$$C_{ij} = \left[\frac{(S_i + N_i) P_{ij}}{\sum_{i=1}^{n} (S_i + N_i) P_{ij}} \right] TC_j \qquad (2.4.6)$$

where C_{ij} is the catch belonging to stock i from residence area j. S_i is the spawning population of stock i that year, N_i is the net catch of stock i, P_{ij} is the proportion of stock i rearing in residence area j, TC_j is the total troll catch in residence area j, and n is the number of stocks in residence. The total troll catch belonging to stock i would simply be the sum of all the separated catches at different ages from all residence areas: $\sum_{i=1}^{m} \sum_{j=a}^{b} C_{ij}$ where m is the number of residence areas for stock i, a and b are the youngest and oldest fish recruited respectively.

The third method relies on various stock identification techniques (e.g. scale analysis, serological and biochemical studies, head tagging and recovery program, etc.) to estimate the contribution of each stock in a mixed fishery. Because of present technical and economic problems, long term data obtained this way either do not exist or were not available (e.g. Fraser sockeye) for this study. Therefore only the first two methods were used to separate the mixed catches and the stock-recruitment analyses from these estimates are compared in the next chapter.

When the age structure, catch and escapement data for a particular stock have been estimated, recruitment from any spawning population would simply be:

$$R_j = \sum_{i=a}^{b} C_i CP_i + \sum_{i=a}^{b} S_i SP_i \qquad (2.4.7)$$

where R_j is the recruitment from spawning population at generation j-1, C_i is the total catch i years after spawning, S_i is the total escapement i years from spawning, CP_i is the proportion of age i fish in the catch, SP_i is the proportion of age i fish in the escapement, a is the youngest age of fish returning, and b is the oldest age of fish returning.

Unfortunately the age structure of the catches in most areas was sampled only from 1957 to 1972, and the escapement age structure has been sampled only sporadically. Appendix Ia lists the raw data obtained from various sources from 1951 to 1979. Because of the presence of many gaps in the data, I decided to combine the age structure of catch and escapement by weighting them with the sample sizes to obtain an average age structure for each year (appendix Ib). This weighted average is assumed to be representative of the age structure for both the catch and escapement for that year. When age structure data is absent in a particular year, the overall average (for all years) in that area is used (appendix Ic). Coho and pink are assumed to recruit exclusively at age 3 and 2 respectively.

Without accurate age structure data, it is apparent that strong year classes may be assigned incorrectly to several brood years, especially for chinook. To examine this problem, the autocorrelation patterns in residuals from the stock-recruitment regression (Ricker model) were plotted (Appendix II). Significant correlations at any lag indicates the presence of aging errors, or biological processes (e.g. cycles) that may invalidate the stationarity assumption of stock-recruitment analysis used in this study.

A stochastic process is said to display stationarity when its properties are not affected by a change of time or origin so that the joint probability distribution of any set of observations, $z_{t_1} \cdots z_{t_m}$, is unaffected by shifting the time of observation forward or backward by any amount of time, k. The nature of this joint distribution can be inferred by the autocorrelation coefficient , ρ_k , at lag k (Box and Jenkins 1970 p. 27):

$$\rho_k = \frac{E[(z_t - u)(z_{t+k} - u)]}{\{E[(z_t - u)^2]\, E[(z_{t+k} - u)^2]\}^{1/2}} = \frac{E[(z_t - u)(z_{t+k} - u)]}{\sigma_z^2} \qquad (2.4.8)$$

A stronger definition of stationarity can be applied in analysing residuals from model predictions. Estimates of autocorrelation coefficients for residuals from a stock-recruitment regression , u_t , at any lag k can be calculated as (from Jekins and Watts 1969, p.182):

$$r_{uu}(k) = \frac{\sum_{t=1}^{n-k} (u_t - \bar{u}_1)(u_{t+k} - \bar{u}_2)}{\left[\sum_{t=1}^{n-k} (u_t - \bar{u}_1)^2 \left(\sum_{t=1}^{n-k} u_{t+k} - \bar{u}_2\right)^2\right]^{1/2}} \qquad (2.4.9)$$

Where $\bar{u}_1$, $\bar{u}_2$ are means of the first and last n-k observations respectively. If the form of the model is correct and the true model parameters are known, then the u's should be uncorrelated and the $r_k(u)$ autocorrelations should be distributed approximately normally about zero with variance $n^{-1/2}$. The statistical significance of apparent departure of these autocorrelations from zero can be assessed approximately by using $n^{-1/2}$ as the standard error for $r_k(u)$, but this method tends to underestimate the statistical significance at low lags (Box and Jenkins 1970, p.290).

2.5 Possible Sources of Error

Before presenting further analysis, it is appropiate to discuss some of the major sources of error that could have arise from the above data and analysis methods. All forms of measurement are more or less subject to error and these errors are sometimes very large, especially in commercial fisheries. Frequently these errors are recognized but are seldom explicitly stated, and the effects of them on the final results of analysis are seldom mentioned. Three major sources of error are found in this study: definiton of stock units, allocation of mixed catches to production areas, and spawning stock estimates. Ludwig and Walters (1981) used formal methods to deal with measurement errors caused by poor escapement counts. Hopefully more effort will be spent on dealing with the other types of error discussed below.

An obvious and immediate problem is that the management units we adopted may not be appropriate units for representing the reproductive dynamics of the populations concerned. To treat organisms that breed and rear in numerous different rivers, streams, tributaries and lakes as a homogenous mass would make most ecologists uncomfortable. However, so long as the fish are being caught in a common ground, compromises have to be made in deciding what constitutes an "appropiate" reproductive unit. By lumping "too large" an area as a unit, the dynamics of smaller production areas within the unit are often masked by that of the larger ones. On the other hand, biased estimates are obtained when using "too small" an area as a unit due to the increasing chance of error in separating the mixed catches into smaller units. Undoubtedly, some of our defined "stocks" may reasonably be broken down into finer units while some "stocks" should have been lumped into a single assessment unit because of their pecularities of migration, run timing or exploitation patterns.

It is acceptable to view any large unit as having some statistical dynamics across the variable reproductive subunits comprising it, and to hypothesize that this statistical behavior will resemble the dynamics of a single unit stock. However, as Ricker (1973) noted, we should at least expect long term changes in the statistical parameters, due to persistent changes in the stock composition (loss of weak stocks). However, for B.C. stocks, such parameter changes may have taken place mostly before 1950, the earliest year used in this study.

Because of the lack of understanding of the migration routes, run timings and exploitation patterns of most stocks, two methods are used to allocate mixed catches back to their production units. The underlying assumptions of these methods were discussed above. To some extent, these assumptions must have been violated in most areas at least during some of the time period covered by this analysis.

Even if the methods of allocating mixed catches could be made more precise, the commercial catch figures do not necessarily represent the real catches from a given area. Modern vessel technology has led to rapid movement of the fishing fleet, and improved cold storage has lengthened the time of stay at sea. Highly mobile fishing gears have the capability of fishing in many of the defined management units in a single outing, while reporting landings only at a single location. Most important is the systematic bias or trend introduced this way by rapid improvement of fishing technology in the past decade.

It is well recognized that errors of different forms and sizes accompany most spawning stock assessment data (spawning counts, age structures, etc.). Depending on the methods used, the reporting system and the manpower involved, these errors are sometimes very large and often they cannot be evaluated due to poor reporting of the methods used. For example, the fishery officers' recording procedure alone (by wide abundance classes) would introduce +- 30% error in spawning counts. Systematic bias of these estimates over time due to technological improvement and/or increased involvement may have had serious consequences, and there has been little instruction for field staff to recognize or correct for these changes.

More important, the presence of one or more of the above errors does not simply make the stock-recruitment relationship noiser and harder to define; rather it biases the apparent relationship, leading to more liberal regulations when in fact very stringent measures of conservation should have been in effect (as shown in the next chapter). Because of the diversity of possible sources of error in the data for different stocks, appendix II lists these major sources on a stock by stock basis, together with other important statistics related to the stock-recruitment dynamics.

3. ESTIMATION OF STOCK-RECRUITMENT RELATIONSHIPS

The importance of stock-recruitment relationships in connection with the successful management of salmon resources has been widely discussed. Larkin (1973) described several types of models that can be used for interpreting these relationships. Depending on the assumptions used, many possible stock-recruitment models can certainly be developed (see Parrish (ed.) 1973). Frequently, identical models can be derived with different assumptions, and the addition of simple plausible biological assumptions can dramatically increase the complexity of models and hence the data requirements. The available records for most B.C. stocks hardly satisfy the data demands for any but the simplest models, but even these should be helpful in the interpretation of historical stock-recruitment dynamics. Obviously as more information becomes available, more complex models should be used to provide a better understanding of the population dynamics of the stocks concerned.

Because of the inherent variability of salmon populations and inaccurate stock assessment methods, it often happens that a set of stock-recruitment data is consistent with more than one model. This can lead to serious problems if the different models imply significantly different management actions. Scientists can only find and describe these models, and management actions should be based on balancing possible outcomes without pretending that any single model is the best choice. The manager should examine possible strategies in light of various plausible models rather than selecting only one and using it as a basis for management (Walters 1977, Walters 1981).

For this study only two simple, two parameter stock-recruitment models were used for most analyses. The first, a Ricker model, assumes a dome-shaped relationship between stock and recruitment, so it admits that large spawning stocks may result in poor returns. The second, a Beverton-Holt model, assumes that recruitment increases to a maximum biological limit as spawning stock increases, but does not collapse if very large spawning stocks are allowed. A third, three parameter model developed by Ludwig (pers. Comm.) was also fitted to some data sets. The Ludwig model allows for the possibility of reduced productivity at low stock sizes due to depensatory mortality agents. However, it generally gave results equivalent to the Ricker model (insignificant depensation), so results for it will not be presented below.

Designing fishery strategies from these models would be very misleading if measurement errors and the range of observations are not taken into account in the analysis. Walters and Ludwig (1980) showed that moderate error in escapement measurements can make recruitments appear to be independent of spawning stocks, which promotes overexploitation rather than simply saying that the relationship does not exist. Further, the observed exploitation history also can have profound effects on the performance of any statistical procedure. Hilborn (1979) showed that estimation performance is generally much poorer when data are available only after the stock becomes heavily exploited, than when data are also available from the early development of the fishery. Dramatic decrease in long-term catches can result with certain combinations of these two factors (see simulation study in Walters and Ludwig,1980)

This chapter first focusses on traditional model-fitting and parameter estimation, then turns to the examination of various measurement errors and their effects on the performance of estimation procedures. It concludes with an examination of apparent patterns in stock-recruitment parameters among species and geographic areas.

3.1 Model Fitting Procedures

Many models can be fitted using multiple linear regression analysis after they are transformed into linear forms. These methods are described in many statistics books and are not repeated here. However, when no transformation will convert an equation into a form that can be handled this way, iterative methods are commonly used to estimate the parameters.

Since the arrival of computers, many iterative methods of parameter estimation have been developed (see Bard 1974). In principle, these are trial-and-error methods so that the prediction residuals left after each iteration show us how to improve the next try. A simple method described by Watt (1968) is:

let

$$f(X,\beta) = f(x_1, x_2, \cdots x_n ; \beta_1, \beta_2 \cdots \beta_k) \qquad (3.1.1)$$

be the model to be fitted to data, where X's are independent variables and β's are parameters to be estimated. Suppose we can obtain estimates, $\underline{b}$, for the true parameters, $\underline{\beta}$. Then we can correct the $\underline{b}$ iteratively by incremental amounts, $\underline{\delta}$,until no significant improvement can be made. That is

$$\hat{\underline{\beta}} = \underline{b} + \underline{\delta} \qquad (3.1.2)$$

the vector $\underline{\delta}_l$ at iteration l can be obtained by

$$\underline{\delta}_l = (X^T X)^{-1} g \qquad (3.1.3)$$

where

$$X^{(n \times k)} = \frac{\partial f_i}{\partial \beta_j} \qquad \begin{cases} i = 1, 2, \cdots n \\ j = 1, 2, \cdots k \end{cases}$$

$$g = \left[\sum_{i=1}^{n} (y_i - f_i) \frac{\partial f_i}{\partial \beta_j} \right] = X^T \left[Y - f(x, \beta_0) \right]$$

3.1.1 <u>Ricker Model</u>

The most commonly used model in salmon research and management is that developed by Ricker (1954), which can be written in various ways. The following form is used in this analysis:

$$R_{t+1} = S_t e^{\alpha + \beta + u_{t+1}} \qquad (3.1.4)$$

where S_t is spawners at generation t, R_{t+1} is recruits resulting from S_t , α is a productivity parameter, β is an equilibrium stock parameter and u_{t+1} is a random environmental factor, normally distributed with mean 0.0 and variance σ_u^2 .

This model can be transformed into a simple linear regression form (Dahlberg 1973, Ricker 1975) as:

$$\ln\left(\frac{R_{t+1}}{S_t}\right) = \alpha + \beta S_t + u_{t+1} \qquad (3.1.5)$$

With $y = \ln(R/S)$ and $x = S$, standard regression analysis can be used to estimate α, β and σ_u^2.

3.1.2 Beverton and Holt Model

An alternative model to Ricker's is that developed by Beverton and Holt (1957) :

$$R_{t+1} = \frac{a S_t e^{u_{t+1}}}{b + S_t} \qquad (3.1.6)$$

where R_{t+1}, S_t and u_{t+1} are the same as in (3.1.5), a and b are new parameters with a/b measuring productivity and a measuring the equilibrium stock size.

The multiplicative, log-normal noise term ,exp(u_{t+1}), has been justified by Allen (1973), Walters and Hilborn (1976), and Peterman (1978). Since no transformation can convert (3.1.6) into a linear form, iterative methods (3.1.2 to 3.1.3) are used to estimate the parameters. The procedure is as follows.

From (3.1.6), we have

$$\frac{R_{t+1}}{S_t} = \frac{a e^{u_{t+1}}}{b + S_t}$$

So, $\ln\left(\frac{R_{t+1}}{S_t}\right) = \ln a - \ln(b + S_t) + u_{t+1}$

Let a'=ln a, then

$$\ln\left(\frac{R_{t+1}}{S_t}\right) = a' - \ln(b + S_t) + u_{t+1} \qquad (3.1.7)$$

The specific form of (3.1.1) in this case is :

$$y_i = \ln \frac{R_{t+1}}{S_t} = \beta_1 - \ln(\beta_2 + X_i) + u_i \qquad (3.1.8)$$

The vector of trial parameter values, $\underline{b}$, is obtained from a linear transformation of (3.1.6), ignoring $e^{u_{t+1}}$:

$$\frac{1}{R_{t+1}} = \frac{b + S_t}{a S_t} + \frac{1}{u_{t+1}}$$

$$\frac{1}{R_{t+1}} = \frac{b}{a}\left(\frac{1}{S_t}\right) + \frac{1}{a} + \frac{1}{u_{t+1}} \qquad (3.1.9)$$

Regression of y=1/R on x=1/S yields the trial parameter vector, $\underline{b}$. The correction vector, $\underline{\delta}$, at iteration l is computed from (3.1.3), using:

$$X^{(n\times 2)} = \frac{\partial f_i}{\partial b_j} \qquad \begin{cases} i = 1, 2, \cdots n \\ j = 1, 2 \end{cases}$$

$$= \begin{bmatrix} 1 & -\frac{1}{b+S_1} \\ \vdots & \vdots \\ 1 & -\frac{1}{b+S_n} \end{bmatrix} \qquad (3.1.10)$$

$$g_l = \left[\sum_{i=1}^{n} (Y_i - f_i)\frac{\partial f_i}{\partial b_j}\right] = X^T(y_i - f_i)$$

$$= X^T \begin{bmatrix} y_1 - \hat{y}_1 \\ \vdots \\ y_n - \hat{y}_n \end{bmatrix} \qquad \begin{cases} \hat{y}_i = \hat{a}_l - \ln(\hat{b}_l - S_i) \\ y_i = \ln(R_{t+1}/S_t) \\ i = 1, 2, \cdots n \end{cases}$$

3.1.3 Power model

When a stock is heavily fished, and if data are collected with little error since the beginning of the fishery, the recruitment points will obviously be distributed over a wide range of spawning populations. Then, the maximum likelihood curve that fits through the data points can be regarded as representative of the stock-recruitment dynamics of the population. Most British Columbia salmon stocks have been exploited heavily since the beginning of this century (MacLeod 1977). Unfortunately, quantitative data were collected (with considerable error) only since 1948. Therefore, it seems likely that none of the data sets used in this analysis represent the full range of a stock-recruitment curve. Rather, a limited portion, especially the left-hand limb of the curve is exhibited. In this case, a simple Power model may describe the data better than the Ricker or Beverton-Holt models. The Power model is

$$R_{t+1} = S_t^{\beta} e^{(\alpha + u_{t+1})} \qquad (3.1.11)$$

where R_{t+1}, S_t, α and u_{t+1} are the same as in the Ricker model (3.1.4), while β is an index of density dependence (Cushing 1971). Equation (3.2.1) cannot be used to fit a fully dome shaped curve, but can be used to fit a left-hand limb or a right-hand limb. Also, a lightly convex curve can be reasonably fitted.

Another advantage of the Power model is that its β parameter varies predictably (downward) with increasing errors in spawning stock measurement. The procedure developed by Ludwig and Walters (see below) can be easily used to estimate the parameter values of this model. By assuming every stock has experienced comparable degrees of exploitation, the index of density dependence, β, can be compared within species and among species for various assumptions about the magnitude of the spawn measurement errors.

3.2 Corrections for Measurement Errors

Measurement errors enter the Ricker model (3.1.4) in the following way. First, it is reasonable to assume that measurement errors are proportional rather than additive. Let r_t and s_t be the observed values, then a simple representation of proportional error is

$$r_t = R_t e^{\varepsilon_1}$$
$$s_t = S_t e^{\varepsilon_2} \qquad (3.3.1)$$

where ε_1 and ε_2 are independent random variables, which Ludwig and Walters (1981) assume are normally distributed with mean 0.0 and variance $\sigma^2_{\varepsilon_1}$ and $\sigma^2_{\varepsilon_2}$ respectively.

Equations (3.1.4) and (3.2.1) imply that

$$r_{t+1} e^{-\varepsilon_1} = s_t e^{-\varepsilon_2} e^{(\alpha + \beta s_t e^{-\varepsilon_2} + u_{t+1})} \qquad (3.3.2)$$

or,

$$\ln\left(\frac{r_{t+1}}{s_t}\right) = \alpha + \beta s_t e^{\varepsilon_2} + \omega - \varepsilon_2$$

where $\omega = u_{t+1} + \varepsilon_1$. If the spawning count error, ε_2, is small, then standard regression statistics still apply.

Equation (3.2.2) suggests that random measurement errors in the recruits, R_{t+1}, increase the variance of the model while sampling errors in the spawners, S_t, bias the parameters. Since the spawning population at generation j is also part of the recruits produced from generation j-1, measurement errors in the spawning counts not only bias the parameters, but also increase the variance of the model.

To illustrate these effects, Walters and Ludwig (1981) used a simulation model to generate "actual" data from the equation

$$R_{t+1} = S_t e^{\alpha + u_{t+1}} \qquad (3.3.3)$$

where S_t is the spawning stock at generation t, R_{t+1} is the resulting recruits from S_t, α is the production parameter and u_{t+1} is the random environment factor, normally distributed with mean 0.0 and variance σ^2_u. This model population was always over-exploited, that is, each additional fish allowed to spawn would produce, on average, at least as many recruits as each spawner already allowed. The population size was regulated by fishing to achieve a fixed escapement goal which was subjected to a random deviation of about 45%. Walters and Ludwig (1981) "sampled" from these model dynamics using equation (3.3.1), and showed that the apparent recruitment relationship can be saturating or dome shaped.

To see the comparative effects of spawning count errors and catch statistics errors on the final appearance of the stock-recruitment data, I used the same model, but generate two sets of "observed" data. In the first case, measurement errors occured in the catch only as:

$$r_t = S_t + R_t h_t e^{r_t} \qquad (3.3.4)$$

where r_t is the observed recruitment, S_t is the actual escapement, R_t is the actual recruitment, h_t is the harvest rate and v_t is a normally distributed random variable with mean 0.0 and variance σ^2_v. The second set of "observed" data was generated from the identical set of "actual" data but with the multiplicative error term, e^{v_t} , occurring in the spawning count only :

$$s_t = S_t e^{v_t} \qquad (3.3.5)$$

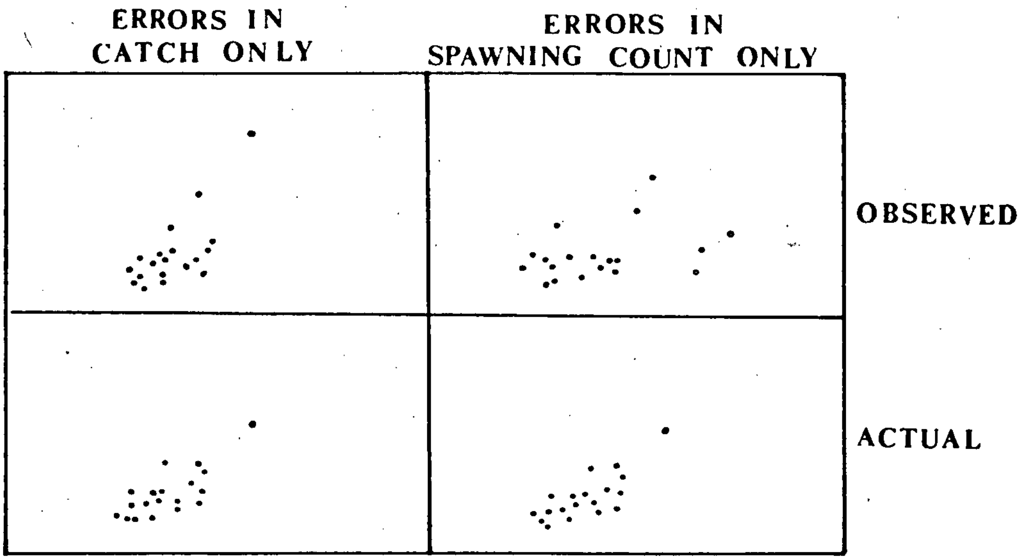
where s_t is the observed spawners, S_t is the actual spawners and v_t is the same as in (3.2.4). Observed recruitment was then calculated as:

$$r_t = s_t + R_t h_t \qquad (3.3.6)$$

Figure 4 shows "actual" and "observed" stock-recruitment data for a simulation case with σ^2_v =0.1 and σ^2_u =0.1 . Random measurement error occuring in the catch only did not have much effect on the functional form of the relationship but the same relative errors in the spawning count made recruitment appear to be independent of spawners.

More simulation cases were examined with σ^2_v ranging from 0.01 to 0.5 . In general, random measurement errors in the spawning stock seemed to have bigger impacts on the stock-recruitment data than comparable errors in the catch. Visual distortion of the "actual" data occured when spawning count errors exceeded about +-45% (σ^2_v=.05). Whereas, significant distortion did not occur until measurement errors in the catch exceeded σ^2_v =.4 (95% limits are .29 C_t and 3.45 C_t). Hastily, one might conclude that errors in the catch seldom have any significant effect on the stock-recruitment relationship because errors of these magnitudes (off by a factor of 2 to 3.5) seldom occur in real catch statistics. However, relatively small nonrandom (biased) errors in the allocation of mixed catches do

Fig. 4. "Acutal" and "observed" stock-recruitment data points with comparable measurement errors in the catch and escapement respectively.


ERRORS IN
CATCH ONLY
ERRORS IN
SPAWNING COUNT ONLY
OBSERVED
ACTUAL

have significant impacts on the stock-recruitment relationship, as shown in the previous chapter.

3.2.1 Correction for Spawning Count Errors

It has been shown that the typical sampling errors in spawning counts (+-50% or more) obliterate the stock-recruitment relationship. Walters and Ludwig (1981) concluded that most spawner and recruitment estimates are of little value unless the accuracy of the estimates is also assessed. If we assume that actual recruitment, R_t, and actual spawners, S_t, are subject to the same relative error, exp(V), (3.3.1) becomes:

$$r_t = R_t e^{v_t}$$
$$s_t = S_t e^{v_t} \qquad (3.3.7)$$

where r_t and s_t are the observed values and v_t are normally distributed independent random variables with mean 0.0 and variance σ_v^2 . Then the Ricker model (3.1.4) becomes

$$r_{t+1} e^{-v_{t+1}} = s_t e^{-v_{t+1}} e^{(\alpha + \beta s_t e^{-v_t} + u_{t+1})}$$

or

$$y_t = a + b s_t + w_{t+1} - v_t \qquad (3.3.8)$$

where $w_t = u_t + v_t$ and $y_t = ln(r_t / s_{t+1})$

If the variance of observation errors, σ_v^2 , is known then consistent estimates of a and b can be obtained (from Walters and Ludwig 1981):

$$\bar{y} = a^* + b^* \bar{s}/B \qquad (3.3.9)$$

$$b^* = \frac{(C_{sy} - \bar{s}\sigma_v^2)B^3}{C_{ss} - \bar{s}^2(B^2-1)} \qquad (3.3.10)$$

where a^* is a consistent estimate of α, b^* is a consistent estimate of β, B is a bias correction factor equal to $\exp(\frac{1}{2}\sigma_v^2)$, C_{sy} is the corrected sum of products and C_{ss} is the corrected sum of squares of S's

However the estimation of σ_v^2 requires large independent data sets which usually do not exist. Another approach is to base all the statistical inference upon the likelihood of the given observations, as a function of the parameters to be estimated. The logarithm of the likelihood of the observations is given by (Ludwig and Walters 1980):

$$L(\alpha,\beta,\sigma_u^2, v_1, \ldots, v_n) = -\frac{1}{2\sigma_u^2}\left[\sum_{i=1}^{n} \mu_i^2 + \frac{1}{\lambda} v_i\right]^2 - n \ln \sigma_u^2 - (n+1) \ln(\lambda \sigma_u) \qquad (3.3.11)$$

where λ must be prescribed as $\lambda = \sigma_v^2/\sigma_u^2$ and $\mu_1, \ldots, \mu_n$ are determined from (3.3.8) where

$$\mu_t = \alpha + \beta S_{t-1} e^{-V_{t-1}} - \ln(v_t/S_{t-1}) - V_{t-1} + \mu_t$$

All the parameters, except σ_u^2, can be estimated by maximizing L and σ_u^2 can be estimated from the residual sum of squares as

$$\sigma_u^2 = \frac{1}{2n+1-(n+3)}\left[\sum_{i=1}^{n} \hat{\mu}_i^2 + \frac{1}{\lambda}\sum_{i=0}^{n} \hat{v}_i^2\right] \qquad (3.3.12)$$

where $\hat{\mu}_i$, and $\hat{v}_i$ are the estimated values which maximize L.

A computer program (Ludwig, per.comm.) which follows the estimation precedure presented by Ludwig and Walters was used to estimate the parameter values of the Ricker and Power model. Since the error ratio, λ , was not known, a range of values between $0 \leq \lambda \leq 2$ were prescribed to each stock and the corresponding parameters were estimated.

3.3 RESULTS

3.3.1 Stock Recruitment Parameter Estimates

Tables 17 to 19 show parameter estimates for the Ricker, Beverton-Holt and Power models respectively without considering measurement errors. The raw stock-recruitment data are presented graphically in appendix II, along with summary assessments based on visual inspection of the data. In the analysis, every data point is given equal weight regardless of its credibility. Obviously a more thorough analysis would include a weighting factor for each data point to reflect its relative accuracy (i.e. for example, in 1958 one million sockeye spawners were excluded from the Adams river with a temporary fence, and therefore this data point should be given less weight in the stock-recruitment analysis). Unfortunately, estimation of weights would involve tremendous amounts of effort to review every piece of historical information, and was beyond the time and manpower constraints of this study.

Back calculation and allocation table methods were used to separate mixed catches back to their production units. Figures 5a and 5b compare the Ricker model α , environmental variance and equilibrium stock parameters obtained by these two methods.

Tables 17-19. Ricker, Power and Beverton-Holt model parameters, estimated by maximum likelihood while ignoring spawning count errors.

* = estimation procedure failed

- = insufficient information or negligible stock

SIG2 = σ_u^2

TABLE 17. RICKER MODEL PARAMETERS

SOCKEYE

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	1.608	-4.82E-06	0.172	11	1.590	-3.62E-06	0.269	11
4	1.163	-7.00E-07	0.260	27	1.012	-5.90E-07	0.292	27
5	1.248	-2.23E-06	0.128	27	1.381	-2.77E-06	0.108	27
6	1.998	-1.93E-06	0.410	27	1.895	-1.85E-06	0.508	27
7	1.463	-1.45E-05	0.447	21	1.922	-1.31E-05	0.432	21
8	-	-	-	-	-	-	-	-
9	2.098	-4.40E-07	0.160	21	2.035	-4.30E-07	0.163	21
10	-	-	-	-	-	-	-	-
11	0.808	-2.38E-06	0.433	21	0.978	-1.65E-06	0.542	21
12	-	-	-	-	-	-	-	-

COHO

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	2.269	-2.47E-05	0.160	20	2.259	-2.21E-05	0.304	19
2	1.516	-1.03E-05	0.226	20	1.258	-8.37E-06	0.122	19
3	2.235	-3.31E-05	0.507	20	2.499	-3.48E-05	0.292	19
4	1.277	-9.05E-06	0.293	20	1.892	-1.18E-05	0.248	19
5	1.968	-4.04E-06	0.277	20	2.432	-5.78E-06	0.250	19
6	2.624	-1.23E-04	0.435	20	3.979	-8.74E-05	0.469	19
7	1.869	-5.65E-06	0.389	20	2.664	-8.17E-06	0.133	19
8	2.637	-3.73E-06	0.257	20	2.011	-3.68E-06	0.134	19
9	2.734	-9.55E-06	0.324	20	2.930	-1.57E-05	0.118	19
10	-	-	-	-	-	-	-	-
11	1.595	-6.81E-06	0.220	20	1.406	-5.73E-06	0.161	19
12	1.965	-2.32E-05	0.239	20	2.146	-2.28E-05	0.337	19

CHUM

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	1.836	-2.04E-05	0.336	27	1.623	-1.95E-05	0.485	26
2	1.294	-2.24E-06	0.238	27	1.238	-2.18E-06	0.348	27
3	2.353	-2.16E-05	0.327	27	2.434	-2.13E-05	0.433	27
4	-	-	-	-	-	-	-	-
5	1.205	-7.60E-07	0.244	27	1.178	-7.70E-07	0.252	27
6	-	-	-	-	-	-	-	-
7	0.872	-2.77E-06	0.461	15	1.088	-2.76E-06	0.570	15
8	1.016	-9.70E-07	0.305	15	0.985	-1.03E-06	0.297	15
9	0.579	+4.10E-07	0.230	15	0.566	+3.50E-06	0.226	15
10	-	-	-	-	-	-	-	-
11	0.661	-1.04E-06	0.358	27	0.661	1.04E-06	0.358	27
12	1.388	-5.50E-06	0.323	27	1.388	-5.50E-06	0.323	27

SPRING

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	1.614	-8.11E-05	0.198	12	2.051	-8.41E-05	0.145	11
4	1.130	-3.18E-05	0.024	12	1.251	-2.33E-05	0.048	11
5	0.884	-1.65E-05	0.038	12	1.651	-2.06E-05	0.032	11
6	2.145	-2.51E-04	0.042	12	3.086	-2.25E-04	0.097	11
7	1.651	-3.85E-05	0.054	12	2.179	-4.15E-05	0.077	11
8	1.443	-2.22E-05	0.036	12	1.686	-1.97E-05	0.034	11
9	3.089	-9.26E-06	0.015	12	2.516	-5.03E-06	0.014	11
10	-	-	-	-	-	-	-	-
11	2.200	-7.15E-05	0.080	12	2.475	-9.00E-05	0.126	11
12	1.182	-6.65E-05	0.036	12	1.370	-6.98E-05	0.084	11

ODD PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	2.648	-1.06E-05	0.352	15	2.902	-1.02E-05	0.554	15
4	1.573	-8.40E-07	0.179	15	1.488	-8.70E-07	0.233	15
5	1.120	-2.20E-07	0.294	15	1.058	-1.50E-07	0.370	15
6	-	-	-	-	-	-	-	-
7	1.159	-1.34E-06	0.680	11	1.599	-1.30E-06	0.700	11
8	0.204	-1.20E-06	0.490	11	1.443	-1.76E-06	0.461	11
9	2.613	-6.50E-07	0.366	11	2.359	-5.80E-07	0.428	11
10	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-

EVEN PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	0.578	-8.70E-07	0.372	15	0.986	-9.50E-07	0.692	14
2	1.494	-1.20E-06	0.235	15	1.371	-1.01E-06	0.448	15
3	2.079	-4.46E-06	0.558	15	1.877	-2.60E-06	0.936	15
4	1.724	-1.08E-06	0.298	15	1.505	-1.03E-06	0.329	15
5	1.632	-1.50E-07	0.384	15	1.580	-1.40E-07	0.401	15
6	3.093	-7.61E-06	1.237	15	2.311	-5.38E-06	1.219	15
7	1.437	-4.90E-07	0.484	15	1.437	-4.90E-07	0.484	15
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	1.349	-2.18E-05	0.964	13	1.349	-2.18E-05	0.964	13
12	1.393	-4.36E-06	0.714	15	1.393	-4.36E-06	0.714	15

TABLE 18. POWER MODEL PARAMETERS

SOCKEYE

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	10.314	0.2042	0.165	11	8.297	0.3883	0.262	11
4	4.163	0.7406	0.270	27	3.353	0.7958	0.300	27
5	6.955	0.4927	0.115	27	7.833	0.4226	0.097	27
6	10.957	0.2343	0.389	27	10.573	0.2589	0.484	27
7	16.048	-0.4024	0.432	21	15.446	-0.2963	0.403	21
8	-	-	-	-	-	-	-	-
9	9.539	0.4245	0.175	21	9.223	0.4440	0.177	21
10	-	-	-	-	-	-	-	-
11	6.734	0.4658	0.399	21	6.089	0.5437	0.511	21
12	-	-	-	-	-	-	-	-

COHO

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	11.456	0.0027	0.202	20	8.668	0.2931	0.300	19
2	7.672	0.3777	0.223	20	5.934	0.5238	0.127	19
3	10.806	0.0487	0.393	20	10.601	0.0898	0.283	19
4	7.635	0.3667	0.286	20	10.920	0.1082	0.213	19
5	10.628	0.2195	0.263	20	13.688	-0.0228	0.254	19
6	8.997	0.1495	0.231	20	8.848	0.3553	0.305	19
7	8.223	0.3936	0.373	20	10.968	0.2003	0.129	19
8	9.703	0.3565	0.260	20	9.278	0.3406	0.132	19
9	9.563	0.3233	0.330	20	15.646	-0.2467	0.095	19
10	-	-	-	-	-	-	-	-
11	7.278	0.4440	0.224	20	6.484	0.5069	0.160	19
12	11.190	0.0303	0.206	20	11.423	0.0280	0.304	19

CHUM

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	11.165	0.0077	0.283	27	10.495	0.0546	0.444	26
2	10.546	0.2004	0.203	27	9.485	0.2816	0.364	27
3	12.779	-0.0772	0.326	27	12.704	-0.0613	0.433	27
4	-	-	-	-	-	-	-	-
5	6.400	0.5727	0.242	27	6.381	0.5718	0.250	27
6	-	-	-	-	-	-	-	-
7	9.503	0.2403	0.405	15	9.716	0.2408	0.514	15
8	6.873	0.5119	0.297	15	7.198	0.4822	0.289	15
9	-1.281	1.1584	0.230	15	-1.010	1.1343	0.226	15
10	-	-	-	-	-	-	-	-
11	4.060	0.7023	0.351	27	4.060	0.7023	0.351	27
12	12.681	-0.0207	0.346	27	12.681	-0.0207	0.346	27

SPRING

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	9.262	0.0576	0.236	12	11.057	-0.0865	0.176	11
4	8.979	0.1448	0.027	12	6.855	0.3878	0.050	11
5	7.842	0.2774	0.034	12	10.363	0.0957	0.021	11
6	9.511	-0.0379	0.020	12	9.848	0.0503	0.037	11
7	12.092	-0.1313	0.031	12	13.208	-0.1978	0.055	11
8	9.397	0.1604	0.039	12	9.468	0.1876	0.039	11
9	8.375	0.4677	0.014	12	5.384	0.7113	0.014	11
10	-	-	-	-	-	-	-	-
11	12.038	-0.1369	0.016	12	14.788	-0.4239	0.125	11
12	8.824	0.0914	0.033	12	9.767	0.0068	0.071	11

ODD PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	13.299	-0.0451	0.248	15	12.893	0.0178	0.486	15
4	11.039	0.2467	0.144	15	11.247	0.2231	0.197	15
5	4.425	0.7481	0.294	15	3.453	0.8139	0.368	15
6	-	-	-	-	-	-	-	-
7	9.525	0.2938	0.627	11	9.879	0.3025	0.600	11
8	3.820	0.6730	0.590	11	7.400	0.4673	0.621	11
9	17.947	-0.1484	0.349	11	16.115	-0.0300	0.413	11
10	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-

EVEN PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	11.297	0.128	0.409	15	7.633	0.4474	0.657	14
2	11.219	0.2083	0.212	15	10.005	0.3006	0.418	15
3	9.391	0.3211	0.532	15	6.092	0.6084	0.928	15
4	11.405	0.2109	0.349	15	10.997	0.2281	0.360	15
5	4.656	0.7668	0.426	15	4.287	0.7904	0.439	15
6	11.045	0.2026	0.884	15	8.648	0.3711	0.909	15
7	6.082	0.6251	0.481	15	6.082	0.6251	0.481	15
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	3.322	0.7437	0.900	13	3.322	0.7437	0.900	13
12	7.753	0.3887	0.669	15	7.753	0.3887	0.669	15

TABLE 19. BEVERTON-HOLT MODEL PARAMETERS

SOCKEYE

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	4.24E+05	3.30E+04	0.150	11	6.72E+05	9.14E+04	0.239	11
4	3.47E+06	1.09E+06	0.254	27	3.87E+06	1.43E+06	0.283	27
5	7.72E+05	1.56E+05	0.117	27	6.91E+05	1.12E+05	0.097	27
6	1.46E+06	8.51E+04	0.371	27	1.40E+06	9.53E+04	0.464	27
7	*	*	*	21	*	*	*	21
8	-	-	-	-	-	-	-	-
9	9.46E+07	8.70E+05	0.163	21	9.42E+06	9.49E+05	0.165	21
10	-	-	-	-	-	-	-	-
11	3.53E+05	9.25E+04	0.394	21	5.92E+05	1.53E+05	0.504	21
12	-	-	-	-	-	-	-	-

COHO

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	1.04E+05	1.39E+03	0.188	20	1.63E+05	9.08E+03	0.281	19
2	2.09E+05	2.90E+04	0.210	20	2.36E+05	5.40E+04	0.115	19
3	8.31E+04	5.76E+02	0.372	20	1.11E+05	2.11E+03	0.259	19
4	1.86E+05	3.30E+04	0.273	20	1.92E+05	2.81E+03	0.203	19
5	7.10E+05	3.56E+04	0.252	20	*	*	*	19
6	3.16E+04	2.97E+02	0.233	20	2.09E+05	1.60E+03	0.329	19
7	5.43E+05	5.21E+04	0.361	20	7.13E+05	2.04E+04	0.120	19
8	*	*	*	20	9.84E+05	8.42E+04	0.125	19
9	*	*	*	20	*	*	*	19
10	-	-	-		-	-	-	-
11	3.96E+05	6.24E+04	0.210	20	4.05E+05	8.03E+04	0.151	19
12	*	*	*	20	*	*	*	19

CHUM

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	8.27E+04	1.88E+03	0.263	27	7.20E+04	2.99E+03	0.408	26
2	5.69E+05	4.58E+04	0.193	27	6.16E+05	8.43E+04	0.340	27
3	*	*	*	27	*	*	*	27
4	-	-	-	-	-	-	-	-
5	2.66E+06	6.76E+05	0.233	27	2.57E+06	6.72E+05	0.241	27
6	-	-	-	-	-	-	-	-
7	3.18E+05	4.46E+04	0.382	15	3.95E+05	4.42E+04	0.483	15
8	1.63E+06	4.88E+05	0.283	15	1.42E+06	4.23E+05	0.275	15
9	*	*	*	22	*	*	*	*
10	-	-	-	-	-	-	-	-
11	1.30E+06	6.28E+05	0.344	27	1.30E+06	6.28E+05	0.344	27
12	2.64E+05	9.92E+03	0.331	27	2.64E+05	9.92E+03	0.331	27

SPRING

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	2.03E+04	1.27E+03	0.205	12	2.84E+04	3.62E+02	0.160	11
4	4.20E+04	5.49E+03	0.024	12	8.30E+04	1.79E+04	0.044	11
5	6.64E+04	1.45E+04	0.032	12	9.39E+04	2.76E+03	0.020	11
6	*	*	*	12	2.90E+04	6.00E+01	0.036	11
7	*	*	*	12	*	*	*	11
8	7.88E+04	7.34E+03	0.034	12	1.20E+05	1.02E+04	0.034	11
9	1.35E+06	4.85E+04	0.013	12	1.80E+06	1.37E+05	0.013	11
10	-	-	-	-	-	-	-	-
11	*	*	*	12	*	*	*	11
12	1.79E+04	1.28E+03	0.030	12	*	*	*	11

ODD PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	*	*	*	15	5.13E+05	3.09E+03	0.448	15
4	2.28E+06	1.92E+05	0.139	15	1.96E+06	1.60E+05	0.189	15
5	1.07E+07	3.03E+06	0.272	15	1.45E+07	4.89E+06	0.343	15
6	-	-	-	-	-	-	-	-
7	8.46E+05	1.20E+05	0.559	11	1.36E+06	1.22E+05	0.536	11
8	7.15E+05	5.86E+05	0.489	11	1.24E+06	2.63E+05	0.515	11
9		*	*	11	*	*	*	11
10	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-

EVEN PINK

	ALLOCATION TABLE				BACK CALCULATION			
AREA	A	B	SIG2	N	A	B	SIG2	N
1	5.49E+05	1.00E+05	0.363	15	1.21E+06	2.97E+05	0.621	15
2	1.43E+06	1.09E+05	0.201	15	1.62E+06	1.93E+05	0.395	15
3	7.66E+05	5.32E+04	0.502	15	1.56E+06	2.11E+05	0.866	15
4	2.07E+06	2.04E+05	0.311	15	1.74E+06	2.08E+05	0.326	15
5	*	*	*	15	*	*	*	15
6	6.02E+05	1.10E+03	0.886	15	4.89E+05	1.62E+04	0.988	15
7	5.32E+06	1.12E+06	0.448	15	5.32E+06	1.12E+06	0.448	15
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	9.60E+04	2.27E+04	0.874	13	9.60E+04	2.27E+04	0.874	13
12	3.37E+05	4.89E+04	0.624	15	3.37E+05	4.89E+04	0.624	15

Fig. 5a. Comparison of α and σ^2_{μ} estimates (Ricker model) obtained by back-calculation versus fixed allocation of mixed catches.

o—o—o fixed allocation

•---•---• back calculation

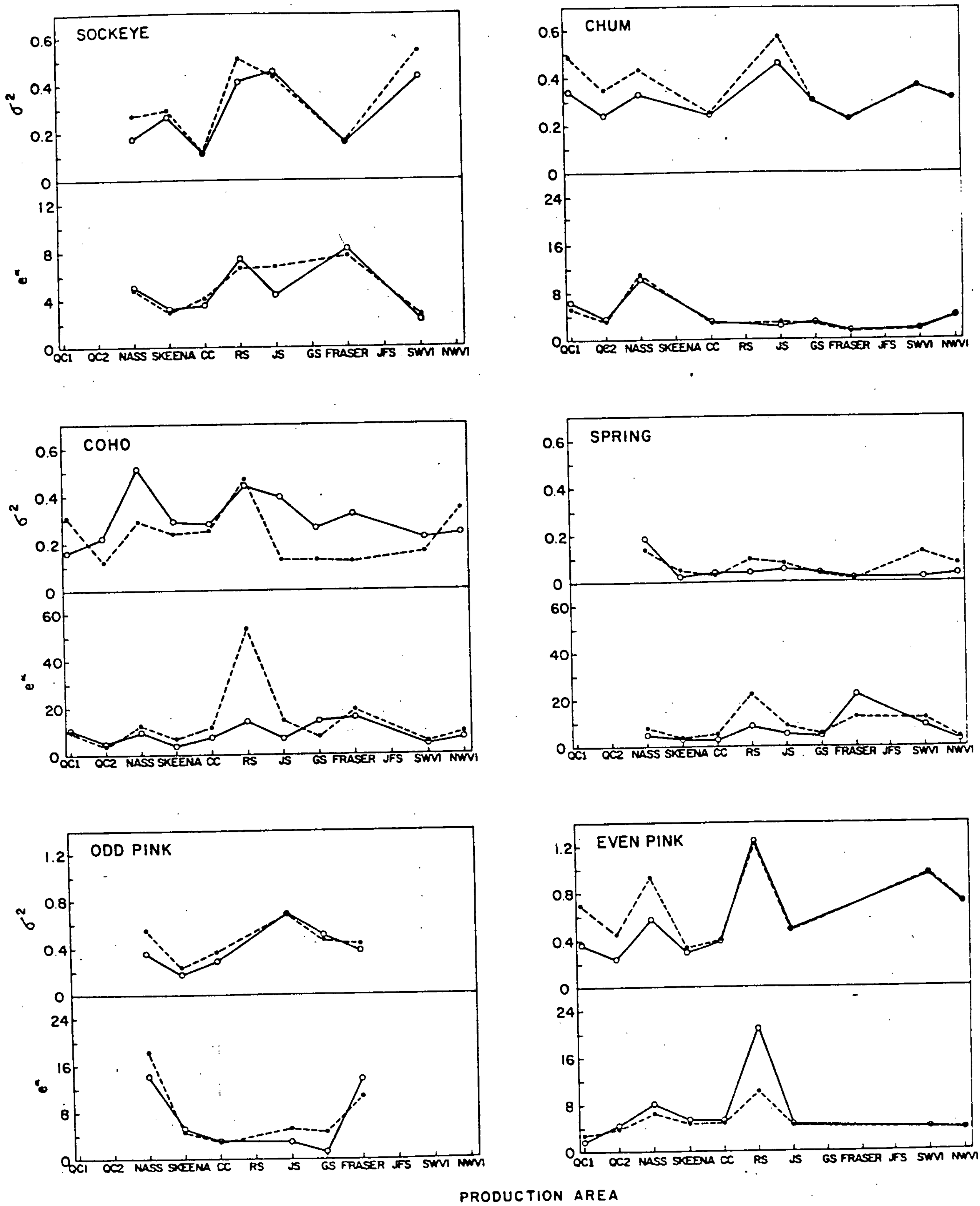
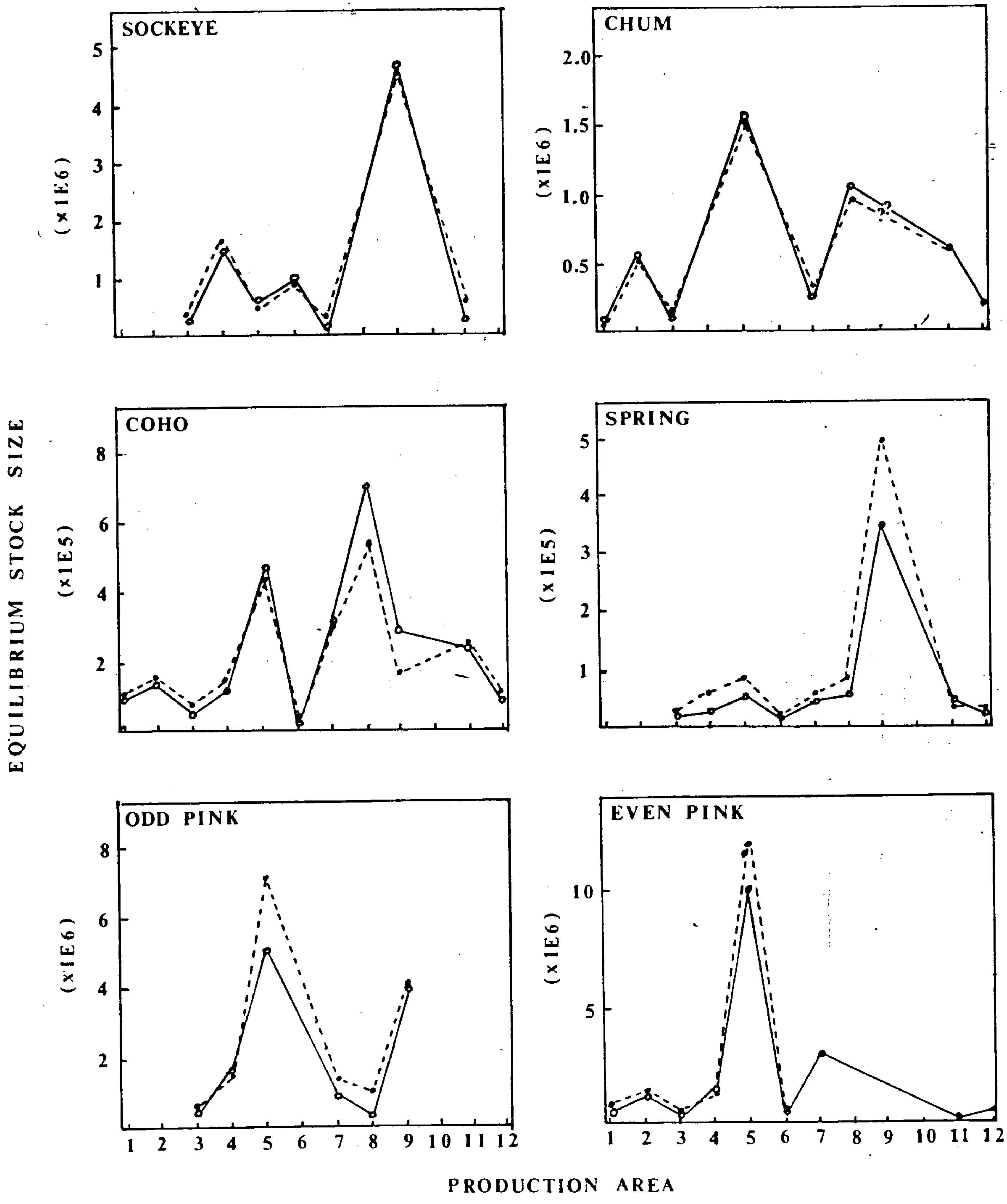

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
σ²
e^α
QC1 QC2 NASS SKEENA CC RS JS GS FRASER JFS SWVI NWVI
PRODUCTION AREA

Fig. 5b. Comparison of equilibrium stock sizes estimated by back-calculation versus fixed allocation of mixed catches.

o—o—o fixed allocation

•--•--• back calculation


SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
(x1E6)
(x1E5)
EQUILIBRIUM STOCK SIZE
1 2 3 4 5 6 7 8 9 10 11 12
PRODUCTION AREA

In general, the two data set result in similar parameter estimates. For sockeye, spring and odd year pink, no difference is detected in the variance. The back-calculated data tend to have higher variances for chum and even year pink, but lower variances for coho. The back-calculated data also estimated higher equilibrium stocks for spring and odd year pink. However, since simulation studies in the previous chapter showed the allocation table method tends to bias the parameters, only data sets based on back calculation were used for the following comparisons.

When a set of stock-recruitment data is consistent with more than one model, and different models have significantly different management implications, the manager is faced with a difficult decision problem. This problem is revealed in figures 6a and 6b which compares "environmental" variances, maximum recruits per spawner, and equilibrium stock sizes estimated by the Ricker and Beverton-Holt models for identical sets of stock-recruitment data. Statistically, the Beverton-Holt model fits the data sets better, in the sense that variances around it are consistently lower than for the Ricker model. It also consistently estimates higher maximum recruits per spawner and higher equilibrium stock sizes than the Ricker model. However, many of the parameter values estimated by the Beverton-Holt model are beyond those considered credible by most salmon biologists (e.g. recruits/spawner over 50 for some coho and spring stocks). Here, we are faced with a dilemma of poorer statistical fit on one hand and inconsistency with popular belief on the other. In most cases, the two models suggest

Fig. 6a. Comparison of maximum recruits per spawner and variance estimated by Ricker and Beverton-Holt models.

•···•···• Ricker model

o—o—o Beverton-Holt model

? estimation procedure failed for Beverton-Holt model

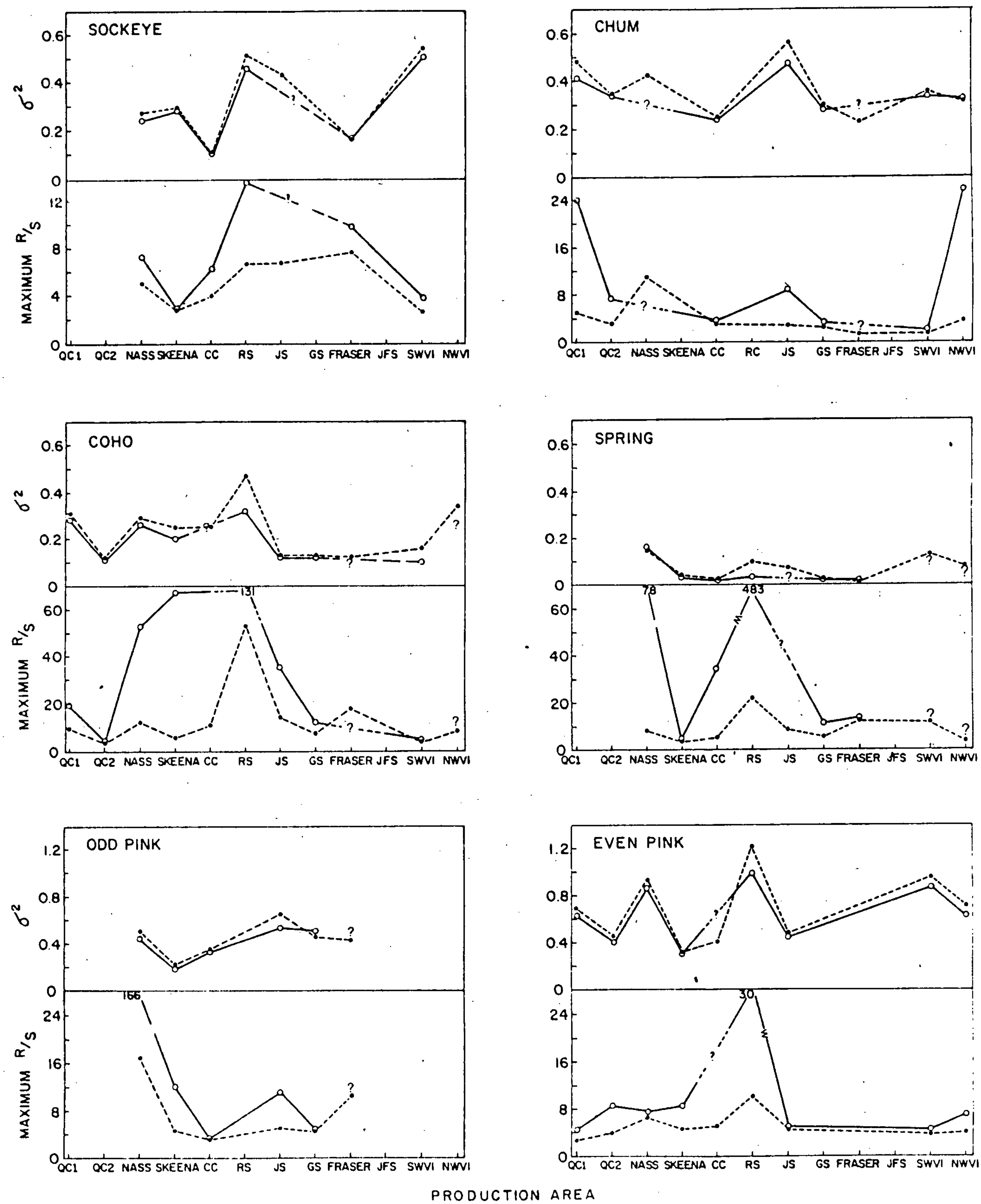
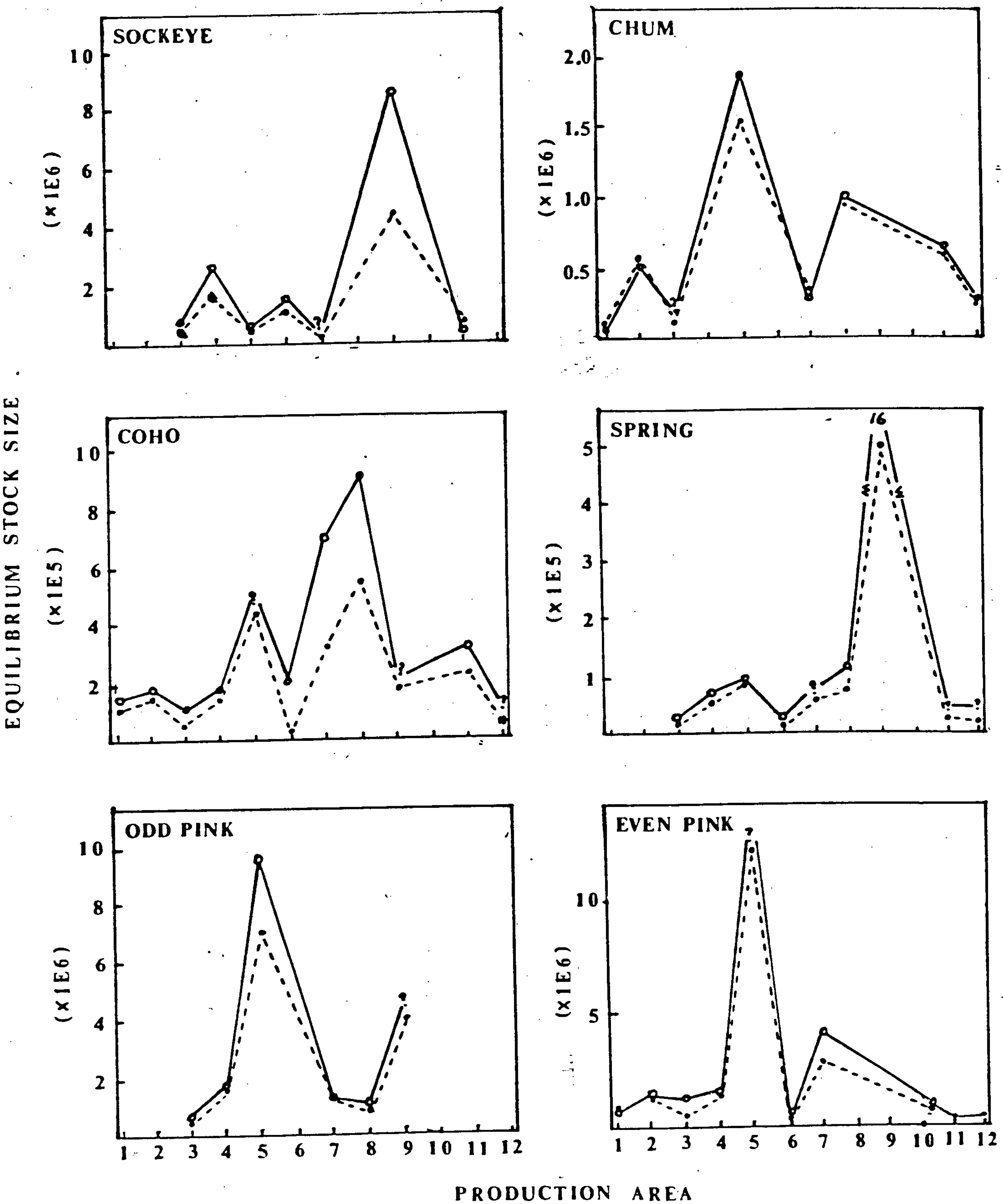

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
σ^2
MAXIMUM R/S
QC1 QC2 NASS SKEENA CC RS JS GS FRASER JFS SWVI NWVI
131
78
483
166
30
PRODUCTION AREA

Fig. 6b. Comparison of equilibrium stock sizes estimated by Ricker and Beverton-Holt models.

•--•--• Ricker model

o—o—o Beverton-Holt model

? estimation procedure failed for Beverton-Holt model


SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
(x1E6)
(x1E5)
EQUILIBRIUM STOCK SIZE
PRODUCTION AREA
16
1 2 3 4 5 6 7 8 9 10 11 12

drastically different management actions. Because the Ricker model is commonly used to study salmon populations, the following comparative study attempts to discern interesting patterns in the parameters estimated for it. The more difficult problem of choosing a basis for management, given alternative models, will be discussed in the next chapter.

3.3.2 Spatial Patterns in Productivity

Although thousands of salmon stocks have been identified on both sides of the Pacific (Atkinson et. Al. 1967, Aro and Shepard 1967), very few attempts have been made to compare the productivity or variability of some of these stocks. Most studies merely report fluctuations in the commercial catches of different species by area or compare the survival of different cohorts of salmon. Figures 7 and 8 show the Ricker model "α" parameters and the variances, σ_u^2, of different salmon species in B.C. (since "β" is related to the equilibrium stock size which will obviously vary from place to place, it is not considered here). A rank test of the Ricker model "α" parameters (table 20) shows that at low spawning populations, coho are significantly more productive than chum, even year pink, and sockeye. Likewise spring are more productive than chum and even year pink. It is plausible that coho and spring are naturally more productive than chum, even year pink and sockeye, especially considering that troll and sport catches take many coho and spring that would have died naturally if these species were taken only in terminal fisheries. However, it is also known that coho and spring spawning populations are more difficult to

Fig. 7. Ricker model "α" parameter and 95% confidence limits (number in graph represents production area).

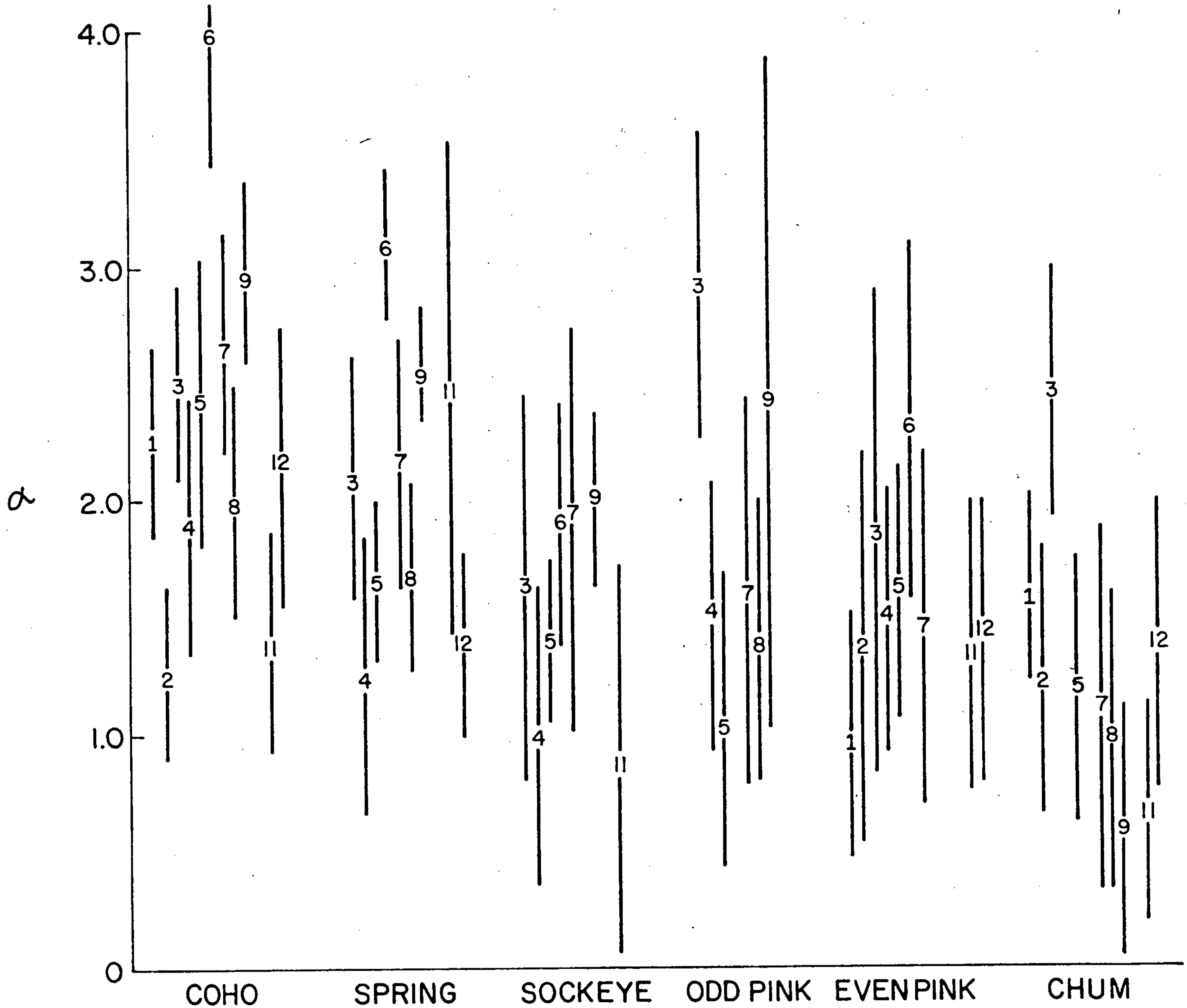
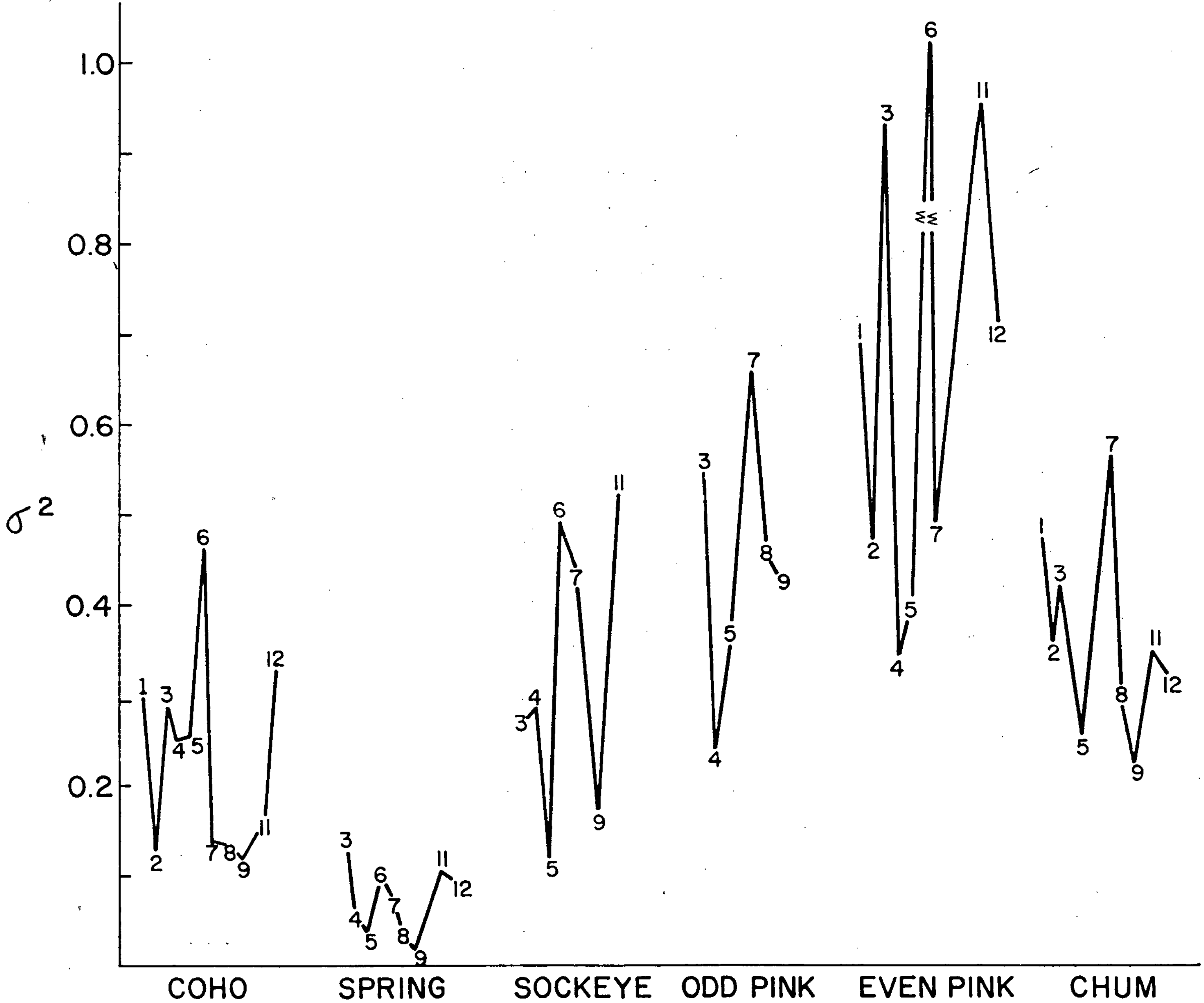

α
4.0
3.0
2.0
1.0
0
COHO
SPRING
SOCKEYE
ODD PINK
EVEN PINK
CHUM

Fig. 8. Ricker model variances (number in graph represents production area).


1.0
0.8
0.6
0.4
0.2
σ 2
COHO
SPRING
SOCKEYE
ODD PINK
EVEN PINK
CHUM

	SOCKEYE	CHUM	COHO	SPRING	O.PINK	E.PINK
SOCKEYE	0.00					
CHUM	1.48	0.00				
COHO	-1.99*	-3.42**	0.00			
SPRING	-1.27	-2.30*	1.22	0.00		
O.PINK	-0.71	-1.65	1.21	0.82	0.00	
E.PINK	0.74	-1.24	2.89**	2.12*	1.06	0.00

** $p < 0.01$
* $p < 0.05$

Table 20 : Rank test of Ricker model "α" parameters of different salmon species in B.C.

enumerate than other salmon species. Also, the exploitation pattern of these two species renders the catch allocation procedure used in this study more prone to error. Consequently, the estimated "α" parameters for coho and spring stocks are expected to be biased upward. Furthermore, it is quite possible that natural production of these species has declined drastically since 1960 from all B.C. rivers, with the trends being masked by more intensive efforts to count escapement and by increases in the catches due to American enhancement production. Since the above hypotheses have significantly different management implications, more research is needed to clarify this problem before any long term policies can be devised for the management of coho and spring stocks in B.C.

The relationships of productivity, variability, and stock size to geographical distribution of different stocks are often of interest to biologists , fisheries managers and fishermen alike. Table 21 shows the within species correlations of production area (from north to south), Ricker model "α" parameter, varicance and stock size (represented by average escapement). Geographically, only chum salmon show a significant trend of decreasing productivity from north to south. Also, the stock size of chum gets significantly larger from north to south, which logically leads to a significant negative correlation between stock size and productivity since spawning stocks do not show similar trends. Significant negative correlation between stock size and variability is also found in chum, coho, spring and odd pink. Coho also show a significant positive correlation between productivity and variability (Figs.

SOCKEYE

	AREA	α	σ^2	ESC.
AREA	1.00			
α	0.32	1.00		
σ^2	0.23	-0.11	1.00	
ESC.	0.37	0.24	-0.35	1.00

CHUM

	AREA	α	σ^2	ESC.
AREA	1.00			
α	-0.88**	1.00		
σ^2	-0.39	0.43	1.00	
ESC.	0.64*	-0.73	-0.62*	1.00

COHO

	AREA	α	σ^2	ESC.
AREA	1.00			
α	0.07	1.00		
σ^2	0.43	0.58*	1.00	
ESC.	0.39	-0.32	-0.56*	1.00

SPRING

	AREA	α	σ^2	ESC.
AREA	1.00			
α	0.32	1.00		
σ^2	-0.36	0.30	1.00	
ESC.	0.44	0.01	-0.77**	1.00

ODD PINK

	AREA	α	σ^2	ESC.
AREA	1.00			
α	-0.15	1.00		
σ^2	0.21	0.35	1.00	
ESC.	0.44	0.01	-0.34	1.00

EVEN PINK

	AREA	α	σ^2	ESC.
AREA	1.00			
α	-0.07	1.00		
σ^2	0.22	0.55	1.00	
ESC.	-0.15	-0.04	-0.66*	1.00

** $p < 0.01$
* $p < 0.05$

Table 21 : Within species correlation of production area, Ricker "α" parameter, variance and average escapement.

9-11). Again, these correlations may represent natural relationships, but they may also be artifacts due to poor data and/or biased assessment methods: chum salmon produced from the south may be caught much further north than we have thought, assessment of larger stocks may be given more attention and effort, smaller stocks are more sensitive to the mixed catch separation problem, and so forth. Further investigations are needed to resolve these hypotheses.

3.3.3 Correlations Among Stocks

Fig. 12 shows correlations among stocks and species of deviations in log recruits per spawner from Ricker model predictions, by species and production area. Significant correlations ($p<.001$) are mostly positive, which suggests that fluctuations in productivity may be affected by some common factors for many stocks (e.g. favourable incubation conditions). However significant correlation within species (especially coho and spring) may also reflect possible errors in the allocation of mixed catches.

Because of the predaceous nature of coho, concerns have been raised about the possible negative impact of coho enhancement on other salmon species. Fig. 13 shows (by species and production area) correlations of deviations in log recruits per spawner from Ricker model predictions versus coho abundance (catch + escapement) at different lags. It is apparent that most significant correlations occur in pink stocks, and at lag t-1 negative correlations occur more frequently than positive correlations. One interpretation is that coho abundance at t-1

Fig. 9. Average escapement versus Ricker model "α" parameter (number in circle represents production area).

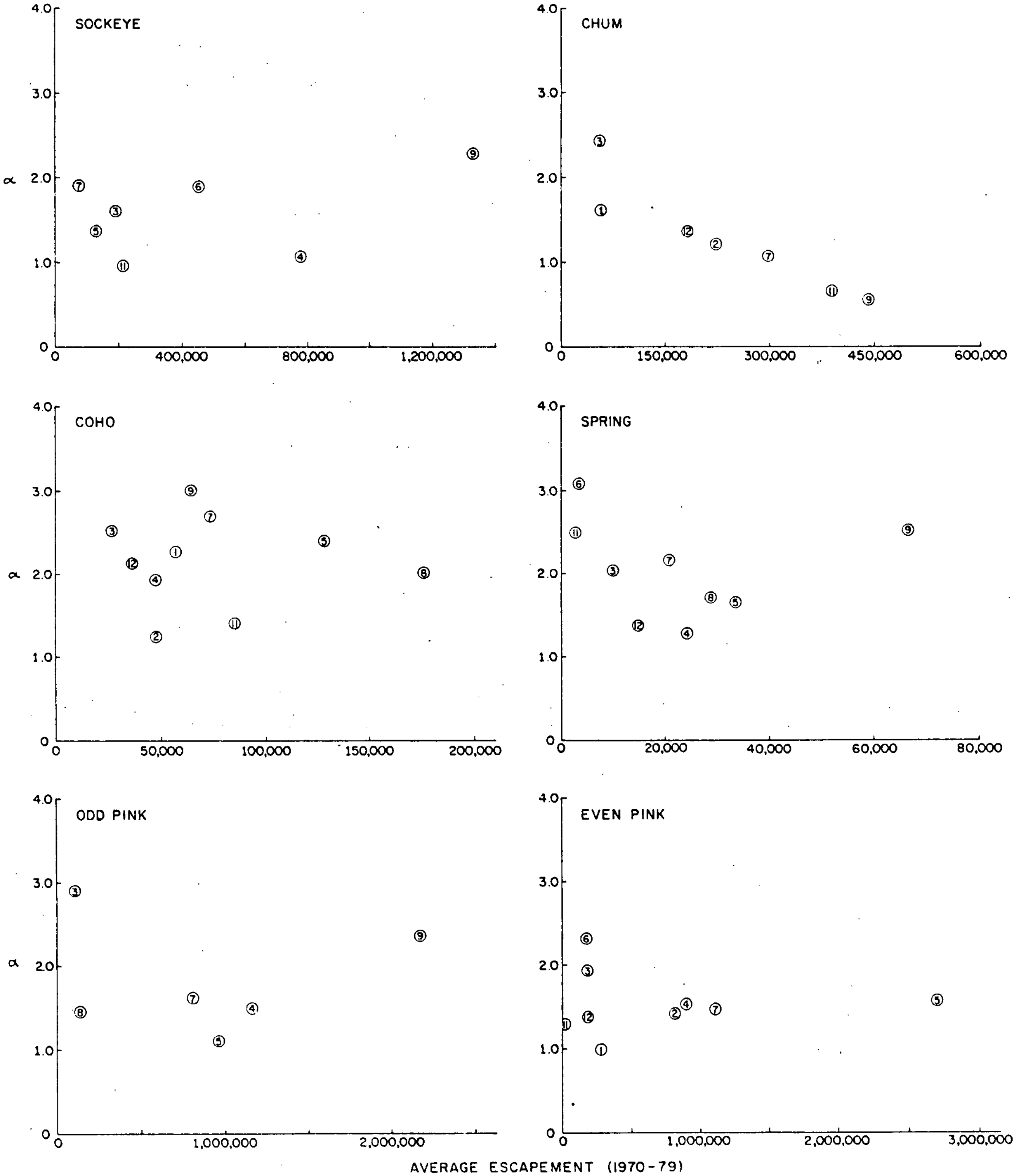

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
α
4.0
3.0
2.0
1.0
0
400,000
800,000
1,200,000
150,000
300,000
450,000
600,000
50,000
100,000
150,000
200,000
20,000
40,000
60,000
80,000
1,000,000
2,000,000
3,000,000
AVERAGE ESCAPEMENT (1970-79)

Fig. 10. Average escapement versus Ricker model variance (number in circle represents production area).

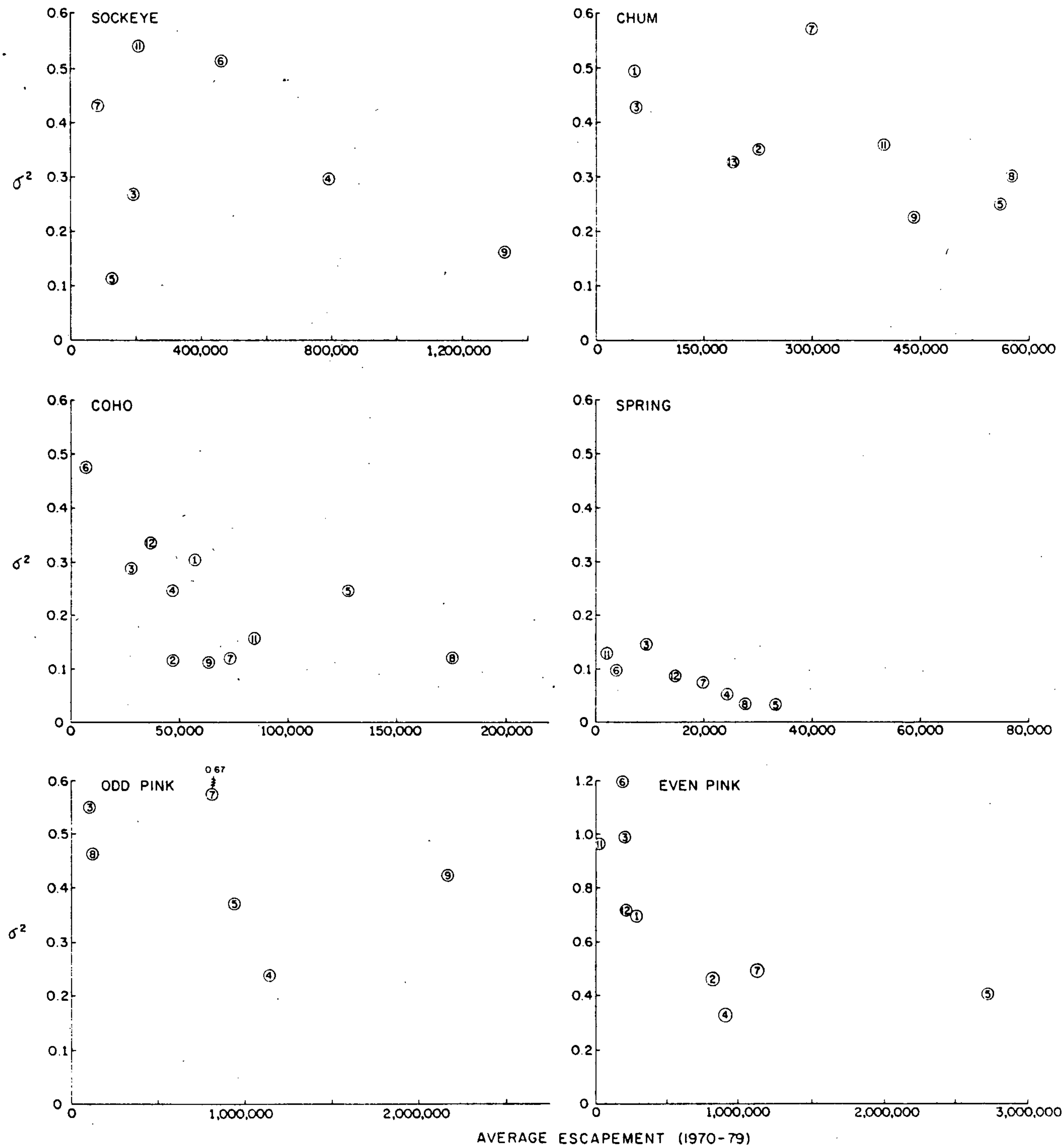

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
σ²
0.67
AVERAGE ESCAPEMENT (1970-79)

Fig. 11. Ricker model "α" parameter versus variance (σ^2_μ)(number in circle represents production area).

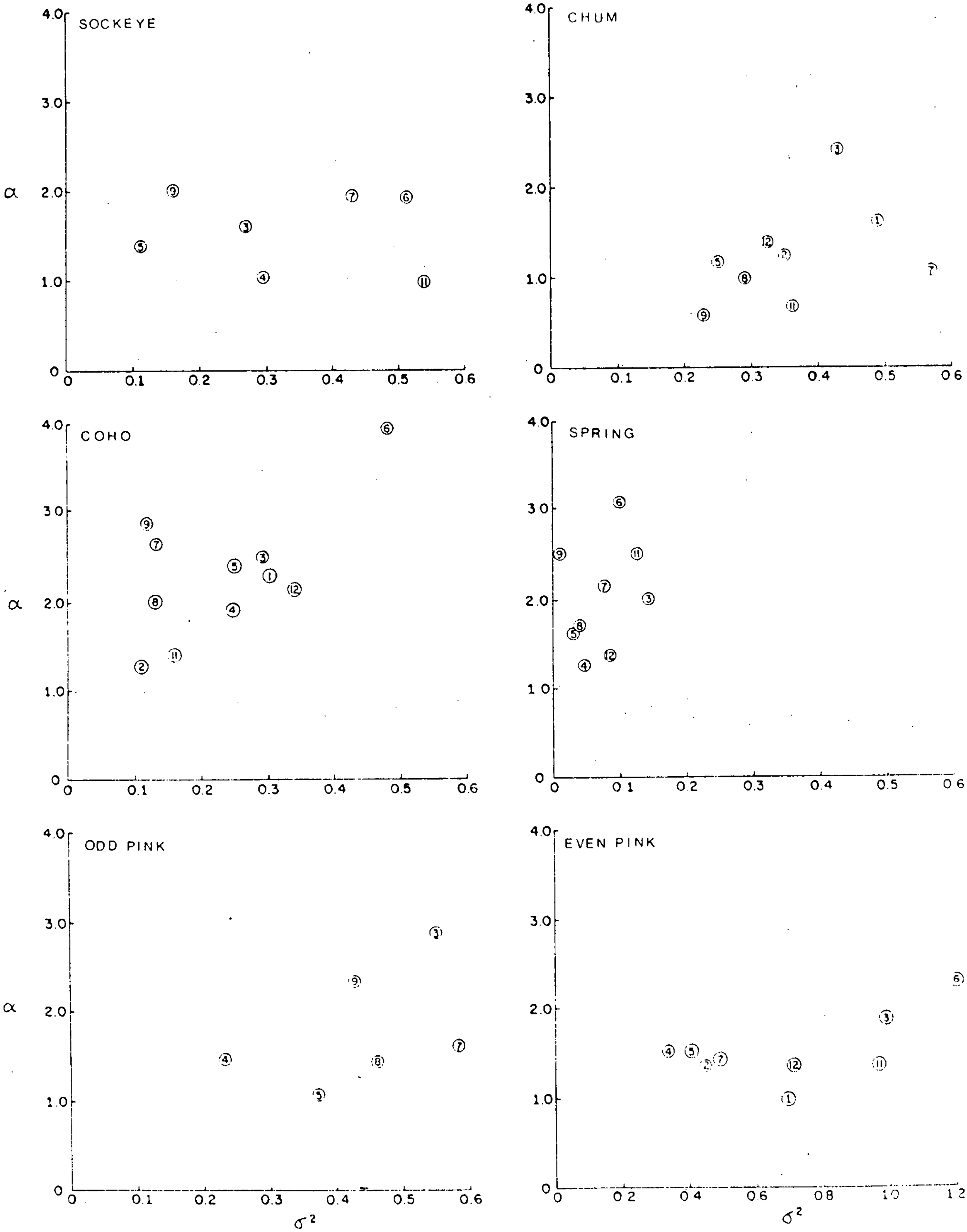

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
α
σ²
0
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0
1.2
2.0
3.0
4.0

Fig. 12. Correlation of deviations in log recruits per spawner from Ricker model predictions by species and production area (each production area is represented by one square within a species).

+ positive correlation ($p < .001$)

− negative correlation ($p < .001$)

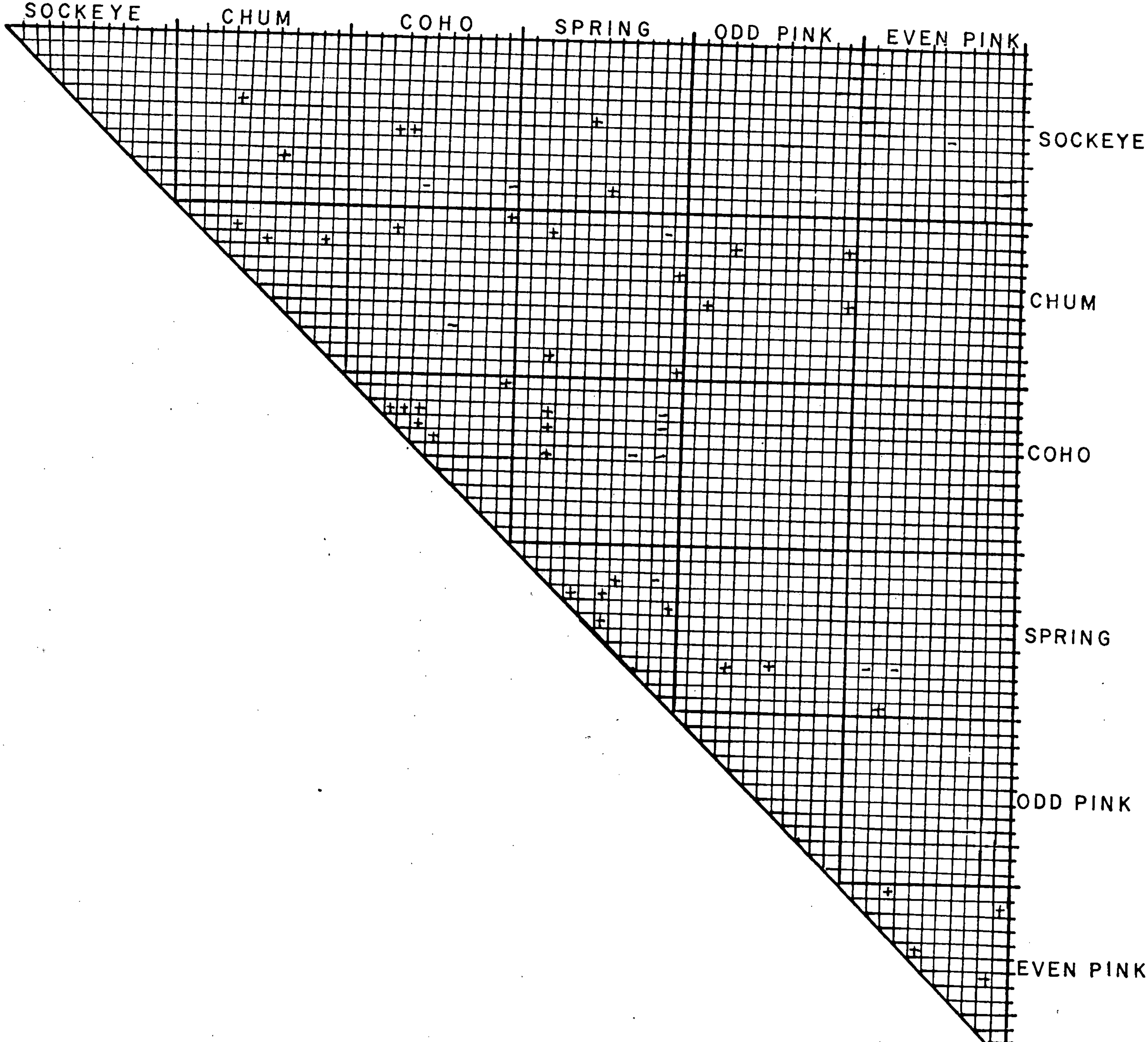
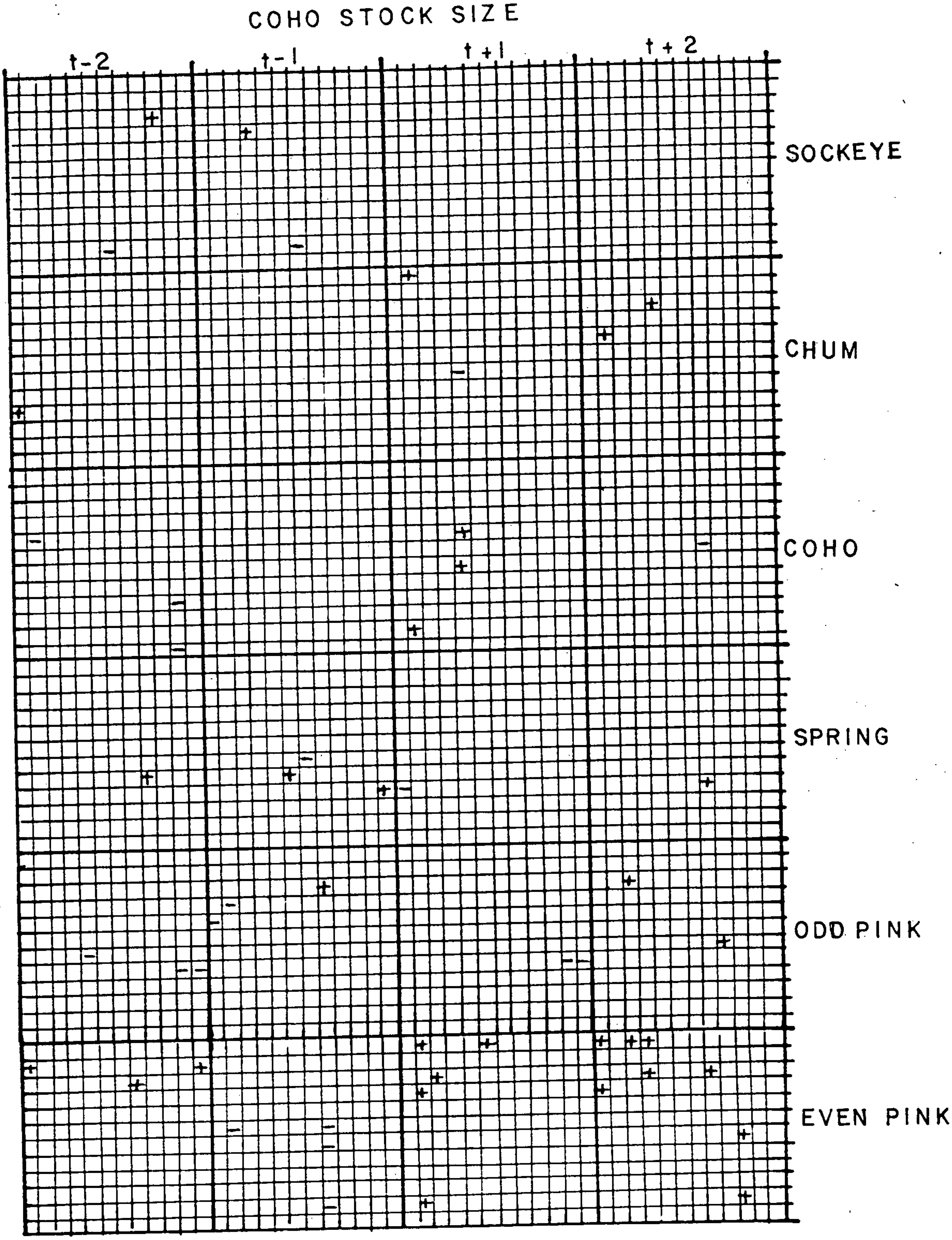

SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK

Fig. 13. Correlation of deviations in log recruits per spawner from Ricker model predictions versus coho stock size (at different lags).

+ positive correlation ($p < .001$)

- negative correlation ($p < .001$)


COHO STOCK SIZE
t-2
t-1
t+1
t+2
SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK

is positively related to spawning stocks at t-1 and subsequent smolt output at t+1 when coho predation on pink fry is most likely to occur.

3.3.4 Density Dependence and Fecundity

Cushing (1971) attempted to establish differences in the stock-recruitment relationships between groups of fish : tuna, cod, flatfish, salmon and herring. That attempt failed because the variation in parameters within a group of fish is as great as between groups. However, he found that the index of density dependence ("β" in Power model) is inversely correlated with the cube root of fecundity. The same analysis was applied to B.C. salmon stocks. No difference was found in the index of density dependence among species (Fig. 14), and no correlation was found between the index of density dependence and the cube root of fecundity (Fig. 15). Since the index of density dependence , β , is highly sensitive to past exploitation pattern and to errors in the measurement of spawning population, catch allocation and age structure, further analysis of β is not warranted.

3.3.5 Effects of Measurement Errors on The Estimates

Results from the Ludwig and Walters (1981) procedure for estimating stock-recruitment parameters in the presence of measurement errors are shown in Fig. 16. Since the required error ratio , λ , is not known, a range of values between

Fig. 14. 95% confidence limits of Power model "β" estimates.

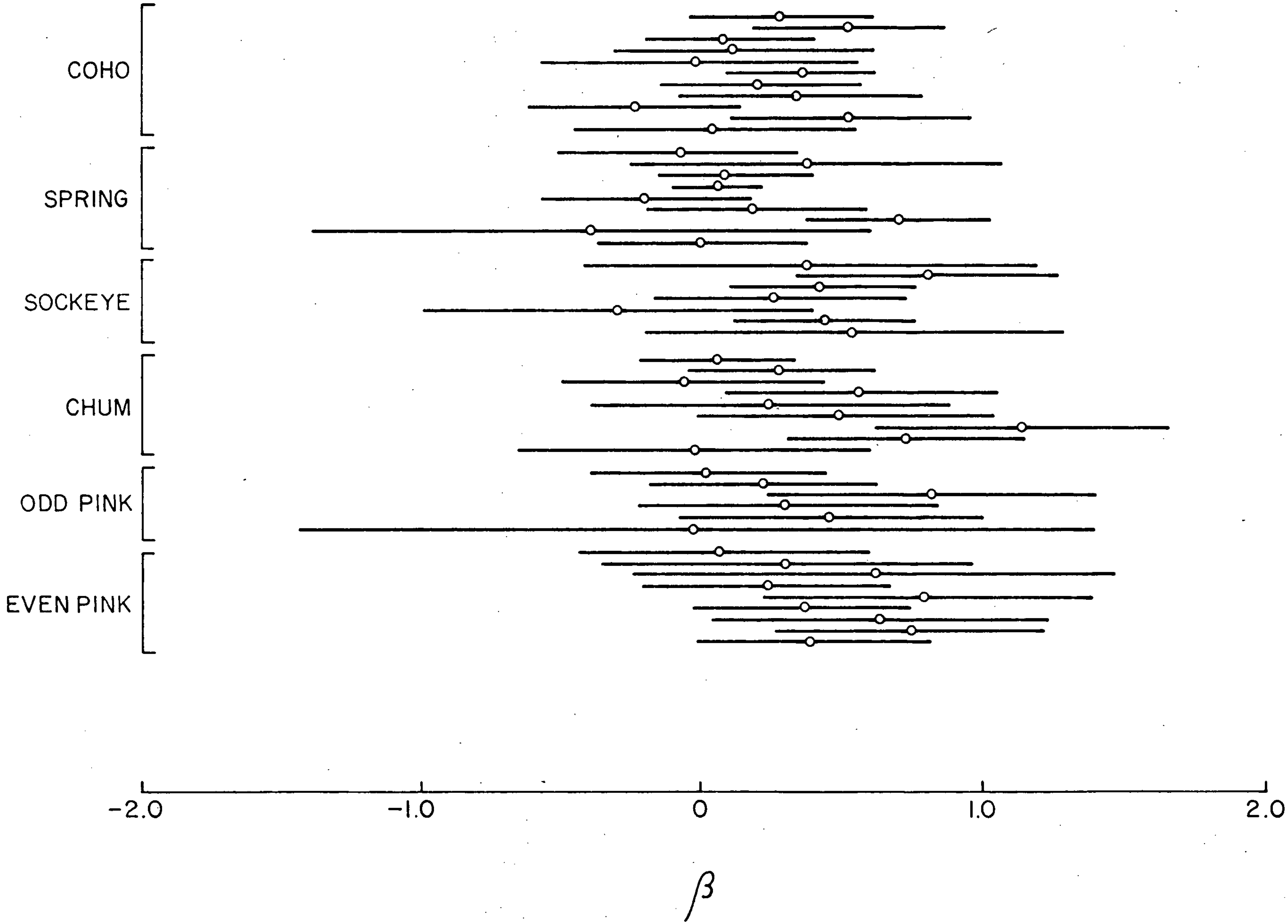
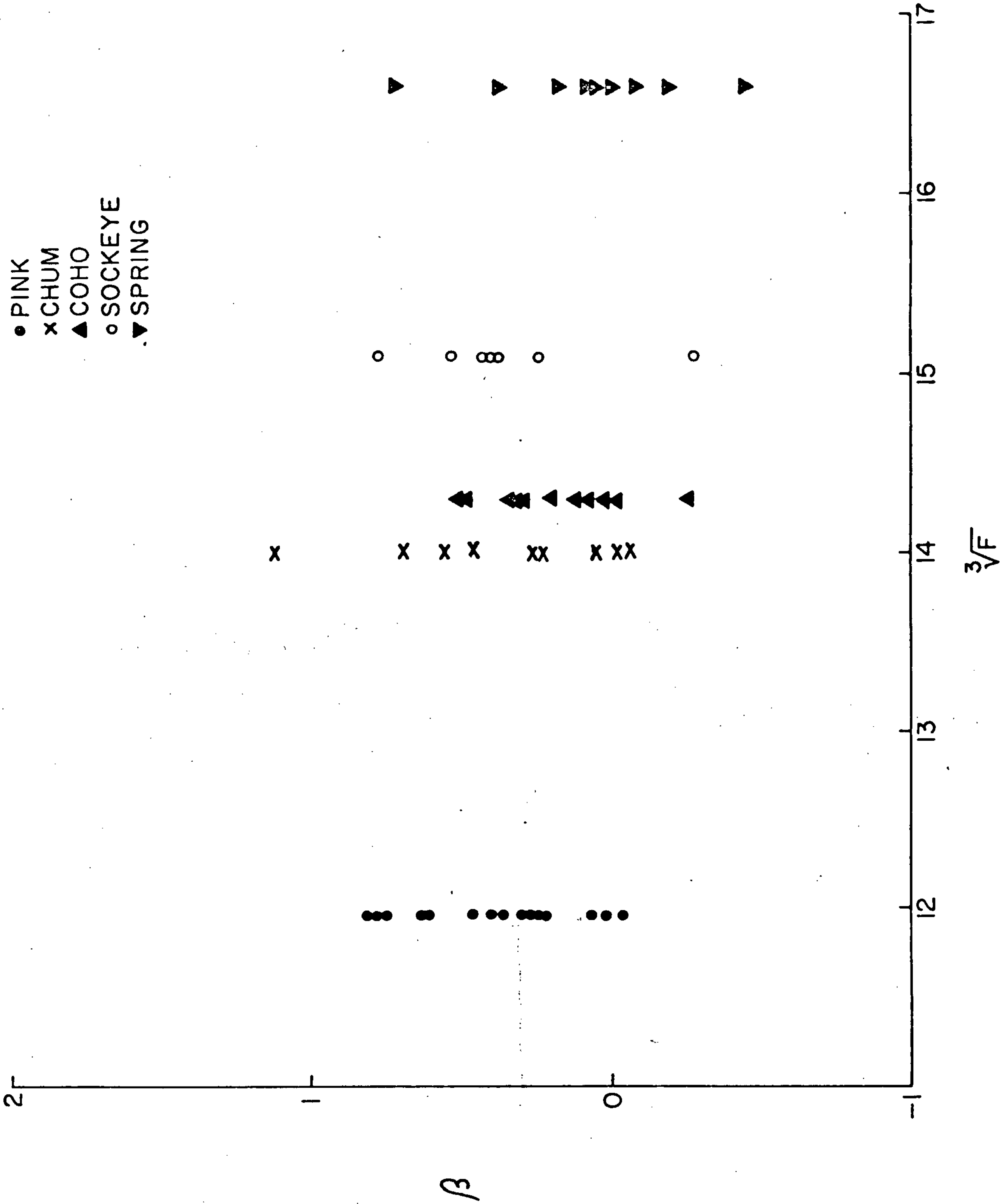

COHO
SPRING
SOCKEYE
CHUM
ODD PINK
EVEN PINK
−2.0
−1.0
0
1.0
2.0
β

Fig. 15. Index of density dependence (Power model "β") versus cube root of fecundity.



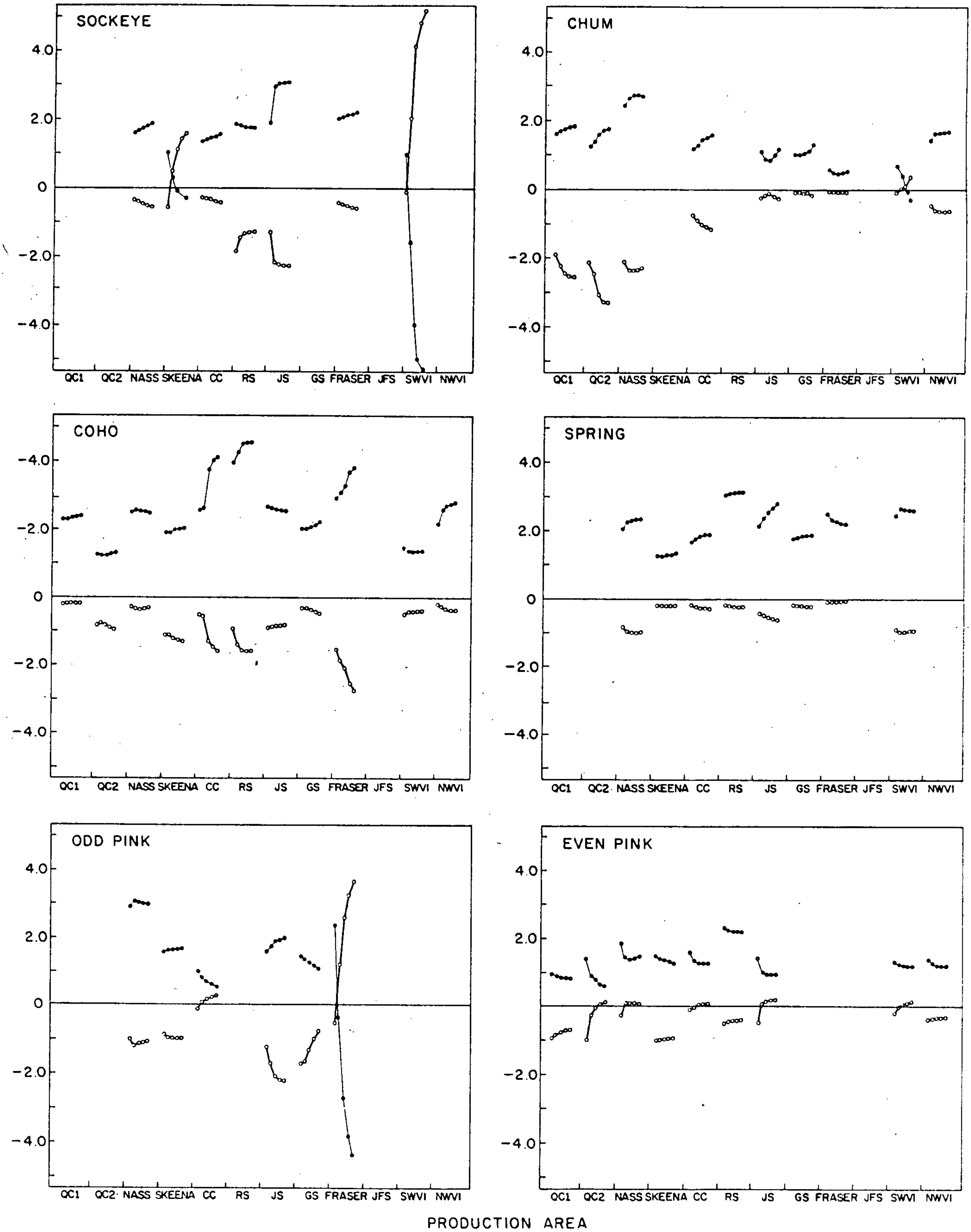
• PINK
× CHUM
▲ COHO
○ SOCKEYE
▼ SPRING
β
$\sqrt[3]{F}$
2
1
0
-1
12
13
14
15
16
17

$0 \leq \lambda \leq 2$ was prescribed to each stock in order to examine the sensitivity of parameter estimates to different levels of measurement error. Figure 16 shows the changes of Ricker model "α" and "β" parameters as λ is increased from 0.0 to 2.0 for each stock. Three general patterns of change are apparent: 1. The "α" parameter increases in value while "β" decreases, for most coho, spring and chum stocks. 2. "α" decreases in value but remains positive while "β" increases in value and may become positive, for most even year pink stocks and some sockeye and odd year pink stocks. 3. "α" decreases in value and becomes negative negative while "β" increases to become positive, for two sockeye, one chum, and one odd year pink stock. These three patterns of change suggest different courses of action when faced with increasing levels of uncertainity in measurement errors. Pattern 1 suggests lowering the escapement to test the productivity of the stock. Pattern 2 favours increasing escapement moderately to test the carrying capacity of the system. Pattern 3 suggests avoiding low escapements at all costs and opt for the highest escapement levels one can possibly get, although the optimum escapement is highly uncertain at this point in time. These are important considerations in estimating optimum policies which will be discussed in the next chapter.

Fig. 16. Changes of Ricker model "α" and "β" parameters as λ is increased from 0.0 to 2.0 (left to right).

•—•—• α

o—o—o β


SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
4.0
2.0
0
-2.0
-4.0
QC1 QC2 NASS SKEENA CC RS JS GS FRASER JFS SWVI NWVI
PRODUCTION AREA

4. OPTIMAL POLICIES

The definition of optimality basically depends on individual preferences among performance measures. It can, but need not be based on the maximization of quantifiable objectives. If fisheries were managed solely in terms of achieving a simple consistent goal (e.g. maximum sustained yield or maximum economic value), management would indeed be a simpler task. However, management agencies have long recognized that different segments of society are affected by different management actions. To favour one side often entails foregoing benefits for the others ,and far too often, decisions that favour special segments of society may not be in the best interest of the society as a whole.

Sinclair(1978) emphasized that the responsibility of a government fishery agency is to manage a fishery resource in the best interest of the owners of the resource, i.e. the tax-payers of the nation. It is important for government agencies to recognize that concerns for the primary users should not be used as justification for establishing programs that may not be in the best interest of the public. Unfortunately to identify a common set of objectives for management in this context is very difficult, especially when people's preferences and interests change over time. Attempts to solicit public opinion by government officials often gather only the opinions of vested-interest groups. Although recent advances in multi-attribute utility analysis can be used to investigate conflicting objectives (Hilborn and Walters 1977, Keeney 1977), uncertainty about future objectives, which is essential in evaluating control strategies, is not addressed. More important, these objectives may change over time with differential rates at the national, provincial and local level, making detailed analysis more ambiguous and uncertain.

In view of the above complexities, it would be naive and presumpteous to suggest that these problems are soluble through some form of biological analysis alone. Only an interdisciplinary program incorporating the expertise from various social, political and economic sciences may contribute towards their resolution. Due to my ignorance in the social, political and economical fields, the following sections consider only the optimal policies that would produce maximum expected yields, for different assumptions of biological uncertainties. Such policies would not necessarily be most desirable nor achievable in practice, but serve as a standard of comparison with other policies that take into account richer sets of objectives and constraints.

4.1 Non-feedback Policies

Walters and Hilborn(1978) classified "equilibrium" and "time-dependent" control rules as non-feedback policies. Here, the dynamics of the system being managed are assumed to be completely deterministic. Examples of such solutions are equilibrium harvest rates, fixed quotas and equilibrium effort. Time-dependent policy analysis does not assume the system to be at or near equilibrium, but instead prescribes an optimal course of action that is dependent on time alone. Some examples are: a list of future harvest rates, future quotas or a ten year development plan.

It is well recognized that uncertainties and unpredictable fluctuations are encountered in most fisheries. Therefore non-feedback policies (which do not require monitoring) are considered to be deceptive and are not discussed further in this analysis.

4.2 Feedback Policies

Implicit in the design of feedback policies is the assumption that uncertainties exist in the dynamics of the systems being managed, and that actions should be modified as new data become available over time. These policies differ from non-feedback policies in that the optimal controls at any time depend on the state of the system at that time, rather than on time alone. Feedback policies may depend on time as well as the future state of the system, but when the optimal policies turn out to be time-independent, they are called stationary feedback policies (Walters and Hilborn 1978).

Depending on the assumptions made about the uncertainties of the stock being managed, various optimization techniques can be used to determine the optimal policy. Three types of uncertainties are generally encountered in establishing fisheries policies: 1. random "environmental" effects, 2. measurement errors, and 3. uncertainty in parameter estimates and model structure.

All these uncertainties exist for most salmon stocks along the B.C. coast, and at least the latter two cannot be precisely quantified with existing data. Therefore, several optimization techniques are examined below, with the hope that their solutions can be compared with existing management practices and with each other to point towards ways of improving present practices.

If the management objective is simply to maximize the sum of expected catches over time regardless of the variability of harvest, the optimal policy is to allow a fixed escapement every year. That is, if S^* is the optimal escapement, then harvest $R-S^*$ of the recruits if $R>S^*$, otherwise do not harvest (Clark 1976). While a feedback policy of this form will be optimal no matter what uncertainties (of the above types) are admitted to the analysis, the optimum value of S^* does depend on these uncertainties. In this section, estimates of S^* are developed for a range of increasingly realistic assumptions about uncertainties.

4.2.1 Random "Environmental" Effects

The simplest assumption about uncertainty is that the recruitment curve is known, and only environmental effects are unpredictable. We might further assume then that statistical expectations are representative of the future states of the system, so future returns can be calculated from these expectations alone. Numerical models which superimpose randomly generated deviations on deterministic models have been used to study the effect of different levels of variability on future yields (Ricker 1958, Larkin and Ricker 1964) and to compare the economic returns of different harvest strategies (Allen 1973). In these studies, the optimal escapements (which provide maximum expected catches) were found to be very similar to the optimal escapements estimated by assuming the systems were completely deterministic.

Instead of basing estimates only on the expected values of future states, a second method recognizes that many different states may arise, so that a series of decisions must be made in sequence. Each decision affects the subsequent state of the system which in turn affects future decisions. Dynamic programming can be used to find the decisions which will maximize the expected catches across these states (Walters 1975, Reed 1975, Walters and Hilborn 1976). This method tends to estimate lower optimal harvest rates than the previous one, but the relative merits of different policies remain unchanged.

In view of the above optimization results, it is generally concluded that optimal policies for stochastic systems are very similar to the optimal policies estimated by assuming deterministic dynamics. Therefore we can reasonably estimate the optimal escapement by assuming the system is completely deterministic when faced with only uncertainty about random "environmental" effects. More conservative policies are favoured only when the objective function involves strong elements of risk aversion or desire to avoid extreme low catches.

Instead of carrying out the lengthy numerical analysis or the tedious dynamic programming as mentioned above, optimal escapements for B.C. salmon stocks were estimated by solving the deterministic versions of the models to maximize the sustained catches. If the deterministic stock-recruitment model is expressed in general terms as:

$$R = f(S) \qquad (4.2.1)$$

Then, the optimal escapement, S^*, can be obtained by choosing S^* as the solution of the equation

$$f'(S) = 1 \qquad (4.2.2)$$

Specifically the optimal escapement, S^*, is obtained by solving for S^* in

$$(1-\beta S^*)e^{(\alpha-\beta S^*)} = 1 \qquad (4.2.3)$$

for the Ricker model (3.1.4), and

$$S^* = \sqrt{ab} - b \qquad (4.2.4)$$

for the Bevelton-Holt model (3.1.6).

4.2.2 Measurement Errors

As mentioned before, measurement errors in the spawning counts obliterate the stock-recruitment relationship, so regression precedures normally used to estimate model parameters become invalid. Other estimation procedures can be developed if either σ_v^2 or σ_u^2 or $\lambda = \sigma_v^2/\sigma_u^2$ is known. At present, since none of these parameters $(\lambda, \sigma_u^2, \sigma_v^2)$ is known for any of the stocks concerned, several λ values (from low to high) were prescribed to each stock and the corresponding parameter values for the Ricker model and Power model were estimated. Because of the non-linearities in the parameters of the Beverton-Holt model, the likelihood estimation procedure becomes extremely complex. Possible solutions are under investigation (Ludwig, pers. comm.).

If uncertainties in the parameters and model structure are ignored, the results of the preceeding section still apply. That is, the optimal escapement for a stock at different λ values can be estimated by (4.2.3) for the Ricker model. The existence of (or lack of) differences among the optimal policy estimates should then give a general idea of how important (or unimportant) it is to measure λ more accurately for future assessments.

Aside from the lack of knowledge of λ values, the parameter correction procedure does not always give reliable or consistent estimates of the true model parameters, especially when data sets are small (n<50) and the range of observation narrow. Even if data sets were large and λ values known, there is still considerable danger of making very poor policy choices, as indicated in the following section.

4.2.3 Uncertainty in Parameter Estimates and Model Structure

So far we have only discussed the effects of random errors on the design of fishing policies. The reason is not that these kinds of error are more important, but that they are easier to deal with in a statistical manner. Non-random errors, introduced via systematic biases in spawning counts, catch allocations or age structure effects are intrinsically inseparable from the estimated model parameters. Besides, the model parameters may have changed due to persistent shifts in the environment or selection by the fishery. Without time specific, independent estimates of these parameter changes and measurement biases, one should always pay more attention to the question of how fishery policies should be modified to take account of uncertainties in parameter estimates and model structure.

Walters (1981) discussed three kinds of approaches that can be taken when faced with these uncertainties. First, one may ignore the analytical results and rely on intuition to make harvesting decisions. This approach can be justified only if the quality of data collected is extremely poor and will likely remain so in the near future; under this extreme of uncertainty, there may not be an optimal policy at all. In this case, intuition is the only basis for making decisions. For salmon management, this usually means just trying to maintain the same escapement as in the recent years. However, given the current amount of government involvement in the B.C. salmon fishery, there is at least some basis and responsibility for following a more sophisticated approach.

The second approach is to launch research projects to study the stock-recruitment dynamics of "model" stocks, but maintain the status quo of all other stocks while waiting for the results. The problem with this approach is that the recommendations thus obtained can only be validated by actual manipulation of escapement of the other stocks. Therefore the research essentially just delays the hard decisions which would have to be made anyway.

The third approach is to develop some form of adaptive policy which emphasizes the need of learning by doing. Here the fishery is monitored to produce more reliable estimates of state indicators (spawning stock size, catches, age structure, etc.). With this information, one or more models can be used to produce improved estimates of the system state and parameters. These estimates provide the basis for choosing the next set of controls, and the whole exercise is repeated year after year. Depending on whether future uncertainty is viewed as a component of the management system, three kinds of adaptive controls can be devised:

A. Operate as though the most likely model is right and pretend the parameter estimates are actually correct (i.e. ignore parameter uncertainty). This aproach is called "passive" adaptive control by Walters and Hilborn (1978), meaning that the uncertainty in model structure or parameter estimates will eventually be resolved by the varying inputs (escapement levels) to the system due to uncontrollable natural or human factors. However, since uncertainty is not explicitly considered in the management plan, the system could be locked into a suboptimal state for a long time without informative variation occurring.

B. Include uncertainties in the formulation of controls each year, but do not consider the effect of the choice of controls now on uncertainties in the future. Here, the analysis admits all possible models (or parameters) by weighting the possible outcomes according to prior odds placed on each model (or parameter). Mendelssohn (1980) and Walters (1981) called this the "Bayes equivalent" policy. "Bayes equivalent" policies for B.C. salmon stocks at different measurement error levels (λ), can be estimated by the computation procedures described by Ludwig and Walters (1981) (computer program developed by Ludwig, pers. comm.).

C. Develop an "active" adaptive policy which takes into account the effect of actions now on the possible long-term benefits of improved knowledge. This approach seeks to optimally balance the trade-offs between short-term yield and learning about the system so as to improve yields in the future. This optimization problem is known as the dual control problem, and it has not been fully resolved even for very simple systems. Besides the mathematical complexities, the time horizon for management and the discount rate can seldom be determined objectively, although they are critically important to the estimates obtained. Intuitively, if the discount rate is low and the time horizon infinite, we would put more emphasis on getting better information for the future. Whereas, if the discount rate were high and the time horizon short, we would put more emphasis on harvesting now but pay less attention to gaining of knowledge for the future. Because of the above problems, "active" adaptive policies are not computed for the stocks concerned in this study. Several approximate solutions of this problem for fisheries systems have been discussed by Walters and Hilborn (1978), Silvert (1978), Smith (1978) and Walters (1981).

As an aid to future design of actively adaptive policies, we have chosen to present tabular estimates of and bounds for optimum escapements based on our (Walters, Hilborn, Staley and myself) informed judgement and intuition regarding each stock. The blind statistical fitting discussed earlier is particularly sensitive to extreme observations involving spawning stocks; in some cases we know that the extreme events either did not actually occur (for example, high Fraser sockeye spawning in 1958), or are likely to be the result of poor spawning counts and/or misallocation of catch to a stock. In these instances, our tabular assessment of optimal escapement is based on discarding the outliers, though we admit them as biological possibilities in setting crude bounds on optimal escapement.

4.3 Results

Tables 22 to 27 show the optimum escapement, optimum yield, optimum exploitation rate and maximum tolerable exploitation rate for each stock estimated by the Ricker and Beverton-Holt models without corrections for measurement error and without consideration for parameter uncertainty. In general, the Ricker model suggests more conservative policies than the Beverton-Holt model. For most stocks, the Ricker model estimates much higher optimum escapement levels with correspondingly higher optimum yields and lower optmum exploitation rates than does the Beverton-Holt model. The Ricker model also estimates lower maximum tolerable rates of exploitation than the Beverton-Holt model for all stocks.

A cross species comparison of optimum exploitation rates

Tables 22-27. Optimum escapement, optimum yield, optimum exploitation rate and maximum tolerable exploitation rate estimated by Ricker and Beverton-Holt models.

M1 = Ricker model

M2 = Beverton-Holt model

Sopt. = optimum escapement

Yopt = optimum yield

Uopt = optimum exploitation rate

Umax = maximum exploitation rate

? = estimation procedure failed

\- = insufficient information or negligible stock

SOCKEYE

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-
Nass	172000	156000	281000	268000	.62	.63	.80	.86
Skeena	743000	924000	577000	600000	.44	.39	.64	.63
C.C.	202000	166000	257000	246000	.56	.60	.75	.84
R-S	377000	270000	872000	765000	.70	.74	.85	.93
J.S.	54000	?	129000	?	.70	?	.85	?
G.S.	-	-	-	-	-	-	-	-
Fraser	1713000	2040000	4610000	4388000	.73	.68	.87	.90
J.F.S.	-	-	-	-	-	-	-	-
SWVI	258000	148000	191000	143000	.43	.49	.62	.74
NWVI	-	-	-	-	-	-	-	-

Table 22 :

CHUM

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	32000	12000	55000	46000	.63	.80	.80	.96
Q.C.2	236000	144000	250000	245000	.52	.63	.71	.86
Nass	38000	?	155000	?	.80	?	.91	?
Skeena	-	-	-	-	-	-	-	-
C.C.	646000	642000	633000	613000	.50	.49	.69	.74
R-S	-	-	-	-	-	-	-	-
J.S.	168000	88000	146000	175000	.46	.67	.66	.89
G.S.	414000	353000	309000	295000	.43	.46	.63	.70
Fraser	?	?	?	?	?	?	?	?
J.F.S.	-	-	-	-	-	-	-	-
SWVI	291000	275000	126000	120000	.30	.30	.48	.52
NWVI	102000	41000	131000	172000	.56	.81	.75	.96

Table 23 :

COHO

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	35000	29000	120000	95000	.77	.76	.90	.94
Q.C.2	62000	59000	68000	64000	.52	.52	.72	.77
Nass	23000	13000	103000	83000	.82	.86	.92	.98
Skeena	59000	20000	136000	149000	.70	.88	.85	.98
C.C.	139000	?	570000	?	.80	?	.91	?
R-S	11000	17000	214000	174000	.95	.91	.98	.99
J.S.	103000	100000	534000	492000	.84	.83	.93	.97
G.S.	197000	204000	516000	492000	.72	.71	.87	.91
Fraser	56000	?	380000	?	.87	?	.95	?
J.F.S.	-	-	-	-	-	-	-	-
SWVI	99000	100000	130000	125000	.57	.56	.76	.80
NWVI	33000	?	100000	?	.75	?	.88	?

Table 24 :

SPRING

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-
Nass	9000	3000	24000	22000	.73	.89	.87	.99
Skeena	22000	21000	24000	24000	.52	.54	.71	.78
C.C.	31000	13000	54000	64000	.64	.83	.81	.97
R-S	4000	1300	32000	26000	.89	.96	.95	.99
J.S.	18000	?	57000	?	.76	?	.89	?
G.S.	33000	25000	60000	60000	.65	.71	.82	.91
Fraser	163000	360000	726000	945000	.82	.72	.92	.92
J.F.S.	-	-	-	-	-	-	-	-
SWVI	9000	?	39000	?	.81	?	.92	?
NWVI	8000	?	10000	?	.56	?	.75	?

Table 25 :

ODD PINK

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-
Nass	86000	37000	568000	436000	.87	.92	.95	.99
Skeena	683000	400000	991000	1000000	.59	.71	.77	.92
C.C.	3011000	3543000	2500000	2568000	.45	.42	.65	.66
R-S	-	-	-	-	-	-	-	-
J.S.	481000	285000	795000	665000	.62	.71	.80	.91
G.S.	329000	308000	451000	361000	.58	.54	.76	.79
Fraser	1370000	?	5198000	?	.79	?	.91	?
J.F.S.	-	-	-	-	-	-	-	-
SWVI	-	-	-	-	-	-	-	-
NWVI	-	-	-	-	-	-	-	-

Table 26 :

EVEN PINK

AREA	Sopt.		Yopt.		Uopt.		Umax.	
	M1	M2	M1	M2	M1	M2	M1	M2
Q.C.1	451000	303000	337000	309000	.43	.51	.63	.76
Q.C.2	553000	367000	695000	698000	.56	.67	.75	.88
Nass	267000	363000	605000	623000	.69	.63	.85	.87
Skeena	582000	394000	861000	745000	.60	.65	.78	.88
C.C.	4482000	?	7245000	?	.62	?	.79	?
R-S	145000	73000	525000	327000	.78	.82	.90	.97
J.S.	1179000	1322000	1607000	1563000	.58	.54	.76	.79
G.S.	-	-	-	-	-	-	-	-
Fraser	-	-	-	-	-	-	-	-
J.F.S.	-	-	-	-	-	-	-	-
SWVI	25000	24000	31000	25000	.55	.51	.74	.76
NWVI	129000	80000	167000	129000	.56	.62	.75	.86

Table 27 :

estimated by the Ricker model shows that springs have the highest optimum exploitation rate at .745 (average weighted by optimum escapement), following by coho (.734), sockeye (.626), even pink (.600), odd pink (.585) and chum (.463). The maximum tolerable rate of exploitation follows the same order, with springs averaging .875 (average weighted by optimum escapement), following by coho (.866), sockeye (.789), even pink (.778), odd pink (.747) and chum (.655). However, since the error structures among species may not be comparable, these tentative results should be verified by independent studies in the future.

When both measurement error and parameter uncertainty are included in the estimation procedure, different optimum escapements are generally suggested. Tables 28 to 33 show the "Bayes equivalent" optimum escapement for each stock estimated by the Ricker model for different levels of λ (measurement error/ environmental error). Even when $\lambda = 0$ (no measurement error), the "Bayes equivalent" optimum escapements are usually much higher than the optimum escapements estimated by the deterministic version of the model (Tables 22 - 27). For some stocks (e.g. Fraser chum, C.C. odd pink), the "Bayes equivalent" optimum escapements cannot be determined due to the high uncertainties in the stock-recruitment parameters. Under these circumstances, escapement levels much higher than the present levels are recommended (Walters 1981).

As λ is increased, four general patterns of change in the "Bayes equivalent" optimum escapement are apparent: 1) the optimum escapement may remain fairly stable, as shown by most spring and some coho stocks; 2) the optimum escapement may

Tables 28-33. "Bayes equivalent" optimum escapement at different levels of λ .

L = estimation procedure failed, optimum escapement is probably much higher than the current escapement

\- = insufficient information or neglibible stock

SOCKEYE

AREA	λ=0.0	λ=0.5	λ=1.0	λ=1.5	λ=2.0
Q.C.1	-	-	-	-	-
Q.C.2	-	-	-	-	-
Nass	181000	159000	135000	125000	125000
Skeena	868000	L	L	L	L
C.C.	199000	193000	181000	168000	159000
R-S	405000	475000	508000	506000	504000
J.S.	54000	38000	37000	38000	36000
G.S.	-	-	-	-	-
Fraser	1670000	1650000	1590000	1530000	1500000
J.F.S.	-	-	-	-	-
SWVI	L	L	L	L	L
NWVI	-	-	-	-	-

Table 28 :

CHUM

AREA	λ=0.0	λ=0.5	λ=1.0	λ=1.5	λ=2.0
Q.C.1	35000	30000	28000	28000	27000
Q.C.2	254000	211000	186000	182000	182000
Nass	38000	33000	34000	35000	35000
Skeena	-	-	-	-	-
C.C.	684000	600000	514000	493000	481000
R-S	-	-	-	-	-
J.S.	187000	222000	L	L	L
G.S.	432000	437000	426000	383000	317000
Fraser	L	L	L	L	L
J.F.S.	-	-	-	-	-
SWVI	372000	L	L	L	L
NWVI	104000	98000	98000	98000	98000

Table 29 :

COHO

AREA	λ =0.0	λ =0.5	λ =1.0	λ =1.5	λ =2.0
Q.C.1	34000	35000	35000	34000	33000
Q.C.2	64000	65000	63000	62000	61000
Nass	22000	21000	22000	22000	23000
Skeena	59000	56000	51000	50000	49000
C.C.	135000	119000	61000	60000	58000
R-S	11000	6500	6000	6000	6000
J.S.	100000	101000	105000	108000	110000
G.S.	201000	194000	184000	172000	158000
Fraser	54000	50000	40000	34000	33000
J.F.S.	-	-	-	-	-
SWVI	102000	121000	131000	132000	132000
NWVI	33000	22000	20000	20000	20000

Table 30 :

SPRING

AREA	λ=0.0	λ=0.5	λ=1.0	λ=1.5	λ=2.0
Q.C.1	-	-	-	-	-
Q.C.2	-	-	-	-	-
Nass	8000	8000	8000	8000	8000
Skeena	22000	22000	21000	21000	21000
C.C.	30000	29000	28000	28000	27000
R-S	4000	4000	3000	3000	3000
J.S.	18000	15000	14000	14000	14000
G.S.	32000	31000	30000	30000	30000
Fraser	205000	L	L	L	L
J.F.S.	-	-	-	-	-
SWVI	9000	8000	8000	8000	8000
NWVI	8000	8000	7000	7000	7000

Table 31 :

ODD PINK

AREA	λ=0.0	λ=0.5	λ=1.0	λ=1.5	λ=2.0
Q.C.1	-	-	-	-	-
Q.C.2	-	-	-	-	-
Nass	87000	70000	71000	73000	77000
Skeena	700000	615000	594000	584000	579000
C.C.	L	L	L	L	L
R-S	-	-	-	-	-
J.S.	497000	370000	312000	282000	272000
G.S.	362000	365000	L	L	L
Fraser	1270000	L	L	L	L
J.F.S.	-	-	-	-	-
SWVI	-	-	-	-	-
NWVI	-	-	-	-	-

Table 32 :

EVEN PINK

AREA	λ=0.0	λ=0.5	λ=1.0	λ=1.5	λ=2.0
Q.C.1	508000	486000	483000	480000	478000
Q.C.2	576000	L	L	L	L
Nass	L	L	L	L	L
Skeena	597000	564000	570000	586000	598000
C.C.	5160000	L	L	L	L
R-S	155000	224000	268000	229000	242000
J.S.	1860000	L	L	L	L
G.S.	-	-	-	-	-
Fraser	-	-	-	-	-
J.F.S.	-	-	-	-	-
SWVI	L	L	L	L	L
NWVI	140000	151000	154000	155000	155000

Table 33 :

increase or decrease more or less steadily, as shown in many sockeye, chum and coho stocks; 3) the optimum escapement may change rapidly at low λ values but become more stable as λ increases, as shown in J.S. sockeye, NWVI chum and some coho stocks; 4) the optimum escapement may become highly uncertain and the estimation procedure fail as λ increases, as shown in many pink, some chum, one sockeye and one spring stocks (Tables 28 - 33). The optimum exploitation rate and maximum exploitation rate show similar changes as λ increases (Tables 34 - 39).

Statistical estimates of optimums are very sensitive to extreme observations involving spawning stocks and/or recruitment. In some cases, we know the extreme events either did not occur or are likely to be the result of poor spawning counts and/or misallocation of catch to a stock. Therefore, tablular estimates of optimum escapements and their probable bounds are presented in tables 40 to 45, Fig. 15, and Appendix II. These estimates are based on the above statistical estimates, plus our informed judgement and intuition regarding each stock. Optimum escapements estimated by the Geographic Working Group of the SEP program and the average escapement from 1975-1979 are also included for comparison.

Table 46 shows that on a coastwide basis, recent escapements (1975-79) of sockeye and even pink were only half of the G.W.G. optimums, while chum, coho, spring and odd pink escapements were only around 40% of the G.W.G. Optimums. Likewise, our estimates (Appendix II) indicate that recent escapements for all species were barely within the lower bounds of our estimates, and were only about 25% to 45% of the upper

Tables. 34-39. Optimum exploitation rate and maximum tolerable exploitation rate at different levels of λ .

? = estimation procedure failed

\- = insufficient information or negligible stock

SOCKEYE

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	-	-	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-	-	-
Nass	.66	.80	.67	.82	.70	.84	.72	.85	.72	.85
Skeena	.48	.64	?	?	?	?	?	?	?	?
C.C.	.59	.75	.59	.76	.60	.77	.62	.79	.64	.79
R-S	.75	.85	.71	.83	.69	.82	.69	.82	.69	.82
J.S.	.77	.85	.90	.95	.90	.95	.90	.95	.90	.95
G.S.	-	-	-	-	-	-	-	-	-	-
Fraser	.76	.87	.76	.88	.76	.88	.77	.89	.77	.89
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	?	?	?	?	?	?	?	?	?	?
NWVI	-	-	-	-	-	-	-	-	-	-

Table 34 :

CHUM

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	.69	.80	.70	.82	.72	.84	.72	.84	.72	.85
Q.C.2	.58	.71	.62	.75	.68	.80	.69	.81	.69	.82
Nass	.84	.92	.76	.93	.86	.93	.86	.93	.86	.93
Skeena	-	-	-	-	-	-	-	-	-	-
C.C.	.54	.69	.56	.72	.60	.76	.61	.77	.62	.78
R-S	-	-	-	-	-	-	-	-	-	-
J.S.	.58	.66	.48	.58	?	?	?	?	?	?
G.S.	.50	.63	.48	.63	.49	.64	.52	.67	.58	.73
Fraser	?	?	?	?	?	?	?	?	?	?
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	.37	.48	?	?	?	?	?	?	?	?
NWVI	.63	.75	.66	.80	.66	.81	.66	.81	.66	.81

Table 35 :

COHO

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	.81	.90	.80	.90	.80	.90	.80	.90	.80	.90
Q.C.2	.55	.72	.63	.71	.53	.71	.53	.72	.54	.72
Nass	.85	.95	.84	.93	.84	.92	.83	.92	.83	.92
Skeena	.73	.85	.73	.85	.75	.86	.75	.87	.75	.87
C.C.	.83	.91	.85	.92	.96	.99	.97	.99	.97	.99
R-S	.96	.98	.97	.99	.98	.99	.97	.99	.97	.99
J.S.	.85	.93	.85	.93	.84	.93	.84	.92	.83	.92
G.S.	.74	.87	.74	.87	.75	.88	.76	.88	.78	.89
Fraser	.88	.95	.90	.96	.92	.96	.94	.97	.94	.98
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	.60	.76	.56	.76	.54	.73	.54	.73	.54	.74
NWVI	.79	.88	.86	.93	.87	.94	.87	.94	.87	.94

Table 36 :

SPRING

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	-	-	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-	-	-
Nass	.76	.87	.79	.90	.79	.90	.79	.90	.79	.90
Skeena	.54	.71	.54	.71	.54	.72	.55	.73	.56	.73
C.C.	.65	.81	.67	.82	.68	.83	.69	.84	.69	.84
R-S	.89	.95	.90	.96	.90	.96	.90	.96	.90	.96
J.S.	.77	.89	.82	.91	.84	.93	.85	.93	.85	.93
G.S.	.66	.82	.67	.82	.68	.83	.68	.83	.68	.83
Fraser	.79	.92	?	?	?	?	?	?	?	?
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	.84	.92	.86	.93	.85	.93	.85	.93	.85	.93
NWVI	.58	.75	.60	.77	.61	.77	.61	.78	.62	.78

Table 37 :

ODD PINK

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	-	-	-	-	-	-	-	-	-	-
Q.C.2	-	-	-	-	-	-	-	-	-	-
Nass	.90	.95	.91	.95	.90	.95	.89	.95	.89	.95
Skeena	.64	.77	.65	.79	.66	.80	.66	.80	.66	.81
C.C.	?	?	?	?	?	?	?	?	?	?
R-S	-	-	-	-	-	-	-	-	-	-
J.S.	.73	.80	.73	.82	.75	.84	.76	.85	.77	.86
G.S.	.65	.76	.60	.74	?	?	?	?	?	?
Fraser	.85	.91	?	?	?	?	?	?	?	?
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	-	-	-	-	-	-	-	-	-	-
NWVI	-	-	-	-	-	-	-	-	-	-

Table 38 :

EVEN PINK

AREA	λ=0.0		λ=0.5		λ=1.0		λ=1.5		λ=2.0	
	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax	Uopt	Umax
Q.C.1	.57	.63	.50	.59	.47	.57	.45	.57	.44	.57
Q.C.2	.64	.75	?	?	?	?	?	?	?	?
Nass	?	?	?	?	?	?	?	?	?	?
Skeena	.66	.78	.62	.76	.60	.75	.58	.73	.56	.72
C.C.	.66	.79	?	?	?	?	?	?	?	?
R-S	.88	.90	.79	.89	.75	.89	.76	.89	.75	.89
J.S.	.57	.76	?	?	?	?	?	?	?	?
G.S.	-	-	-	-	-	-	-	-	-	-
Fraser	-	-	-	-	-	-	-	-	-	-
J.F.S.	-	-	-	-	-	-	-	-	-	-
SWVI	?	?	?	?	?	?	?	?	?	?
NWVI	.68	.75	.60	.73	.57	.72	.56	.71	.55	.71

Table 39 :

Tables 40-45. Current escapement, G.W.G. Optimum escapement estimates, and our optimum escapement estimates with probable bounds.

? = no estimate

\- = insufficient information or negligible stock

SOCKEYE

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	25000	55000	?	?	?
Q.C.2	13000	40000	?	?	?
Nass	195000	250000	181000	120000	360000
Skeena	820000	880000	868000	600000	1500000
C.C.	100000	325000	200000	100000	400000
R-S	390000	1200000	500000	400000	2000000
J.S.	37000	132000	?	?	?
G.S.	-	-	-	-	-
Fraser	1370000	?	4000000	2000000	8000000
J.F.S.	-	-	-	-	-
SWVI	260000	300000	300000	100000	1000000
NWVI	10000	?	?	?	?

Table 40 :

CHUM

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	78000	85000	?	?	?
Q.C.2	155000	450000	600000	206000	1000000
Nass	53000	90000	?	?	?
Skeena	10000	50000	?	?	?
C.C.	380000	1300000	684000	400000	1000000
R-S	34000	115000	?	?	?
J.S.	242000	430000	210000	150000	350000
G.S.	472000	1460000	415000	300000	500000
Fraser	435000	700000	1000000	600000	3000000
J.F.S.	18000	75000	?	?	?
SWVI	471000	362000	372000	300000	500000
NWVI	117000	280000	150000	100000	200000

Table 41 :

COHO

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	70000	150000	35000	15000	75000
Q.C.2	48000	?	80000	50000	140000
Nass	26000	45000	30000	10000	60000
Skeena	35000	148000	54000	10000	120000
C.C.	137000	369000	135000	80000	250000
R-S	5000	45000	10000	4000	?
J.S.	52000	122000	100000	40000	180000
G.S.	155000	410000	201000	100000	400000
Fraser	61000	175000	54000	20000	100000
J.F.S.	-	-	-	-	-
SWVI	48000	?	100000	50000	200000
NWVI	27000	?	35000	20000	50000

Table 42 :

SPRING

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	1000	5000	?	?	?
Q.C.2	-	-	-	-	-
Nass	7000	30000	80000	6000	10000
Skeena	22000	80000	22000	20000	50000
C.C.	29000	82000	30000	16000	50000
R-S	3000	10000	4000	3000	8000
J.S.	17000	50000	18000	10000	30000
G.S.	19000	148000	32000	20000	50000
Fraser	68000	155000	200000	100000	400000
J.F.S.	-	-	-	-	-
SWVI	15000	23000	?	?	?
NWVI	5000	?	?	?	?

Table 43 :

ODD PINK

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	13000	10000	?	?	?
Q.C.2	-	-	-	-	-
Nass	130000	300000	?	?	?
Skeena	1120000	1600000	701000	500000	900000
C.C.	1020000	3500000	3280000	2000000	?
R-S	58000	800000	?	?	?
J.S.	600000	1400000	600000	400000	1000000
G.S.	86000	?	362000	250000	2000000
Fraser	2440000	?	2000000	1500000	6000000
J.F.S.	-	-	-	-	-
SWVI	-	-	-	-	-
NWVI	-	-	-	-	-

Table 44 :

EVEN PINK

AREA	CURRENT ESC.	G.W.G. OPT.	OPT.	LOWER	UPPER
Q.C.1	251000	1000000	750000	600000	2500000
Q.C.2	692000	1600000	576000	400000	1000000
Nass	278000	300000	?	600000	?
Skeena	700000	1400000	600000	500000	1000000
C.C.	3300000	5345000	5160000	3000000	?
R-S	193000	275000	155000	100000	?
J.S.	1350000	1523000	?	1000000	?
G.S.	8000	426000	?	?	?
Fraser	-	-	-	-	-
J.F.S.	-	-	-	-	-
SWVI	7000	?	?	25000	?
NWVI	131000	255000	?	150000	?

Table 45 :

	G.W.G.	OPT.	LOWER	UPPER
SOCKEYE	.58	.52	.94	.24
CHUM	.46	.66	1.11	.35
COHO	.37	.80	1.66	.42
SPRING	.31	.53	.94	.28
O. PINK	.39	.76	1.13	.43
E. PINK	.57	.71	1.08	?

Table 46 : Ratio of current escapement to various optimum escapement estimates.

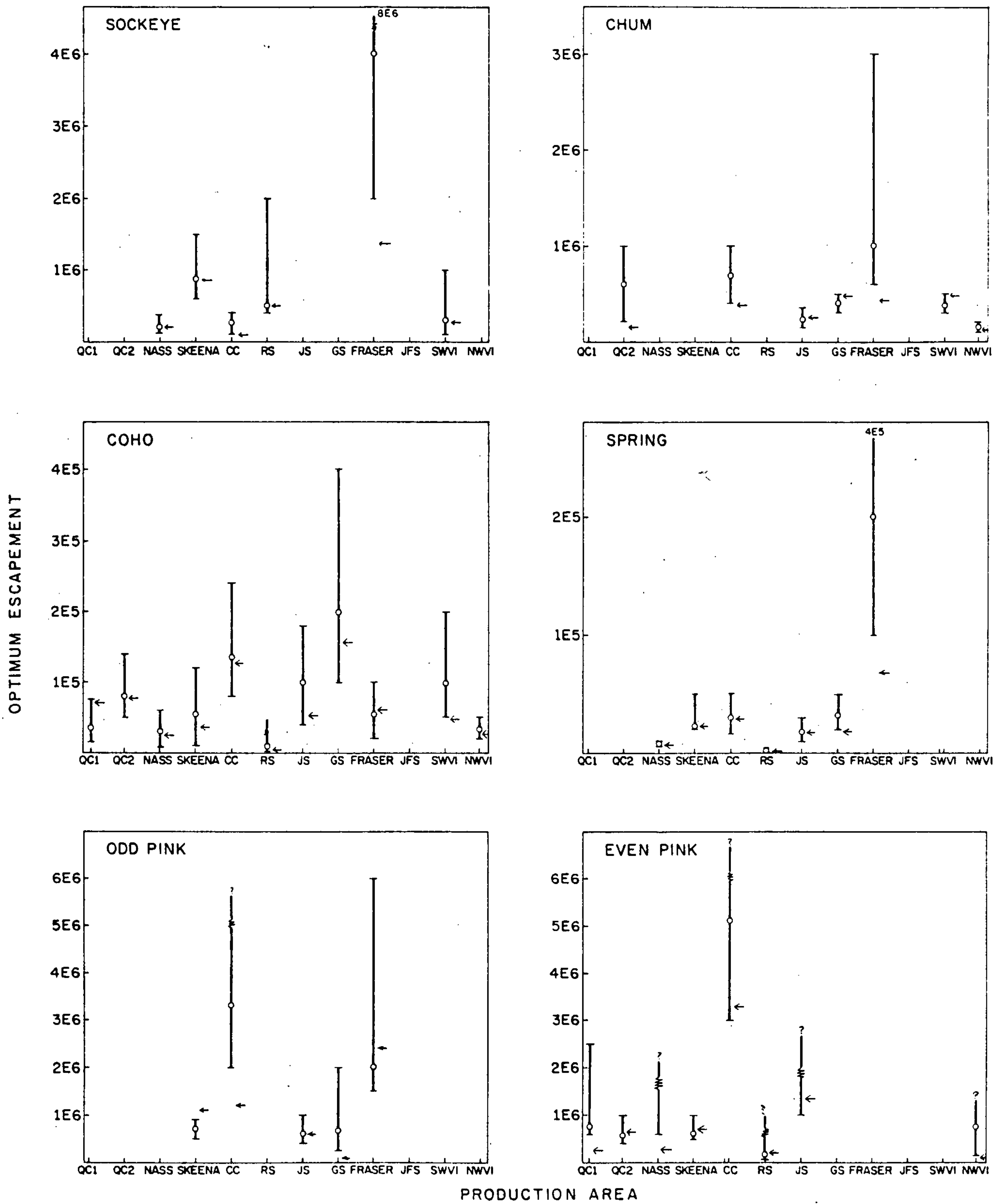
? = no estimate

bounds. Figure 17 shows graphically our optimum escapement estimates and their probable bounds, with arrows pointing to the average escapements from 1975-1979. It is apparent that most stocks are now being overexploited, with many larger ones being severely depleted (Fraser sockeye, Fraser chum, C.C. chum, Q.C. 2 chum, J.S. coho, SWVI coho, Fraser spring, G.S. odd pink, C.C. odd pink, Q.C.1 even pink and C.C. even pink).

Fig. 17. Optimum escapement estimates and probable bounds.

← = average escapement from 1975-1979

? = no estimate


SOCKEYE
CHUM
COHO
SPRING
ODD PINK
EVEN PINK
8E6
4E5
4E6
3E6
2E6
1E6
4E5
3E5
2E5
1E5
6E6
5E6
QC1 QC2 NASS SKEENA CC RS JS GS FRASER JFS SWVI NWVI
OPTIMUM ESCAPEMENT
PRODUCTION AREA

5. DISCUSSION AND CONCLUSION

Much time and effort have been spent in the past 30 years to monitor B.C. salmon catches and escapements. Yet few attempts have been made to systematically study the stock-recruitment problem. Because of difficulties in separating mixed catches and the presence of large sampling error in spawning counts, most researchers and biologists shy away from using the data to estimate "optimum" escapements. With little or no help from researchers, some managers attempt to resolve this difficult problem by defining "desired" or "optimum" escapement very simplistically (for example, the largest escapement since 1950 that has produced an equal or higher subsequent escapement). Some settle for the preservation of the status quo without questioning whether the current condition is even near optimum. And some simply react to whatever political pressure is on hand regardless of the consequences to the stocks that may be affected.

Until recently, it was generally believed that "adequate seeding" has been maintained in most rivers because recruitments have appeared to be independent of spawning stocks. However Walters and Ludwig (1981), Ludwig and Walters (1981) and the previous chapters have demonstrated that errors in spawning counts and/or poor catch separation techniques can lead to the appearance that recruitment is independent of spawners even for badly overexploited stocks. Despite such obvious biases, the data used in this study clearly show that many B.C. salmon stocks are now severely depleted (namely, Fraser sockeye, Fraser chum, C.C. chum, J.S. coho, SWVI coho, Fraser spring, G.S. odd pink, C.C. odd pink, Q.C.1 even pink and C.C. even pink). Restoration of these stocks by increasing escapement to the optimum levels, according to our estimates in Appendix II, would increase the annual sustainable yield of sockeye by 3.5 million pieces (around 50% of current yield), chum by 1.3 million (83%), spring by .2 million (23%), odd pink by 2.8 million (25%), and even pink by 6.8 million (65%). We predict the total increase in catch would be 14.7 million pieces (43% of current yield). Conclusive estimates cannot be made for most of the other stocks (which account for about half of the total B.C. production) because of poor escapement counts and/or difficulties in separating mixed catches (especially coho and spring stocks). Further, experimental management (by increased escapement) appears to be the best policy for a few stocks (e.g. R-S sockeye, G.S. coho, Skeena spring, Fraser odd pink, Nass even pink and J.S. even pink).

Three options have been suggested (Walters et. al. 1982) for increasing B.C. salmon production. One option ("bite the bullet") is to stop fishing Fraser sockeye, most chum and pink stocks and a few spring stocks for some years, and then exploit the resulting larger stocks at a lower rate into the future. Such drastic action is obviously unaccaptable both socially and politically. A second option ("the American plan") is to continue increasing the productivity of some stocks by enhancement technology (hatcheries, spawning channels etc.) to sustain the current large fleet and high effort. The higher exploitation rates required to harvest this enhanced production would inevitably cause a sharp decline in wild stocks (traditional fishing methods are incapable of harvesting enhanced stocks separately). This approach would best serve the immediate demands of today's commercial and sport industry. The third option ("Hilborn plan") is to co-ordinate the current SEP enhancement projects with management efforts to "buffer" the natural stocks with enhancement production. Under this option, mixed area catches would be limited to current or lower levels, with much enhancement production taken at (or near) enhancement facilities. By limiting the catches in the mixed areas, increased stock sizes due to enhancement would result in lower exploitation rates on wild stocks and these should begin a gradual recovery to optimum levels. One drawback in this approach is the potential economic loss and marketing problem associated with terminal harvest of lower quality enhanced fish, and the less desireable style of fishing imposed on fishermen to harvest the enhanced stocks near enhancement facilities. A second drawback with the "Hilborn Plan" is the environment for management created by the fishermen seeing increasing abundance and catch per effort combined with reduced fishing time (less effort to take the same quota); it might prove politically impossible to hold the line with fixed quotas.

Regardless of the future approach to enhancement, improved monitoring of catches, escapements, age structure, migration routes, and fishing effort should be given the highest priority among departmental programs. It has been clearly demonstrated in this study that occasional tagging studies and intuitive escapement evaluations are not adequate to provide a sound basis for salmon management. It is imperative that a long term program, provided with adequate resources and well trained staff, be established within the Department of Fisheries and Oceans to conduct proper sampling and ensure the efficient distribution of essential data. Without such a program, current management policies can never be evaluated, and the likely consequences of new policies cannot be perceived.

As long as salmon fishing is conducted on maturing fish in coastal waters,the most crucial need in management will continue to be understanding of the relationship between spawning stock and subsequent recruitment. To measure the quantitative effect of different spawning levels on subsequent recruitment, this study has taken as an initial working hypothesis that for each stock there exists a stationary (time independent) probability distribution of recruits for each possible level of spawning population, with the means of these distributions varying smoothly according to some stock-recruitment curve. By fitting stock-recruitment curves through historical data, deviations from the curves can be used as a crude test of the stationarity hypothesis. No clear trends in these deviations were evident for most stocks (Appendix II). However, because of difficulties in separating mixed catches, many "stocks" from large geographical areas were aggregated as "production areas" to form the basic units of this analysis. Under these circumstances, the stationarity hypothesis is valid only if the component "stocks" within the aggregated unit have stable relative vulnerabilities to fishing and are subject to the same or correlated environmental influences. Otherwise the stock-recruitment relationship for the aggregated unit should change over time, and the optimum rate of exploitation becomes very difficult to define (Ricker 1973). It is more difficult to detect overexploitation in aggregated units before considerable damage has been done, and rehabilitation efforts (by increasing overall escapement) may require much longer than would be predicted by assuming stationarity of historical patterns.

One of the biggest uncertainties encountered in this analysis is the estimation of the contribution of stocks to mixed fisheries. The past decade witnessed a dramatic increase in the efficiency of fishing gears, especially purse seines, used in the B.C. salmon fishery. To prevent overfishing of some local stocks, the Department of Fisheries has been moving fishing areas away from river mouths into areas where stocks are mixed (Anderson 1980). International conflicts prompted the development of the Johnstone Strait mixed fishery to take Fraser pink and sockeye before they reach the I.P.S.F.C. conventional waters where they are split 50:50 with the Americans. Similarly the troll fleet, which operates where all North American stocks are mixed, has been encouraged to take advantage of the American enhancement production of coho and spring. The result of all this is that it is now almost impossible to measure the contribution of any single stock very accurately. Hopefully, the recent increase in fuel costs, the interim agreement with the United States and the possibility of area licencing will provide the rationale for moving the fisheries back into more terminal areas. And by increasing the use of stock identification techniques (e.g. scale analysis, coded wire tags, parasite composition, etc.), the contribution of stocks to mixed fisheries can be estimated more accurately in the future.

Equally uncertain is the estimation of spawning populations for most stocks. Apart from the few rivers equipped with counting fences, there are no standardized sampling procedures or prescribed observation sites to ensure consistency in spawning estimates made by fisheries officers. Discrepancies by an order of magnitude have been found between officer estimates and independent checks through mark recovery, diving or fence counts. Appraisals by different officers also show large and inconsistent discrepancies among different streams. Furthermore, the recording procedure alone (by wide abundance classes) would introduce errors of +- 30%. Obviously more rigorous and consistent procedures are needed for the enumeration of spawning populations. However, to accurately enumerate more than 1200 streams, each with 1 to 5 species of salmon spawning at different times of the year, would require substantially more resources and manpower. Given the limited resources available today, a better approach to this problem may be to rigorously assess a few representative stocks in each production area, rather than trying to obtain doubtful information for all stocks.

Because of the generally poor quality of the data base and lack of understanding of its error structure, conclusive remarks cannot be made about the stock-recruitment dynamics of more than half of the B.C. salmon stocks. However, several findings are worth further investigation. Perhaps the largest uncertainty about future salmon production concerns coho and spring. This study indicates that they are significantly more productive than the other species. But it is also known that coho and spring spawning stocks are generally the most difficult to enumerate. Besides, the exploitation pattern of these two species (mostly by trolling in areas where many stocks mix) renders the catch allocation procedures more prone to error. Consequently the estimated "α" parameters (Ricker model) for coho and spring stocks are most likely to be biased upward. Furthermore, it is quite possible that natural production of these species has declined drastically since 1960 from all B.C. rivers, with the trend being masked by more intensive efforts to count escapements and by increases in the catches due to American enhancement production.

Chum salmon stocks show a significant trend of decreasing productivity from north to south. However, the population sizes of chum stocks in the south are significantly larger than those in the north. Hence a significant negative correlation is found between stock size and productivity. A significant negative correlation is also found between stock size and variability in chum salmon stocks. These observations may represent natural relationships or they may be due to poor data and/or assessment methods. For example, chum salmon produced from the south might be caught much further north than we have though; assessment of larger stocks might have been given more attention and effort; and smaller stocks are more sensitive to the mixed catch allocation problem. In any case, further investigation is recommended.

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Appendix Ia. Age composition of catch (from Bilton et. Al.)

area = statistical area

3/2 = 3 : three years old, left freshwater at age 2

= number sampled

%F = percent female

? = no data

SOCKEYE

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
3	51	0	410	90	0	0	310	130	?	?
3	52	0	280	190	0	0	460	40	?	?
3	53	0	230	220	0	0	460	90	?	?
3	54	0	350	200	0	0	400	50	?	?
3	55	0	120	150	0	0	700	20	?	?
3	56	0	270	90	0	0	500	140	?	?
3	57	2	135	120	0	1	704	35	996	583
3	58	1	254	275	0	0	425	40	1916	544
3	59	1	56	258	0	5	635	38	1264	551
3	60	2	523	101	0	0	270	85	771	378
3	61	2	515	131	1	1	301	8	1883	505
3	62	1	180	503	1	1	270	41	1759	583
3	63	1	523	109	0	1	314	51	493	507
3	64	16	127	372	0	2	460	14	1241	583
3	65	9	508	161	1	3	222	91	914	517
3	66	59	367	326	0	0	212	31	1413	548
3	67	1	432	495	0	1	46	19	2452	521
3	68	3	121	646	3	0	194	31	429	586
3	69	5	287	309	0	2	353	43	781	531
3	70	7	308	296	0	3	313	73	308	574
3	71	0	420	199	0	0	324	54	203	502
3	72	29	216	365	0	5	307	76	817	558
3	73									
3	74									
3	75									
3	76									
3	77									
3	78									
3	79									
4	51	0	330	610	0	0	40	10	?	?
4	52	0	660	260	0	0	30	50	?	?
4	53	0	480	430	0	0	60	30	?	?
4	54	0	330	540	0	0	100	20	?	?
4	55	0	150	590	0	0	140	110	?	?
4	56	0	840	140	0	0	10	10	?	?
4	57	6	677	268	0	0	41	8	1022	488
4	58	2	338	630	0	1	25	3	3033	585
4	59	1	139	654	0	1	181	24	943	587
4	60	4	492	373	0	1	53	74	1099	473
4	61	1	783	177	0	1	23	14	2240	557
4	62	1	319	630	1	0	33	14	1931	610
4	63	3	619	252	0	1	102	20	1794	488
4	64	1	225	706	0	0	54	11	3324	602
4	65	0	432	487	1	0	47	32	853	588
4	66	8	449	456	0	1	62	24	2258	547
4	67	0	442	510	0	0	19	28	1499	522
4	68	1	111	829	0	0	34	25	677	654
4	69	2	484	424	0	0	64	25	914	557
4	70	1	606	302	0	0	50	39	572	591
4	71	2	568	385	0	0	30	13	660	589
4	72	16	207	724	0	2	34	16	752	621
4	73	0	544	367	0	0	66	3	?	?
4	74	0	325	637	0	0	28	10	?	?
4	75	0	702	271	0	0	23	3	?	?
4	76	0	387	602	0	0	8	3	?	?
4	77	0	441	530	0	0	27	2	?	?
4	78									
4	79									
5	57									
5	58									
5	59	10	289	403	0	3	234	58	1137	517
5	60	14	487	267	4	3	109	112	565	501
5	61	19	573	276	0	12	80	33	738	548
5	62	40	465	272	0	15	181	24	750	498
5	63	27	475	137	0	11	297	43	614	534
5	64	15	219	526	0	6	180	49	632	551
5	65	8	523	309	0	1	92	58	643	550
5	66	75	311	475	0	28	76	24	453	527
5	67	7	561	211	0	3	172	30	267	492
5	68	2	305	529	2	0	118	40	331	559
5	69	4	366	369	0	0	235	24	276	496
5	70									
5	71	12	473	340	0	18	97	50	276	551
5	72	59	287	461	1	26	119	44	614	559
5	73									
5	74									
5	75									
5	76									
5	77									
5	78									
5	79									
6	57									
6	58									
6	59	1	233	427	0	3	236	100	361	520
6	60	11	445	309	1	6	116	112	1002	512
6	61	39	487	282	0	18	96	42	729	498
6	62	24	387	431	2	5	119	21	1400	543
6	63	95	575	119	0	39	113	32	694	392
6	64	5	187	601	0	7	144	42	538	598
6	65	30	518	269	5	17	109	30	658	517
6	66	130	385	395	3	16	50	11	602	462
6	67	17	504	394	0	2	42	13	228	428
6	68	8	240	550	0	7	131	43	405	564
6	69	48	290	428	0	0	205	19	240	537
6	70	96	356	127	0	19	144	231	104	471
6	71	0	627	240	0	0	120	13	75	560

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
6	72	37	351	385	4	17	129	50	757	574
6	73									
6	74									
6	75									
6	76									
6	77									
6	78									
6	79									
7	57									
7	58									
7	59									
7	60	21	596	84	2	19	232	45	507	522
7	61	99	643	121	0	76	55	3	378	446
7	62	19	563	248	0	4	144	14	863	534
7	63	27	793	30	0	18	132	0	535	545
7	64	25	446	242	0	28	247	12	611	537
7	65	28	572	201	0	4	145	40	254	568
7	66	1	802	146	0	0	39	4	868	533
7	67	15	714	97	0	21	134	8	795	530
7	68	8	390	312	0	27	214	6	409	551
7	69	55	295	308	0	0	342	0	57	561
7	70	62	547	131	11	24	81	119	434	449
7	71									
7	72									
7	73									
7	74									
7	75									
7	76									
7	77									
7	78									
7	79									
8	57									
8	58									
8	59	9	537	262	0	1	164	20	496	597
8	60	16	704	167	2	1	93	11	1528	538
8	61	13	641	147	0	6	183	2	606	521
8	62	33	631	187	1	8	129	2	1787	583
8	63	21	755	97	0	5	107	1	965	560
8	64	12	391	413	0	4	150	17	1865	612
8	65	182	588	76	3	8	106	6	743	466
8	66	7	649	244	0	1	75	3	1117	578
8	67	7	722	59	0	4	179	8	2147	552
8	68	11	231	564	0	8	149	10	756	640
8	69	0	465	143	0	0	321	0	28	607
8	70	130	572	115	2	17	71	26	469	559
8	71	0	794	87	0	0	106	0	277	563
8	72									
8	73									

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
8	74									
8	75									
8	76									
8	77									
8	78									
8	79									
9	51	0	380	600	0	0	10	10	?	?
9	52	0	410	580	0	0	10	0	?	?
9	53	0	730	260	0	0	10	0	?	?
9	54	0	600	390	0	0	10	0	?	?
9	55	0	450	540	0	0	0	10	762	?
9	56	0	100	900	0	0	0	0	?	?
9	57	1	645	336	3	0	9	4	1000	455
9	58	2	280	701	1	0	10	2	1545	472
9	59	2	187	764	4	0	28	12	1289	524
9	60	2	381	552	3	0	20	40	2079	525
9	61	1	486	460	0	1	30	20	1299	545
9	62	3	904	55	1	1	27	4	1657	428
9	63	2	371	581	0	1	22	18	1636	514
9	64	1	127	776	1	0	16	74	1678	593
9	65	8	690	250	2	0	21	5	836	483
9	66	1	336	637	0	1	17	3	1182	560
9	67	1	782	141	0	1	57	8	2777	368
9	68	1	69	894	1	1	5	26	1282	639
9	69	1	350	592	10	1	17	20	1070	460
9	70	6	425	433	9	0	40	40	223	646
9	71	1	753	159	0	1	65	11	427	492
9	72	0	442	474	0	0	18	37	283	392
9	73	0	82	916	0	0	0	0	827	?
9	74	0	421	567	12	0	0	0	323	?
9	75	11	735	250	4	0	0	0	616	?
9	76									
9	77									
9	78									
9	79									
10	51	0	220	770	0	0	0	0	?	?
10	52	0	80	910	0	0	0	0	?	?
10	53	0	890	100	0	0	0	10	?	?
10	54	10	610	380	0	0	0	0	?	?
10	55	0	420	580	0	0	0	0	?	?
10	56	0	40	960	0	0	0	0	?	?
10	57	0	584	410	1	0	2	3	661	478
10	58	0	257	724	0	0	19	0	310	577
10	59	1	159	782	1	1	37	9	593	471
10	60	1	226	712	2	0	20	35	2038	535
10	61	0	446	514	1	0	26	9	1287	546
10	62	1	859	65	0	0	65	6	1332	436
10	63	0	314	653	0	0	23	6	705	525

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
10	64	0	135	773	0	4	34	36	819	539
10	65	0	646	296	4	0	41	2	1124	460
10	66	0	56	920	0	0	6	6	177	594
10	67	0	708	178	0	0	58	13	1165	330
10	68	1	181	783	0	0	6	2	777	572
10	69	0	211	767	11	0	0	0	97	515
10	70	12	290	575	0	4	23	62	304	566
10	71	0	604	370	2	0	16	0	205	551
10	72									
10	73									
10	74									
10	75									
10	76									
10	77									
10	78									
10	79									
12	57									
12	58	1	976	10	0	0	13	0	1082	544
12	59	5	869	66	1	1	53	5	1214	581
12	60	5	892	75	1	1	22	4	2227	547
12	61	27	848	97	0	2	21	1	1783	519
12	62	9	847	74	0	6	62	2	1120	524
12	63	6	843	84	0	1	59	5	1522	551
12	64	9	336	512	0	1	112	19	1637	571
12	65	56	775	97	0	5	59	1	953	480
12	66	31	901	49	0	1	12	2	1766	524
12	67	1	917	34	0	1	42	1	4151	550
12	68	8	543	325	0	0	106	16	416	600
12	69	16	792	146	0	0	42	2	1324	493
12	70	18	899	59	0	1	19	1	822	490
12	71	4	892	67	0	0	32	0	846	510
12	72	1	814	120	0	0	53	11	290	559
13	57									
13	58	6	974	11	0	0	7	0	920	578
13	59	9	843	84	0	1	59	4	657	549
13	60	3	950	31	0	2	13	1	867	494
13	61	55	877	55	1	3	6	2	1650	477
13	62	0	978	0	0	15	7	0	107	701
13	63	22	908	19	0	1	47	0	329	545
13	64	44	783	90	0	5	66	10	304	591
13	65	226	676	75	0	4	19	0	332	480
13	66									
13	67	3	945	20	0	1	28	0	817	602
13	68	0	845	99	0	0	53	2	129	527
13	69	39	792	111	0	0	32	26	307	541
13	70	0	974	0	0	0	0	0	38	737
13	71	1	933	45	0	0	21	0	527	512
13	72	0	798	174	0	0	21	0	128	500

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
16	57									
16	58									
16	59									
16	60									
16	61	23	920	33	0	2	21	0	274	550
16	62	6	927	41	0	0	26	0	227	620
16	63	0	919	23	0	12	46	0	86	558
16	64	0	845	95	0	0	60	0	84	464
16	65									
16	66									
16	67									
16	68									
16	69									
16	70									
16	71									
16	72	0	780	147	0	0	73	0	41	527
20	57									
20	58									
20	59									
20	60									
20	61									
20	62									
20	63	29	836	16	0	0	110	0	115	606
20	64									
20	65	126	748	43	0	7	63	2	806	477
20	66	19	924	25	0	1	22	5	562	517
20	67	2	956	22	0	1	16	1	1878	562
20	68	6	922	40	0	0	31	0	402	592
20	69	21	815	103	0	1	33	19	602	535
20	70	15	941	15	0	0	27	1	453	556
20	71	3	923	37	0	0	31	0	804	474
20	72	7	921	22	0	1	20	17	635	527
23	57									
23	58									
23	59									
23	60	0	738	118	0	0	134	10	660	515
23	61	0	810	147	0	3	17	21	467	528
23	62	0	748	135	0	0	111	3	1154	506
23	63	0	743	101	0	0	143	10	219	508
23	64	0	621	150	0	0	136	7	678	469
23	65									
23	66									
23	67	0	635	122	0	0	156	70	115	391
23	68									
23	69	0	761	159	0	0	80	0	113	487
23	70	0	408	487	0	0	65	26	76	447
23	71	0	741	153	10	0	87	9	104	413
23	72	0	749	87	0	0	156	6	241	512

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
23	73									
23	74									
23	75									
23	76									
23	77									
23	78									
23	79									
24	57									
24	58									
24	59									
24	60	0	633	354	0	0	11	2	315	474
24	61	46	681	221	0	5	16	1	331	507
24	62	0	953	26	0	0	21	0	568	450
24	63									
24	64	5	579	386	0	0	30	0	424	513
24	65									
24	66									
24	67	0	795	190	0	0	10	0	283	473
24	68	0	394	578	0	0	18	8	187	532
24	69	1	442	512	1	1	40	3	155	506
24	70									
24	71									
24	72									
27	57									
27	58									
27	59									
27	60									
27	61									
27	62									
27	63									
27	64									
27	65									
27	66									
27	67	0	738	115	3	0	119	10	466	352
27	68	0	46	814	0	0	46	94	43	488
27	69	0	815	148	0	0	37	0	27	370
27	70									
27	71	0	812	128	0	0	50	0	179	475
27	72									
29	57									
29	58									
29	59									
29	60									
29	61									
29	62	1	938	27	0	1	30	1	2412	527
29	63	2	932	4	0	5	53	2	1627	518
29	64	9	828	101	0	1	47	11	1868	499
29	65	5	911	42	0	0	39	2	2562	539
29	66	13	880	75	0	0	28	2	1772	511
29	67	3	956	28	0	1	9	1	3223	560
29	68	1	878	57	0	4	54	0	914	517
29	69	1	877	82	0	0	36	4	1163	538
29	70	6	944	18	0	1	21	1	684	542
29	71	1	934	41	0	16	3	0	1207	526
29	72	0	874	71	0	0	46	2	677	558
29	73									
29	74									
29	75									
29	76									
29	77									
29	78									
29	79									

CHUM

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
3	57	0	108	776	116	0	1176	458
3	58	0	125	734	141	0	1627	418
3	59	0	169	622	209	0	805	468
3	60	0	183	803	14	0	1237	482
3	61	0	45	917	38	0	1665	521
3	62	0	377	331	292	0	1116	405
3	63	0	215	768	14	3	373	495
3	64	0	56	917	27	0	923	518
3	65	1	68	723	208	0	286	242
3	66	0	58	893	49	0	190	511
3	67	0	219	580	201	0	767	575
3	68	0	18	909	68	5	512	585
3	69	0	150	559	291	0	264	466
3	70	0	28	961	11	0	199	472
3	71	0	173	433	394	0	84	464
3	72	0	17	945	36	2	581	520
3	73							
3	74							
3	75							
3	76							
3	77							
3	78							
3	79							
4	57	0	39	926	35	0	744	353
4	58	0	68	829	103	0	1000	399
4	59							
4	60	0	186	791	23	0	355	456
4	61	0	89	873	38	0	1230	433
4	62	0	274	510	216	0	1123	434
4	63	0	286	690	24	0	825	413
4	64	0	95	852	53	0	379	373
4	65	0	0	1000	0	0	8	625
4	66	0	20	980	0	0	50	680
4	67	0	285	402	313	0	133	505
4	68	0	17	952	25	6	262	441
4	69	0	264	491	245	0	130	308
4	70	0	0	867	133	0	14	643
4	71	0	153	553	294	0	36	500
4	72	0	9	935	56	0	622	485
4	73							
4	74	0	0	809	191	0	?	?
4	75	0	0	875	125	0	?	?
4	76	0	0	1000	0	0	?	?
4	77	0	0	929	71	0	?	?
4	78							
4	79							
5	57	0	177	734	89	0	192	364
5	58	0	54	907	39	0	301	514
5	59	0	329	528	143	0	333	400
5	60	0	602	392	6	0	353	510
5	61	0	113	864	23	0	773	521
5	62	2	256	596	146	0	975	506
5	63	0	482	484	32	2	701	465
5	64	0	209	772	19	0	1233	531
5	65	0	142	795	63	0	123	543
5	66	0	80	900	20	0	582	555
5	67	0	308	549	143	0	91	418
5	68	0	31	950	19	0	412	516
5	69	0	130	217	653	0	23	521
5	70	0	58	922	13	0	126	476
5	71	0	392	469	139	0	66	469
5	72	0	28	900	72	0	371	483
5	73							
5	74							
5	75							
5	76							
5	77							
5	78							
5	79							
6	57							
6	58	0	28	944	28	0	201	447
6	59	0	554	246	200	0	235	527
6	60	0	640	355	4	1	1275	482
6	61	0	328	657	14	1	795	574
6	62	0	226	745	29	0	2612	480
6	63	0	658	311	31	0	967	508
6	64	0	189	801	10	0	544	540
6	65	0	127	792	81	0	322	443
6	66	0	105	866	29	0	1236	603
6	67	0	250	510	240	0	150	324
6	68	0	21	975	4	0	587	590
6	69	0	235	550	215	0	149	316
6	70	0	61	937	2	0	843	471
6	71							
6	72	0	73	902	23	2	958	515
6	73							
6	74							
6	75							
6	76							
6	77							
6	78							
6	79							
7	57							
7	58	0	91	884	25	0	1768	493
7	59	0	349	524	127	0	394	460
7	60	0	598	391	11	0	3376	498

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
7	61	0	533	456	11	0	1715	467
7	62	0	398	592	10	0	1008	481
7	63	0	546	434	20	0	1164	501
7	64	0	97	875	28	0	1655	535
7	65	0	257	637	106	0	496	488
7	66	0	151	837	12	0	1428	521
7	67	0	343	523	134	0	895	458
7	68	1	172	814	12	1	753	481
7	69	0	599	347	49	5	330	400
7	70	0	117	883	0	0	707	554
7	71							
7	72	0	204	740	56	0	303	514
7	73							
7	74							
7	75							
7	76							
7	77							
7	78							
7	79							
8	57							
8	58	0	101	856	43	0	2695	488
8	59	0	269	671	60	0	492	570
8	60	0	585	405	10	0	3817	489
8	61	2	366	615	17	0	1395	454
8	62	0	484	493	23	0	2838	461
8	63	1	480	506	13	0	1959	489
8	64	1	34	941	24	0	2021	477
8	65	0	142	544	314	0	392	461
8	66	0	184	802	14	0	2670	509
8	67	0	304	533	162	1	1252	464
8	68	0	36	939	25	0	1102	501
8	69	0	691	229	80	0	304	326
8	70	0	52	948	0	0	458	443
8	71	0	160	753	87	0	243	280
8	72	0	0	1000	0	0	49	449
8	73							
8	74							
8	75							
8	76							
8	77							
8	78							
8	79							
9	57							
9	58	0	114	869	17	0	341	443
9	59							
9	60	0	745	249	6	0	1099	572
9	61	0	320	659	21	0	739	478
9	62	0	257	723	20	0	531	397

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
9	63	0	586	399	15	0	619	531
9	64	0	58	920	22	0	91	381
9	65	0	185	720	95	0	212	415
9	66	0	163	815	22	0	497	504
9	67	0	375	459	166	0	800	532
9	68	0	34	956	9	1	532	468
9	69	0	772	137	90	1	556	343
9	70	0	83	915	2	0	329	486
9	71							
9	72							
9	73							
9	74							
9	75							
9	76							
9	77							
9	78							
9	79							
10	57							
10	58							
10	59	0	398	530	72	0	194	456
10	60	0	713	275	12	0	812	536
10	61	0	433	560	7	0	149	552
10	62	0	161	816	23	0	270	466
10	63	0	693	297	10	0	178	535
10	64	0	142	850	8	0	278	520
10	65	0	137	645	218	0	209	345
10	66	0	190	760	50	0	79	316
10	67	0	395	546	59	0	1283	517
10	68	0	62	931	5	2	445	499
10	69	0	303	518	179	0	75	253
10	70	0	175	825	0	0	163	528
10	71							
10	72							
10	73							
10	74							
10	75							
10	76							
10	77							
10	78							
10	79							
12	57							
12	58	0	81	907	12	0	549	425
12	59	0	317	660	23	0	1230	487
12	60	0	416	571	12	1	2602	488
12	61	1	100	881	18	0	1790	554
12	62	0	617	355	28	0	766	511
12	63	0	386	606	8	0	1812	547
12	64	1	133	854	12	0	2014	538

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
12	65	3	84	839	74	0	519	426
12	66	1	261	686	52	0	637	470
12	67	0	384	533	83	0	1226	398
12	68	0	155	837	7	1	413	523
12	69	1	385	558	56	0	1678	423
12	70	0	50	942	8	0	709	479
12	71	0	326	545	129	0	322	435
12	72	0	78	895	27	0	842	568
12	73							
12	74							
12	75							
12	76							
12	77							
12	78							
12	79							
13	57							
13	58	0	428	571	1	0	322	421
13	59	0	355	627	18	0	1241	506
13	60	0	417	576	7	0	1626	464
13	61	0	125	842	33	0	1120	552
13	62	0	833	142	25	0	511	394
13	63	0	347	652	1	0	748	554
13	64	0	125	750	125	0	110	386
13	65	0	191	681	128	0	47	553
13	66							
13	67	0	594	384	22	0	471	435
13	68	0	228	769	3	0	425	533
13	69	0	450	503	47	0	577	478
13	70	0	70	925	5	0	362	497
13	71	0	382	383	235	0	115	330
13	72	0	64	922	11	3	651	534
13	73							
13	74							
13	75							
13	76							
13	77							
13	78							
13	79							
14	57							
14	58							
14	59							
14	60	0	429	564	7	0	227	427
14	61	0	92	903	5	0	110	752
14	62	0	767	206	27	0	219	429
14	63							
14	64							
14	65							
14	66							

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
14	67							
14	68							
14	69							
14	70							
14	71							
14	72							
16	57							
16	58							
16	59	0	345	645	10	0	474	553
16	60	0	460	539	1	0	279	420
16	61	0	176	820	4	0	274	547
16	62	0	788	184	28	0	261	487
16	63							
16	64							
16	65							
16	66							
16	67							
16	68							
16	69							
16	70							
16	71							
16	72							
18	57							
18	58							
18	59							
18	60	0	596	388	16	0	312	526
18	61	0	235	763	2	0	455	533
18	62	0	846	148	6	0	182	516
18	63	0	281	719	0	0	423	643
18	64	0	652	348	0	0	89	719
18	65							
18	66							
18	67							
18	68							
18	69							
18	70							
18	71							
18	72	0	40	960	0	0	101	545
20	57							
20	58	2	716	264	18	0	352	465
20	59	4	297	695	4	0	828	487
20	60	0	674	320	6	0	958	494
20	61	0	266	725	9	0	390	539
20	62	0	840	148	12	0	441	536
20	63	2	490	503	5	0	515	542
20	64	2	716	272	1	0	1392	524
20	65	0	114	882	4	0	735	488
20	66	2	451	500	47	0	753	457

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
20	67	0	598	389	13	0	1156	494
20	68	1	186	800	13	0	574	500
20	69	1	167	802	3	0	613	506
20	70	0	262	724	14	0	398	487
20	71	0	508	447	45	0	87	368
20	72	0	20	973	7	0	422	637
20	73							
20	74							
20	75							
20	76							
20	77							
20	78							
20	79							
20	80							
22	57							
22	58							
22	59							
22	60	0	424	575	1	0	441	464
22	61							
22	62							
22	63							
22	64							
22	65							
22	66							
22	67							
22	68							
22	69							
22	70							
22	71	0	957	14	29	0	70	?
22	72	0	16	984	0	0	540	525
22	73	0	9	523	468	0	643	?
22	74	0	394	129	477	0	155	?
22	75							
22	76	0	206	765	29	0	?	?
22	77	0	84	897	19	0	107	?
22	78	0	300	600	100	0	?	?
22	79							
22	80							
23	57							
23	58							
23	59	0	414	564	22	0	276	436
23	60	0	467	520	13	0	566	472
23	61	0	518	459	17	0	446	501
23	62	0	575	417	4	0	273	538
23	63							
23	64							
23	65							
23	66							

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
23	67							
23	68							
23	69	0	160	840	0	0	?	?
23	70	0	392	584	24	0	209	?
23	71	0	301	676	23	0	216	?
23	72	0	102	866	32	0	385	?
23	73	0	149	770	81	0	87	?
23	74							
23	75	0	222	754	25	0	394	?
23	76	0	54	901	45	0	?	?
23	77	0	450	500	50	0	478	?
23	78	0	200	777	3	0	?	?
23	79							
23	80							
24	57							
24	58							
24	59							
24	60	0	407	585	8	0	232	394
24	61	0	423	554	23	0	267	506
24	62							
24	63	0	504	496	0	0	224	371
24	64							
24	65							
24	66							
24	67							
24	68							
24	69	0	400	600	0	0	?	?
24	70							
24	71	0	437	523	40	0	197	?
24	72							
24	73							
24	74	0	176	583	221	0	240	?
24	75	0	399	593	8	0	391	?
24	76	0	138	846	14	0	282	?
24	77	0	430	500	7	0	634	?
24	78							
24	79							
24	80							
25	57							
25	58							
25	59	0	598	396	6	0	394	353
25	60	0	800	200	0	0	411	513
25	61	0	259	730	10	0	1189	500
25	62	0	430	554	12	0	905	537
25	63	0	711	278	11	0	270	441
25	64	0	327	673	0	0	617	584
25	65							
25	66							

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
25	67							
25	68							
25	69	0	583	417	0	0	?	?
25	70	0	319	681	0	0	91	?
25	71	0	349	580	71	0	612	?
25	72	0	94	885	21	0	192	?
25	73	0	143	675	181	0	154	?
25	74	0	261	595	144	0	383	?
25	75	0	137	806	57	0	124	?
25	76	0	266	649	35	0	?	?
25	77	0	561	413	26	0	726	?
25	78							
25	79							
25	80							
26	57							
26	58							
26	59	0	569	408	21	0	363	493
26	60	0	634	359	7	0	472	424
26	61	0	142	848	10	0	906	558
26	62	0	504	482	11	0	759	526
26	63	0	469	520	11	0	179	447
26	64							
26	65							
26	66							
26	67							
26	68							
26	69							
26	70							
26	71							
26	72	0	147	833	20	0	102	?
26	73							
26	74							
26	75	0	165	694	141	0	?	?
26	76	0	90	840	64	0	?	?
26	77	0	644	339	17	0	492	?
26	78							
26	79							
26	80							
27	57							
27	58							
27	59							
27	60	0	917	83	0	0	305	450
27	61							
27	62							
27	63							
27	64							
27	65							
27	66							

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
27	67							
27	68							
27	69							
27	70							
27	71							
27	72							
27	73	0	66	778	156	0	486	?
27	74							
27	75							
27	76							
27	77	0	611	377	12	0	424	?
27	78							
27	79							
27	80							
29	57	0	259	697	44	0	329	427
29	58	0	571	424	5	0	452	446
29	59	0	408	587	5	0	1576	481
29	60	0	346	643	11	0	1660	427
29	61	0	75	907	18	0	1417	600
29	62	0	772	206	22	0	1157	454
29	63	0	289	707	4	0	745	547
29	64	0	147	832	21	0	954	487
29	65	0	21	970	9	0	168	452
29	66	0	70	908	22	0	231	515
29	67	0	549	423	28	0	733	523
29	68	0	203	791	6	0	790	495
29	61	0	375	601	24	0	525	368
29	70	0	90	906	4	0	332	494
29	71							
29	72	0	21	976	3	0	321	574
29	73							
29	74							
29	75							
29	76							
29	77							
29	78							
29	79							
29	80							

Age composition of escapement (from district management biologists)

SOCKEYE

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
3	64	0	48	120	0	0	810	11	?	?
3	65	0	591	15	0	0	311	46	?	?
3	66	0	64	247	0	0	664	15	?	?
3	67	0	594	102	0	0	233	55	?	?
3	68	0	119	172	0	0	555	22	?	?
3	69	0	464	96	0	0	366	55	?	?
3	70	0	237	122	0	0	580	48	1239	?
3	71	0	301	105	0	0	551	28	2022	605
3	72	0	183	158	0	0	463	154	999	530
3	73	0	427	66	0	0	461	26	2330	548
3	74	0	73	317	0	0	484	125	1566	471
3	75	0	222	77	0	0	631	46	990	512
3	76	0	251	90	0	0	592	37	1290	541
3	77	0	286	194	0	0	448	46	2093	531
3	78	0	74	224	0	0	578	119	?	?
3	79	0	236	62	0	0	618	36	1312	583
3	80	0	157	62	0	0	638	48	915	?
4	57	*								
4	58	*								
4	59	*								
4	60	*								
4	61	*								
4	62	*								
4	63	*								
4	64	0	294	655	1	0	41	8	1386	480
4	65	0	593	312	0	0	49	46	1059	520
4	66	0	469	406	0	0	74	50	1114	490
4	67	0	639	313	0	0	25	22	1631	446
4	68	0	142	808	0	0	23	27	1084	536
4	69	35	595	338	0	1	20	10	1455	478
4	70	0	634	301	0	0	33	13	?	?
4	71	0	561	379	0	0	26	37	?	?
4	72	0	295	675	0	0	9	20	?	?
4	73	0	481	502	0	0	11	7	?	?
4	74	0	407	578	0	0	8	7	?	?
4	75	0	760	226	0	0	11	3	?	?
4	76	0	417	555	0	0	15	13	?	?
4	77	0	470	503	0	0	24	3	?	?
4	78	0	228	723	0	0	15	32	?	?
4	79	0	792	135	0	0	53	19	1106	?
4	80	0	218	727	0	0	14	41	1346	?
9	69	26	590	372	12	0	0	0	294	?
9	70	66	313	536	85	0	0	0	816	?
9	71	0	662	326	12	0	0	0	351	?
9	72	61	680	222	37	0	0	0	550	?
9	73	0	82	917	0	0	0	0	827	?
9	74	21	250	721	1	0	0	0	469	?
9	75	0	564	432	0	0	0	0	2121	?
9	76	0	580	420	0	0	0	0	?	?
9	77	0	400	600	0	0	0	0	?	?
9	78	0	60	940	0	0	0	0	?	?
9	79	0	640	360	0	0	0	0	?	?

AREA	YEAR	3/2	4/2	5/2	6/2	4/3	5/3	6/3	#	%F
12	58	0	952	48	0	0	0	0	?	?
12	59	0	895	100	5	0	0	0	?	?
12	60	0	783	217	0	0	0	0	?	?
12	61	0	880	119	1	0	0	0	?	?
12	62	0	785	210	5	0	0	0	?	?
12	63	0	713	274	13	0	0	0	?	?
12	64	0	741	237	22	0	0	0	?	?
12	65	12	808	177	3	0	0	0	?	?
12	66	5	861	131	3	0	0	0	?	?
12	67	2	834	162	2	0	0	0	?	?
12	68	0	83	871	46	0	0	0	?	?
12	69	11	795	193	1	0	0	0	?	?
12	70	44	721	233	2	0	0	0	?	?
12	71	4	898	98	0	0	0	0	?	?
12	72	0	660	335	5	0	0	0	?	?
12	73	0	500	479	21	0	0	0	?	?
12	74	0	428	571	1	0	0	0	?	?
12	75	0	319	667	14	0	0	0	?	?

CHUM

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	#	%F
2	61	0	330	680	20	0	748	?
2	64	0	220	780	0	0	1449	?
2	65	0	50	920	30	0	233	?
2	71	0	90	870	40	0	1200	?
2	72	0	160	750	80	10	1079	?
2	73	0	100	750	150	0	465	?
2	74	0	110	750	140	0	1302	?
2	75	0	220	740	40	0	685	?
2	76	0	0	940	60	0	53	?
2	79	0	563	332	105	0	325	?
2	80	0	535	465	0	0	86	?
4	74	0	0	809	191	0	?	?
4	75	0	0	875	125	0	?	?
4	76	0	0	1000	0	0	?	?
4	77	0	0	929	71	0	?	?
4	78	0	13	827	160	0	75	?
4	79	0	527	404	69	0	146	?
4	80	0	7	965	28	0	142	?
29	60	0	271	629	0	0	529	?
29	61	0	110	884	6	0	1167	?
29	62	0	766	227	7	0	972	?
29	63	0	359	639	2	0	999	?
29	64	0	236	758	6	0	1892	?
29	65	0	317	660	23	0	1245	?
29	66	0	112	876	12	0	1183	?
29	67	0	565	408	27	0	2175	?
29	68	0	160	837	3	0	1975	?
29	69	0	405	573	22	0	2309	?
29	70	0	78	915	7	0	?	?
29	71	0	354	545	101	0	?	?
29	72	0	35	936	29	0	?	?
29	73	0	33	804	163	0	?	?
29	74	0	192	568	240	0	?	?
29	75	0	537	444	19	0	?	?
29	76	0	172	823	5	0	?	?
29	77	0	237	742	21	0	?	?
29	78	0	132	851	17	0	?	?
29	79	0	258	606	136	0	?	?

Appendix Ib. Average age composition of catch and escapement (age at maturity)

area = "production area" (see table 1)

SOCKEYE

AREA	YEAR	4	5	6
3.	51.	0.410	0.400	0.130
3.	52.	0.280	0.650	0.040
3.	53.	0.230	0.680	0.090
3.	54.	0.350	0.600	0.050
3.	55.	0.120	0.850	0.020
3.	56.	0.270	0.590	0.140
3.	57.	0.136	0.824	0.035
3.	58.	0.254	0.700	0.040
3.	59.	0.061	0.893	0.038
3.	60.	0.523	0.371	0.085
3.	61.	0.516	0.432	0.009
3.	62.	0.181	0.773	0.042
3.	63.	0.524	0.423	0.051
3.	64.	0.129	0.832	0.014
3.	65.	0.511	0.383	0.092
3.	66.	0.367	0.538	0.031
3.	67.	0.433	0.541	0.019
3.	68.	0.121	0.840	0.034
3.	69.	0.289	0.662	0.043
3.	70.	0.311	0.609	0.073
3.	71.	0.420	0.523	0.054
3.	72.	0.221	0.672	0.076
3.	73.	0.427	0.527	0.026
3.	74.	0.073	0.801	0.125
3.	75.	0.222	0.708	0.046
3.	76.	0.251	0.682	0.037
3.	77.	0.286	0.642	0.046
3.	78.	0.074	0.802	0.119
3.	79.	0.236	0.680	0.036
4.	51.	0.330	0.650	0.010
4.	52.	0.660	0.290	0.050
4.	53.	0.480	0.490	0.030
4.	54.	0.330	0.640	0.020
4.	55.	0.150	0.730	0.110
4.	56.	0.840	0.150	0.010
4.	57.	0.677	0.309	0.008
4.	58.	0.339	0.655	0.003
4.	59.	0.140	0.835	0.024
4.	60.	0.493	0.426	0.074
4.	61.	0.784	0.200	0.014
4.	62.	0.319	0.663	0.015
4.	63.	0.620	0.354	0.020
4.	64.	0.225	0.760	0.011
4.	65.	0.432	0.534	0.033
4.	66.	0.450	0.518	0.024
4.	67.	0.442	0.529	0.028
4.	68.	0.111	0.863	0.025
4.	69.	0.484	0.488	0.025
4.	70.	0.606	0.352	0.039
4.	71.	0.568	0.415	0.013
4.	72.	0.209	0.758	0.016
4.	73.	0.544	0.433	0.003

AREA	YEAR	4	5	6
4.	74.	0.325	0.665	0.010
4.	75.	0.702	0.294	0.003
4.	76.	0.387	0.610	0.003
4.	77.	0.441	0.557	0.002
4.	78.	0.228	0.738	0.032
4.	79.	0.792	0.188	0.019
5.	57.			
5.	58.			
5.	59.	0.343	0.589	0.056
5.	60.	0.588	0.332	0.062
5.	61.	0.597	0.328	0.023
5.	62.	0.529	0.419	0.014
5.	63.	0.674	0.253	0.018
5.	64.	0.349	0.602	0.025
5.	65.	0.556	0.318	0.034
5.	66.	0.598	0.340	0.009
5.	67.	0.701	0.261	0.010
5.	68.	0.290	0.654	0.022
5.	69.	0.334	0.613	0.019
5.	70.	0.559	0.206	0.093
5.	71.	0.641	0.320	0.024
5.	72.	0.343	0.544	0.050
5.	73.			
5.	74.			
5.	75.			
5.	76.			
5.	77.			
5.	78.			
5.	79.			
6.	51.	0.300	0.690	0.005
6.	52.	0.245	0.750	0.0
6.	53.	0.810	0.185	0.005
6.	54.	0.605	0.390	0.0
6.	55.	0.435	0.560	0.005
6.	56.	0.070	0.930	0.0
6.	57.	0.621	0.372	0.006
6.	58.	0.276	0.716	0.002
6.	59.	0.178	0.801	0.014
6.	60.	0.304	0.651	0.040
6.	61.	0.467	0.515	0.015
6.	62.	0.885	0.103	0.005
6.	63.	0.355	0.625	0.014
6.	64.	0.131	0.797	0.062
6.	65.	0.665	0.309	0.006
6.	66.	0.300	0.689	0.003
6.	67.	0.761	0.209	0.009
6.	68.	0.112	0.857	0.018
6.	69.	0.339	0.622	0.028
6.	70.	0.349	0.545	0.056
6.	71.	0.705	0.277	0.008
6.	72.	0.442	0.492	0.037
6.	73.	0.082	0.915	0.0

AREA	YEAR	4	5	6
6.	74.	0.420	0.565	0.012
6.	75.	0.734	0.250	0.004
6.	76.	0.580	0.420	0.0
6.	77.	0.400	0.600	0.0
6.	78.	0.060	0.940	0.0
6.	79.	0.640	0.360	0.0
7.	57.			
7.	58.	0.952	0.048	0.0
7.	59.	0.895	0.100	0.005
7.	60.	0.783	0.217	0.000
7.	61.	0.880	0.119	0.001
7.	62.	0.785	0.210	0.005
7.	63.	0.713	0.274	0.013
7.	64.	0.741	0.237	0.022
7.	65.	0.808	0.177	0.003
7.	66.	0.861	0.131	0.003
7.	67.	0.834	0.162	0.002
7.	68.	0.083	0.871	0.046
7.	69.	0.795	0.193	0.001
7.	70.	0.721	0.233	0.002
7.	71.	0.898	0.098	0.0
7.	72.	0.660	0.335	0.005
7.	73.	0.500	0.479	0.021
7.	74.	0.428	0.571	0.001
7.	75.	0.319	0.667	0.014
7.	76.			
7.	77.			
7.	78.			
7.	79.			
8.	57.			
8.	58.			
8.	59.			
8.	60.			
8.	61.	0.922	0.054	0.0
8.	62.	0.927	0.067	0.0
8.	63.	0.931	0.069	0.0
8.	64.	0.845	0.155	0.0
8.	65.			
8.	66.			
8.	67.			
8.	68.			
8.	69.			
8.	70.			
8.	71.			
8.	72.	0.780	0.220	0.0
9.	57.			
9.	58.			
9.	59.			
9.	60.			
9.	61.			
9.	62.	0.939	0.057	0.001
9.	63.	0.937	0.057	0.002

AREA	YEAR	4	5	6
9.	64.	0.829	0.148	0.011
9.	65.	0.911	0.081	0.002
9.	66.	0.880	0.103	0.002
9.	67.	0.957	0.037	0.001
9.	68.	0.882	0.111	0.0
9.	69.	0.877	0.118	0.004
9.	70.	0.945	0.039	0.001
9.	71.	0.950	0.044	0.0
9.	72.	0.874	0.117	0.002
9.	73.			
9.	74.			
9.	75.			
9.	76.			
9.	77.			
9.	78.			
9.	79.			
10.	57.			
10.	58.			
10.	59.			
10.	60.			
10.	61.			
10.	62.			
10.	63.	0.836	0.126	0.0
10.	64.			
10.	65.	0.755	0.106	0.002
10.	66.	0.925	0.047	0.005
10.	67.	0.957	0.038	0.001
10.	68.	0.922	0.071	0.0
10.	69.	0.816	0.136	0.019
10.	70.	0.941	0.042	0.001
10.	71.	0.923	0.068	0.0
10.	72.	0.922	0.042	0.017
11.	57.			
11.	58.			
11.	59.			
11.	60.	0.704	0.289	0.007
11.	61.	0.760	0.194	0.013
11.	62.	0.816	0.180	0.002
11.	63.	0.740	0.243	0.010
11.	64.	0.605	0.336	0.004
11.	65.			
11.	66.			
11.	67.	0.749	0.223	0.020
11.	68.	0.392	0.593	0.008
11.	69.	0.577	0.420	0.002
11.	70.	0.403	0.545	0.026
11.	71.	0.734	0.238	0.019
11.	72.	0.746	0.242	0.006
11.	73.			
11.	74.			
11.	75.			
11.	76.			

AREA	YEAR	4	5	6
11.	77.			
11.	78.			
11.	79.			
12.	57.			
12.	58.			
12.	59.			
12.	60.			
12.	61.			
12.	62.			
12.	63.			
12.	64.			
12.	65.			
12.	66.			
12.	67.	0.738	0.234	0.013
12.	68.	0.046	0.860	0.094
12.	69.	0.815	0.185	0.0
12.	70.			
12.	71.	0.812	0.178	0.0
12.	72.			

CHUM

AREA	YEAR	3	4	5
1.	57.			
2.	57.			
2.	58.			
2.	59.			
2.	60.			
2.	61.	0.330	0.680	0.020
2.	62.			
2.	63.			
2.	64.	0.220	0.780	0.0
2.	65.	0.050	0.920	0.030
2.	66.			
2.	67.			
2.	68.			
2.	69.			
2.	70.			
2.	71.	0.090	0.870	0.040
2.	72.	0.160	0.750	0.080
2.	73.	0.100	0.750	0.150
2.	74.	0.110	0.750	0.140
2.	75.	0.220	0.740	0.040
2.	76.	0.000	0.940	0.060
2.	77.			
2.	78.			
2.	79.	0.563	0.332	0.105
3.	57.	0.108	0.776	0.116
3.	58.	0.125	0.734	0.141
3.	59.	0.169	0.622	0.209
3.	60.	0.183	0.803	0.014
3.	61.	0.045	0.917	0.038
3.	62.	0.377	0.331	0.292
3.	63.	0.215	0.768	0.014
3.	64.	0.056	0.917	0.027
3.	65.	0.068	0.723	0.208
3.	66.	0.058	0.893	0.049
3.	67.	0.219	0.580	0.201
3.	68.	0.018	0.909	0.068
3.	69.	0.150	0.559	0.291
3.	70.	0.028	0.961	0.011
3.	71.	0.173	0.433	0.394
3.	72.	0.017	0.945	0.036
3.	73.			
3.	74.			
3.	75.			
3.	76.			
3.	77.			
3.	78.			
3.	79.			
4.	57.	0.039	0.926	0.035
4.	58.	0.068	0.829	0.103
4.	59.			
4.	60.	0.186	0.791	0.023
4.	61.	0.089	0.873	0.038
4.	62.	0.274	0.510	0.216
4.	63.	0.286	0.690	0.024
4.	64.	0.095	0.852	0.053
4.	65.	0.0	1.000	0.0
4.	66.	0.020	0.980	0.0
4.	67.	0.285	0.402	0.313
4.	68.	0.017	0.952	0.025
4.	69.	0.264	0.491	0.245
4.	70.	0.0	0.867	0.133
4.	71.	0.153	0.553	0.294
4.	72.	0.009	0.935	0.056
4.	73.			
4.	74.	0.0	0.809	0.191
4.	75.	0.0	0.875	0.125
4.	76.	0.0	1.000	0.0
4.	77.	0.0	0.929	0.071
4.	78.			
4.	79.			
5.	57.	0.177	0.734	0.089
5.	58.	0.092	0.873	0.036
5.	59.	0.350	0.530	0.120
5.	60.	0.599	0.392	0.009
5.	61.	0.379	0.605	0.015
5.	62.	0.352	0.608	0.039
5.	63.	0.532	0.446	0.021
5.	64.	0.108	0.869	0.023
5.	65.	0.181	0.662	0.157
5.	66.	0.149	0.833	0.017
5.	67.	0.315	0.528	0.156
5.	68.	0.068	0.915	0.016
5.	69.	0.553	0.336	0.109
5.	70.	0.077	0.921	0.002
5.	71.	0.210	0.692	0.098
5.	72.	0.085	0.875	0.039
5.	73.			
5.	74.			
5.	75.			
5.	76.			
5.	77.			
5.	78.			
5.	79.			
6.	57.			
6.	58.	0.114	0.869	0.017
6.	59.	0.398	0.530	0.072
6.	60.	0.731	0.260	0.009
6.	61.	0.339	0.642	0.019
6.	62.	0.225	0.754	0.021
6.	63.	0.610	0.376	0.014
6.	64.	0.121	0.867	0.011
6.	65.	0.161	0.683	0.156
6.	66.	0.167	0.807	0.026
6.	67.	0.387	0.513	0.100
6.	68.	0.047	0.945	0.007
6.	69.	0.716	0.182	0.101
6.	70.	0.113	0.885	0.001
6.	71.			
6.	72.			
6.	73.			
6.	74.			
6.	75.			
6.	76.			
6.	77.			
6.	78.			
6.	79.			
7.	57.			
7.	58.	0.209	0.783	0.008
7.	59.	0.336	0.643	0.020
7.	60.	0.416	0.573	0.010
7.	61.	0.110	0.866	0.024
7.	62.	0.703	0.270	0.027
7.	63.	0.375	0.619	0.006
7.	64.	0.133	0.849	0.018
7.	65.	0.093	0.826	0.078
7.	66.	0.261	0.686	0.052
7.	67.	0.442	0.492	0.066
7.	68.	0.192	0.803	0.005
7.	69.	0.402	0.544	0.054
7.	70.	0.057	0.936	0.007
7.	71.	0.341	0.502	0.157
7.	72.	0.072	0.907	0.020
7.	73.			
7.	74.			
7.	75.			
7.	76.			
7.	77.			
7.	78.			
7.	79.			
8.	57.			
8.	58.			
8.	59.	0.344	0.642	0.010
8.	60.	0.503	0.488	0.008
8.	61.	0.197	0.800	0.003
8.	62.	0.797	0.181	0.022
8.	63.	0.280	0.716	0.0
8.	64.	0.638	0.340	0.0
8.	65.			
8.	66.			
8.	67.			
8.	68.			
8.	69.			
8.	70.			
8.	71.			
8.	72.	0.039	0.941	0.0
8.	73.			

AREA	YEAR	3	4	5
8.	74.			
8.	75.			
8.	76.			
8.	77.			
8.	78.			
8.	79.			
9.	57.	0.259	0.697	0.044
9.	58.	0.571	0.424	0.005
9.	59.	0.408	0.587	0.005
9.	60.	0.346	0.643	0.011
9.	61.	0.156	0.824	0.020
9.	62.	0.772	0.206	0.022
9.	63.	0.289	0.707	0.004
9.	64.	0.147	0.832	0.021
9.	65.	0.021	0.970	0.009
9.	66.	0.070	0.908	0.022
9.	67.	0.549	0.423	0.028
9.	68.	0.203	0.791	0.006
9.	69.	0.405	0.573	0.22
9.	70.	0.090	0.906	0.004
9.	71.	0.354	0.545	0.101
9.	72.	0.021	0.976	0.003
9.	73.	0.033	0.804	0.163
9.	74.	0.192	0.568	0.240
9.	75.	0.537	0.444	0.019
9.	76.	0.172	0.823	0.005
9.	77.	0.237	0.742	0.021
9.	78.	0.132	0.851	0.017
9.	79.	0.258	0.606	0.136
10.	57.			
10.	58.	0.716	0.264	0.018
10.	59.	0.297	0.695	0.004
10.	60.	0.674	0.320	0.006
10.	61.	0.266	0.725	0.009
10.	62.	0.840	0.148	0.012
10.	63.	0.490	0.503	0.005
10.	64.	0.716	0.272	0.001
10.	65.	0.114	0.882	0.004
10.	66.	0.451	0.500	0.047
10.	67.	0.598	0.389	0.013
10.	68.	0.186	0.800	0.013
10.	69.	0.167	0.802	0.003
10.	70.	0.262	0.724	0.014
10.	71.	0.508	0.447	0.045
10.	72.	0.020	0.973	0.007
10.	73.			
10.	74.			
10.	75.			
10.	76.			
10.	77.			
10.	78.			
10.	79.			

AREA	YEAR	3	4	5
11.	57.			
11.	58.			
11.	59.	0.411	0.560	0.022
11.	60.	0.440	0.552	0.008
11.	61.	0.482	0.494	0.019
11.	62.	0.571	0.414	0.004
11.	63.	0.500	0.492	0.0
11.	64.			
11.	65.			
11.	66.			
11.	67.			
11.	68.			
11.	69.	0.187	0.480	0.0
11.	70.	0.388	0.578	0.024
11.	71.	0.452	0.518	0.031
11.	72.	0.052	0.934	0.013
11.	73.	0.026	0.552	0.421
11.	74.	0.261	0.404	0.321
11.	75.	0.310	0.673	0.017
11.	76.	0.138	0.846	0.014
11.	77.	0.407	0.535	0.025
11.	78.	0.167	0.459	0.034
11.	79.			
12.	57.			
12.	58.			
12.	59.	0.583	0.401	0.013
12.	60.	0.764	0.233	0.003
12.	61.	0.208	0.781	0.010
12.	62.	0.463	0.521	0.012
12.	63.	0.613	0.374	0.011
12.	64.	0.326	0.671	0.0
12.	65.			
12.	66.			
12.	67.			
12.	68.			
12.	69.	0.194	0.139	0.0
12.	70.	0.312	0.666	
12.	71.	0.348	0.578	0.071
12.	72.	0.112	0.864	0.021
12.	73.	0.084	0.752	0.162
12.	74.	0.260	0.592	0.143
12.	75.	0.136	0.799	0.057
12.	76.	0.119	0.496	0.033
12.	77.	0.599	0.382	0.020
12.	78.			
12.	79.			

Age composition of catch and escapement (spring)

area 40 = stat. Area 20-27

area 41 = stat. Area 13-19+28

area 42 = stat. Area 6-12

area 43 = stat. Area 1-5

area 29 = stat. Area 29

= number sampled

SPRING

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	2/2	3/2	4/2	5/2	6/2	#
43	52	0	53	789	158	0	0	0	0	0	0	19
43	53	74	474	371	11	0	0	41	18	11	0	175
43	54	14	247	595	123	0	0	0	14	27	0	73
43	55	112	243	336	178	9	0	37	28	57	0	107
43	56											
43	57											
43	58											
43	59											
43	60											
43	61											
43	62											
43	63											
43	64	1	205	532	107	3	11	78	60	3	0	2116
43	65											
43	66	17	361	381	110	1	51	64	14	2	0	?
43	67	2	339	370	131	10	33	80	33	1	0	5031
43	68											
43	69											
43	70											
43	71											
43	72											
43	73											
43	74											
43	75	101	351	378	112	5	24	19	5	1	0	1564
43	76	183	495	242	69	1	8	3	0	0	0	1174
43	77	34	546	369	34	1	3	7	5	0	0	926
43	78	0										
43	79											
40	52	310	610	60	0	0	0	20	0	0	0	115
40	53	149	561	108	11	0	0	119	52	0	0	269
40	54	144	448	299	0	0	0	52	52	5	0	194
40	55	105	648	199	14	0	3	6	22	3	0	361
40	56	32	608	264	6	0	0	29	55	6	0	311
40	57	35	577	282	32	2	0	15	47	5	0	602
40	58	16	470	277	30	0	2	50	108	45	2	560
40	59	9	374	424	32	0	0	9	107	36	9	439
40	60											
40	61											
40	62											
40	63											
40	64	25	585	244	19	0	0	36	76	16	0	9315
40	65	36	558	293	19	1	0	16	58	18	1	7576
40	66	6	538	371	35	0	0	5	34	10	0	6204
40	67	1	497	398	50	1	0	1	41	11	0	7101
40	68	1	489	436	33	0	0	4	28	8	0	4076
40	69											
40	70											
40	71											

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	2/2	3/2	4/2	5/2	6/2	#
40	72											
40	73											
40	74											
40	75	78	553	276	35	1	1	38	16	1	0	2936
40	76	60	585	297	48	0	0	3	6	0	0	3986
40	77	43	689	243	17	0	0	3	3	1	0	3758
40	78	23	506	414	29	0	0	8	13	6	0	4745
40	79											
41	52	410	570	10	0	0	0	10	0	0	0	156
41	53	97	822	48	0	0	0	33	0	0	0	62
41	54	103	647	174	0	0	4	22	41	9	0	224
41	55	156	682	156	0	0	0	3	3	0	0	288
41	56	135	723	101	0	0	0	7	20	14	0	148
41	57	153	490	222	7	0	0	84	36	7	0	275
41	58	130	576	150	14	0	0	51	72	7	0	293
41	59	40	618	222	11	0	7	51	36	15	0	275
41	60											
41	61											
41	62											
41	63											
41	64	215	544	150	5	0	59	26	2	0	0	2923
41	65	40	669	203	8	0	33	35	9	0	0	1773
41	66	209	591	154	7	0	24	13	3	0	0	5814
41	67	120	702	149	4	0	8	14	3	0	0	3183
41	68	58	552	347	7	0	14	18	3	0	0	3937
41	69											
41	70											
41	71											
41	72											
41	73											
41	74											
41	75	95	601	249	24	0	18	12	1	0	0	2642
41	76	8	766	215	8	0	0	2	0	0	0	1959
41	77											
41	78	14	695	274	8	0	2	6	1	0	0	2499
41	79											
29	52	340	140	260	0	0	0	170	90	0	0	35
29	53	136	340	175	19	0	0	155	117	58	0	103
29	54	50	325	275	0	0	0	225	100	25	0	40
29	55	56	366	169	0	0	0	225	184	0	0	71
29	56	40	476	323	46	5	0	59	40	8	3	372
29	57	126	188	334	16	0	3	176	110	44	0	318
29	58	8	174	305	35	0	0	54	225	188	11	368
29	59	0	51	414	58	0	0	7	199	261	10	293
29	60											
29	61											
29	62											
29	63											

AREA	YEAR	2/1	3/1	4/1	5/1	6/1	2/2	3/2	4/2	5/2	6/2	#
29	64	24	111	392	23	0	23	161	265	2	0	4674
29	65	14	111	256	45	0	64	269	231	10	0	4091
29	66	31	218	405	31	0	13	177	123	1	0	2701
29	67											
29	68											
29	69											
29	70											
29	71											
29	72											
29	73											
29	74											
29	75	170	439	306	61	0	25	0	0	0	0	172
29	76	0	422	510	66	0	1	0	1	0	0	362
29	77	61	500	371	3	0	6	17	38	6	0	332
29	78	0	226	644	17	0	0	25	88	0	0	303
29	79											
42	52											
42	53											
42	54											
42	55											
42	56											
42	57											
42	58											
42	59											
42	60											
42	61											
42	62											
42	63											
42	64											
42	65	2	278	484	126	3	5	56	47	0	0	860
42	66	53	456	289	98	2	17	68	14	3	0	2190
42	67	26	437	339	130	2	12	38	16	1	0	3161
42	68	15	321	457	134	2	15	35	23	0	0	1229
42	69											
42	70											
42	71											
42	72											
42	73											
42	74											
42	75	8	279	431	190	2	29	36	24	0	0	1606
42	76	170	354	344	112	0	2	7	7	3	0	553
42	77	115	484	164	145	0	0	12	12	23	46	55
42	78											
42	79											

AREA	SOCKEYE			CHUM			SPRING			
	4	5	6	3	4	5	3	4	5	6
1	.29	.65	.05	.18	.75	.07	.30	.40	.20	0.
2	.29	.65	.05	.18	.75	.07	.30	.40	.20	0.
3	.29	.65	.05	.13	.74	.13	.30	.40	.20	0.
4	.45	.53	.02	.09	.80	.10	.20	.45	.35	0.
5	.51	.41	.03	.26	.68	.06	.30	.45	.25	0.
6	.43	.54	.02	.32	.64	.04	.30	.45	.25	0.
7	.70	.29	.01	.28	.69	.04	.30	.45	.25	0.
8	.88	.11	0.	.40	.59	.01	.30	.45	.25	0.
9	.91	.08	0.	.27	.69	.05	.20	.60	.20	0.
10	.89	.08	.01	.42	.56	.01	.20	.60	.20	0.
11	.66	.32	.01	.32	.57	.06	.20	.60	.20	0.
12	.37	.55	.05	.34	.55	.04	.20	.60	.20	0.

APPENDIX IC. OVERALL AVERAGE AGE DISTRIBUTION BY AREA BY SPECIES

APPENDIX II

This appendix summarizes stock-recruitment relationships for the major salmon production units in B.C. Each production unit is represented by one page of information containing four graphs, a table of optimums, a short summary of key uncertainties in the recruitment analysis and the major management problems associated with that production unit.

The first graph for each stock shows the time series of escapements and total stock. Each year, escapement is the adult population estimated to be in the river systems of that area, while total stock is the escapement plus all the catches estimated (by back-calculation) to have produced by the stock over all harvesting areas. Some of the time series extend only back to the 1960's, because of lack of information for separating mixed catches.

The stock-recruitment graph presents each data point as a number representing the year of spawning. Recruitment is the total number of fish produced by that spawning population and having survived to be caught by the fishery or escaped to spawn. The diagonal dotted line is the "replacement line" when recruits equal spawners. Three curves are fitted throught the data points without correcting for spawning count errors and each point is given equal weight regardless of its credibility. A dome-shaped Ricker model (——), a saturating Beverton-Holt model (x—x—), and a Power model (x - -) are presented in most cases. When the iteration scheme for estimating the Beverton-Holt model parameters fails, only the Ricker and Power models are shown.

The next graph shows the time series deviations of observed log recruits per spawner from the values predicted by the Ricker curve. This graph measures trends in productivity per spawner that cannot be attributed simply to trends in spawning stock size alone.

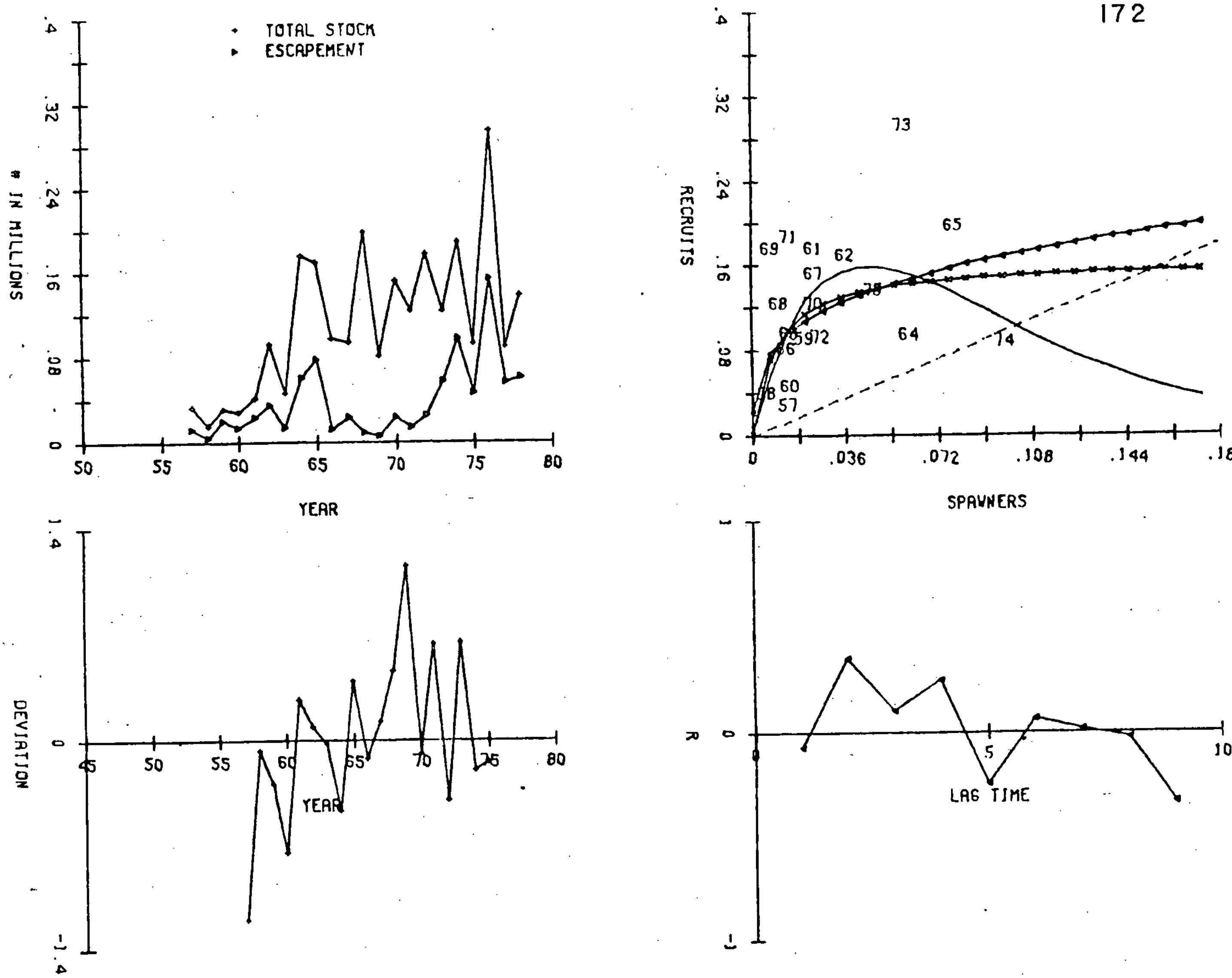
The last graph shows the auto-correlation pattern in the regression residuals (deviation in log recruits per spawner from Ricker prediction) at different lags (in years). Significant correlation at any lag indicates the presence of data errors or biological processes that may invalidate the assumption of a stationary distribution of recruits for any fixed spawning stock. For chinook, significant correlations at lags 1-5 are common, and are thought to reflect changes in age composition; in our calculations, strong year classes may be assigned incorrectly to several production years.

The tabulated optimum escapements and probable bounds are estimated as described in chapter IV - by statistical analyses tempered with judgements about data problems, historical performance, and available habitat. Estimates of optimum exploitation rates are simply the catch / (catch+escapement) from the same column of the table. Current escapement and catch are five year averages from 1975-1979 (five-cycle averages for pinks from 1970-1979).

A short verbal summary of key uncertainties in the recruitment analysis and key management problems follows the table of optimums. These problems were explained to us by government biologists, or mentioned in the unpublished Geographical Working Group summaries prepared recently for the

Salmonid Enhancement Program.

Q.C.1 COHO

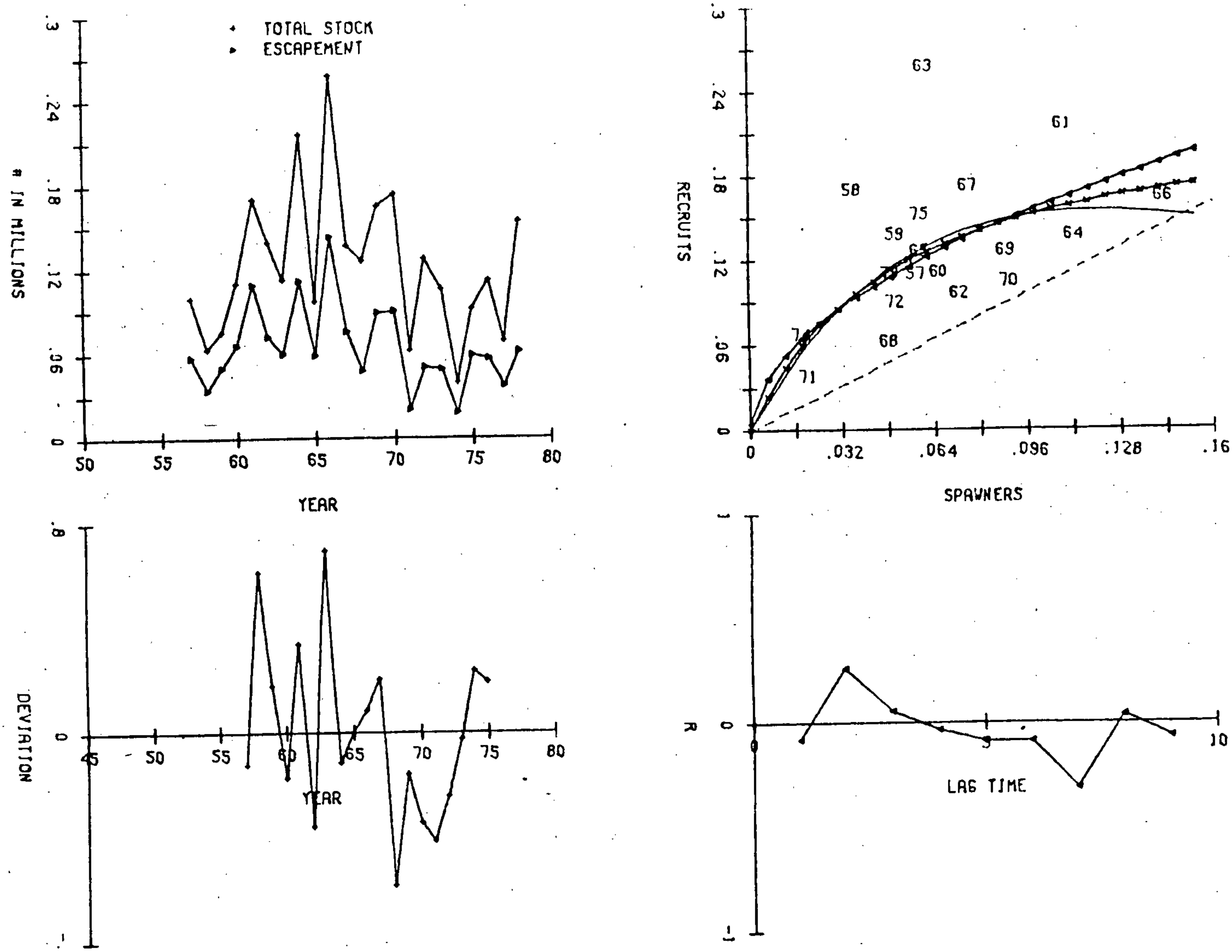


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	70,000	35,000	15,000	75,000
CATCH	74,000	140,000	120,000	240,000
EXPLOITATION RATE	.51	.80	.89	.76

I. Major Uncertainties in Analysis
   1. large uncertainty in catch allocation
   2. age composition not available
   3. Alaska interception not available

II. Impediments to Improved Management
   1. interception by Alaska troll fleet
   2. no opportunity for terminal fishery

Q.C.2 COHO



			PROBABLE LIMITS ON OPTIMUM	
	CURRENT	OPTIMUM	LOWER	UPPER
ESCAPEMENT	48,000	80,000	50,000	140,000
CATCH	52,000	100,000	50,000	110,000
EXPLOITATION RATE	.52	.53	.54	.50

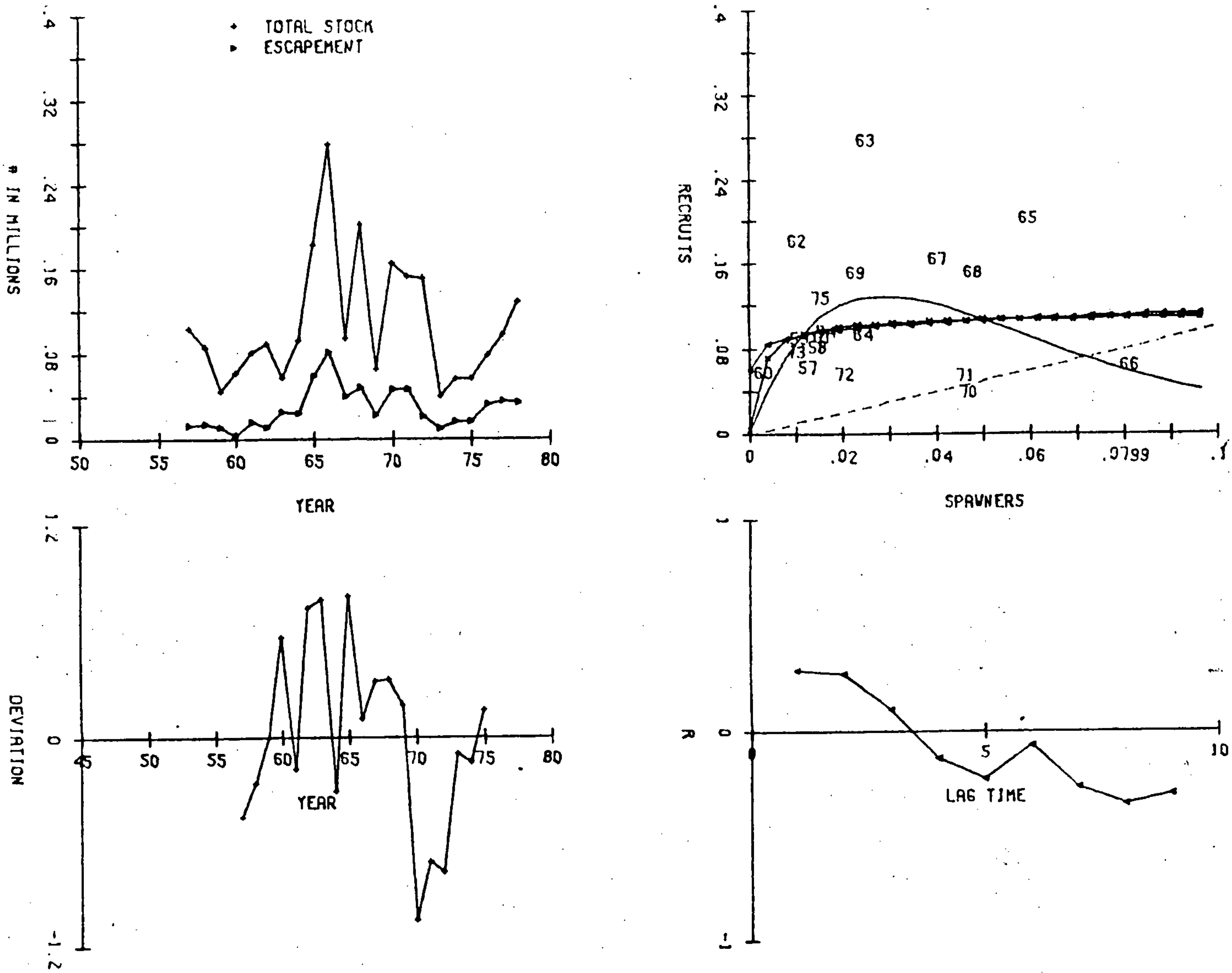
I. Major Uncertainties in Analysis

1. large uncertainty in catch allocation
2. age composition not available
3. Alaska interception not available
4. escapement estimates are extremely unreliable (many holes in escapement records)

II. Impediments to Improved Management

1. interception by Alaska troll fleet
2. no opportunity for terminal fishery

NASS COHO

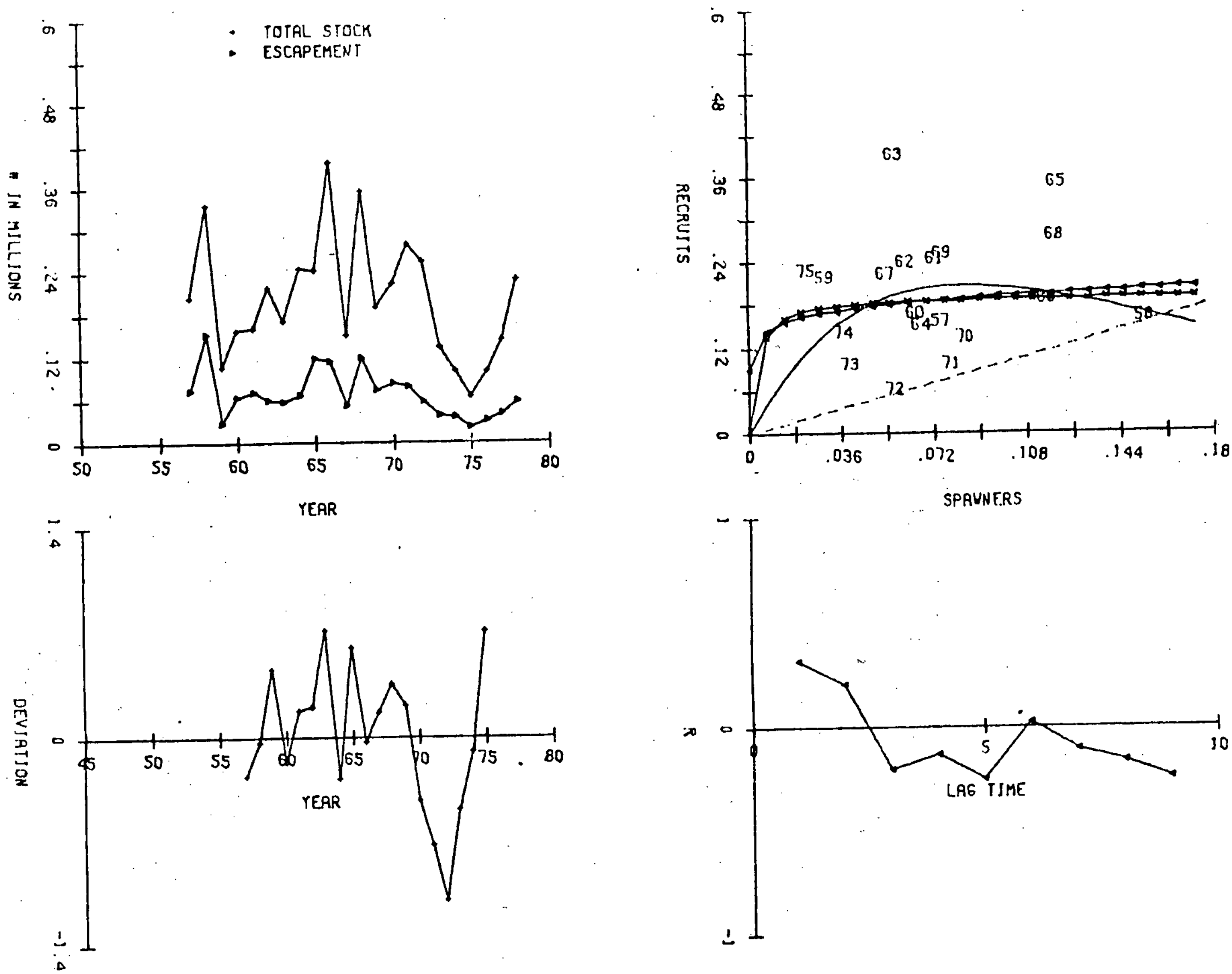


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	26,000	30,000	10,000	60,000
CATCH	61,000	120,000	70,000	140,000
EXPLOITATION RATE	.70	.80	.88	.70

I. Major Uncertainties in Analysis
1. large uncertainty in catch allocation
2. age composition not available
3. Alaska interception not available
4. escapements before 1964 are less reliable

II. Impediments to Improved Management
1. interception by Alaska troll fleet

SKEENA COHO



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM: LOWER	PROBABLE LIMITS ON OPTIMUM: UPPER
ESCAPEMENT	35,000	54,000	10,000	120,000
CATCH	96,000	130,000	120,000	180,000
EXPLOITATION RATE	.73	.73	.79	.67

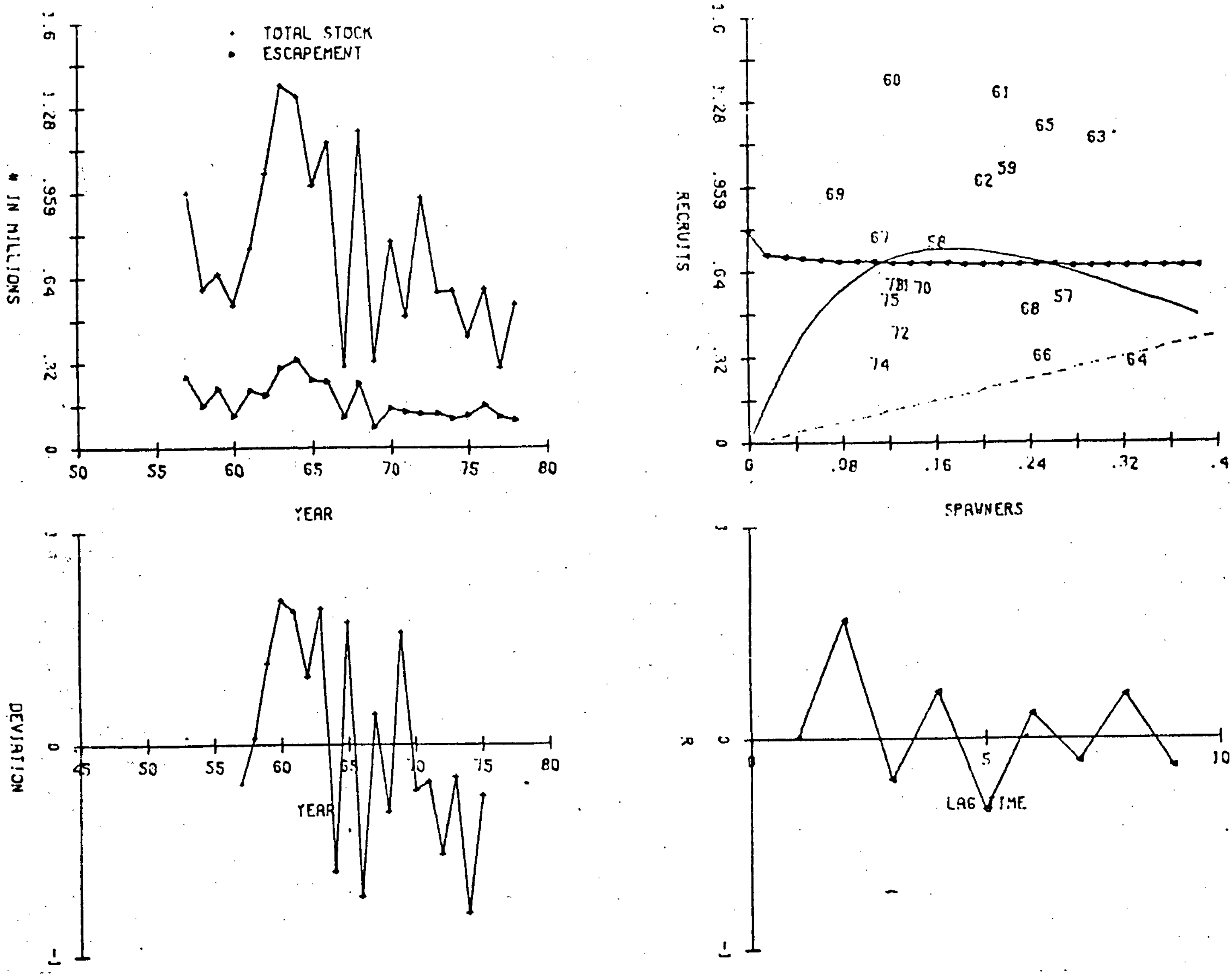
I. Major Uncertainties in Analysis

1. large uncertainty in catch allocation
2. age composition not available
3. Alaska interception not available

II. Impediments to Improved Management

1. interception by Alaska troll fleet

C.C. COHO

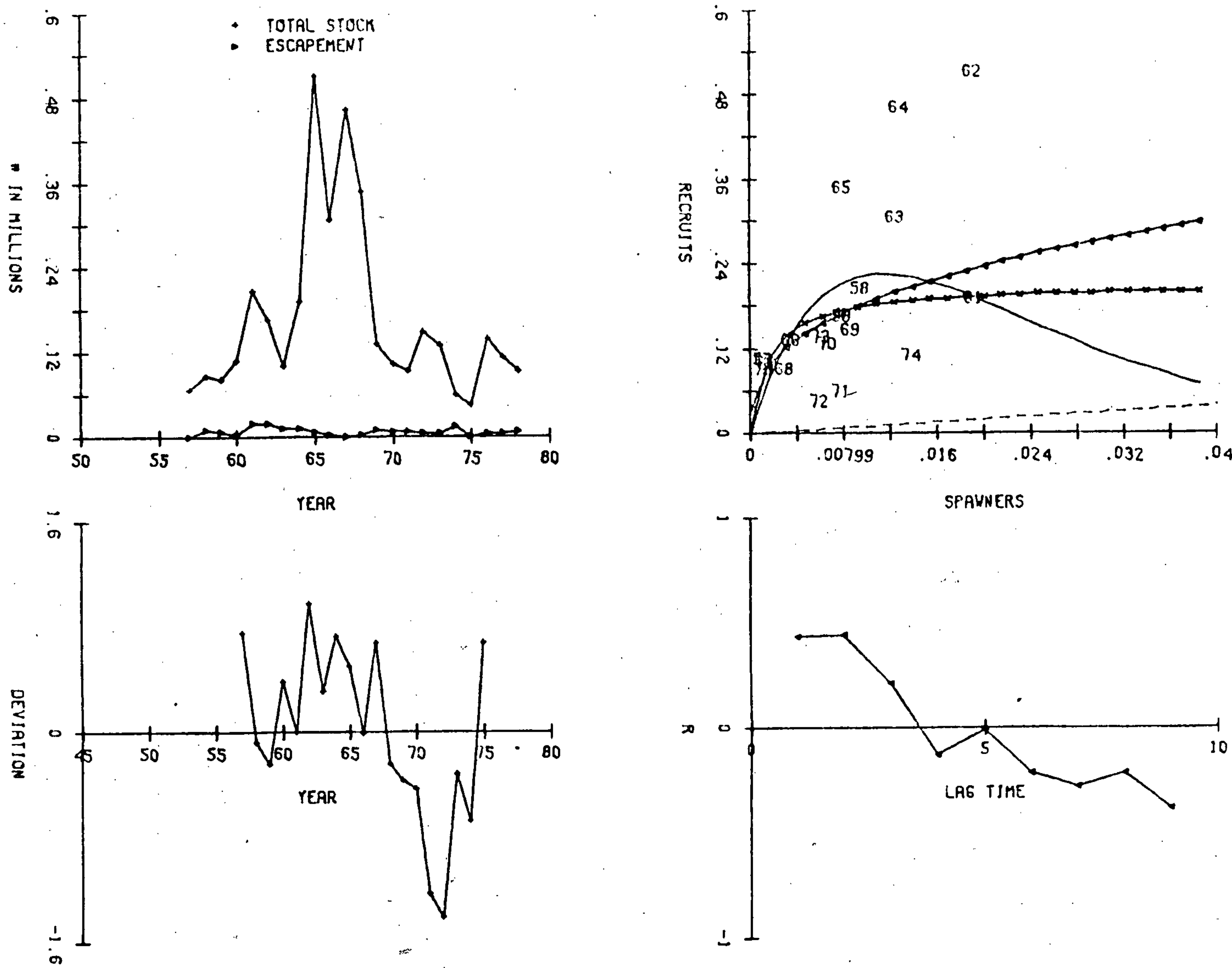


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	127,000	135,000	80,000	240,000
CATCH	337,000	670,000	550,000	800,000
EXPLOITATION RATE	.73	.83	.91	.67

I. Major Uncertainties in Analysis
   1. large uncertainty in catch allocation
   2. a decreasing trend of recruits per spawner in recent years may indicate lower quality of habitat
   3. Alaska interception not available

II. Impediments to Improved Management
   1. interception by Alaska troll fleet

R-S COHO

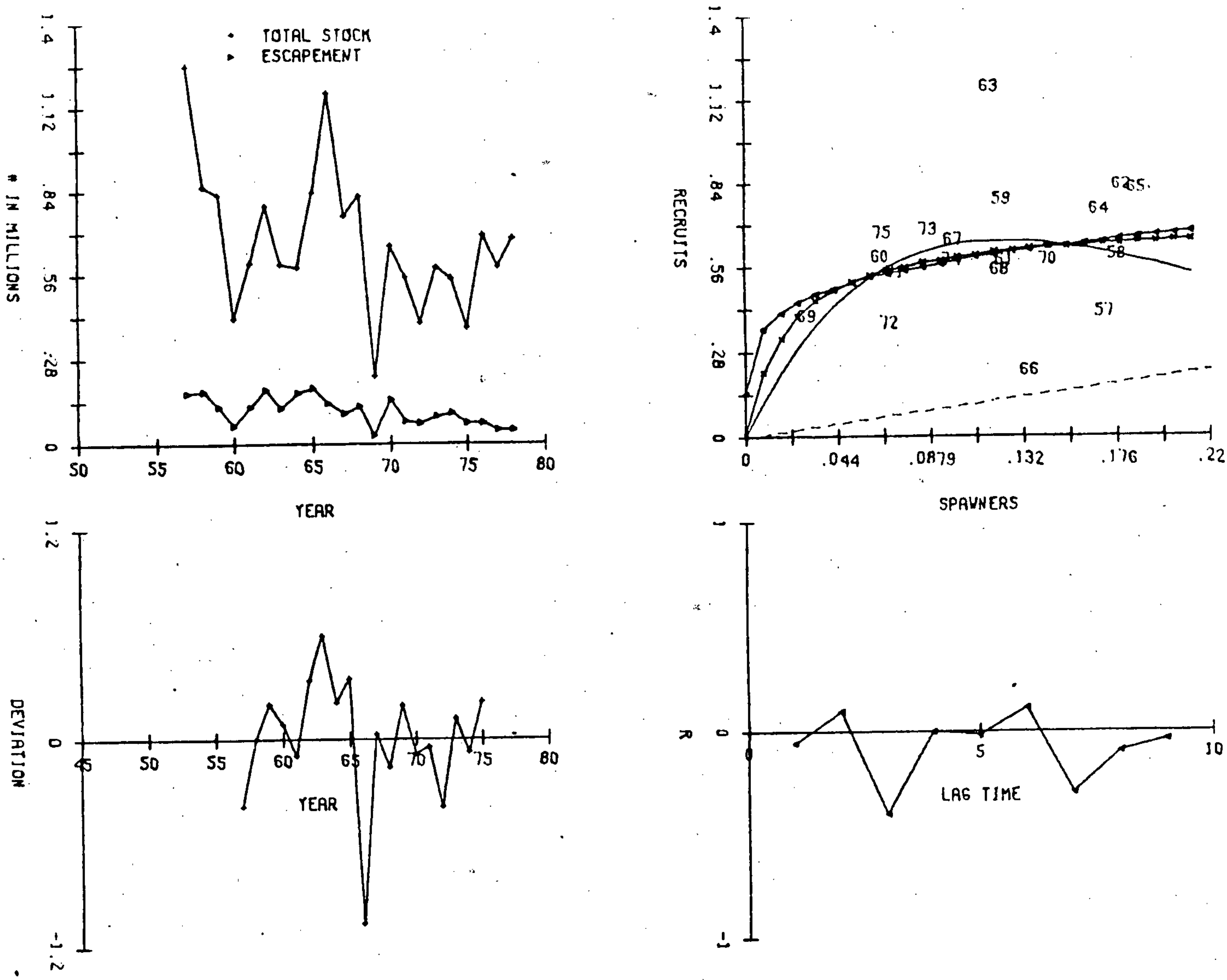


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	5,000	10,000	4,000	?
CATCH	94,000	180,000	120,000	?
EXPLOITATION RATE	.95	.97	.96	?

I. Major Uncertainties in Analysis
   1. large uncertainty in catch allocation
   2. production at higher escapement is highly uncertain but seems to be favourable

II. Impediments to Improved Management

J.S. COHO

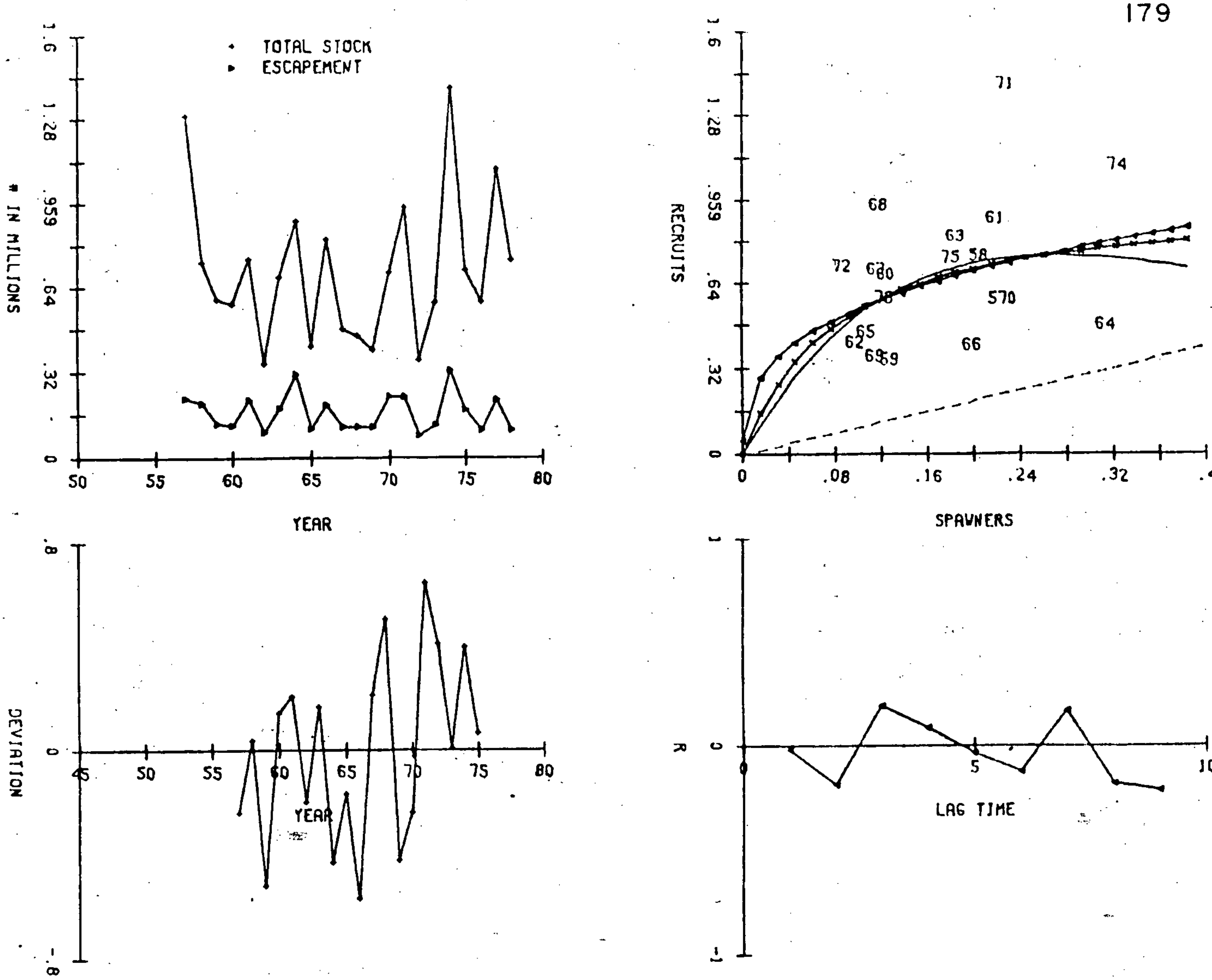


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	52,000	100,000	40,000	180,000
CATCH	530,000	580,000	250,000	700,000
EXPLOITATION RATE	.91	.85	.85	.79

I. <u>Major Uncertainties in Analysis</u>
   1. uncertainty in sports fishing estimates
   2. large uncertainty in catch allocation

II. <u>Impediments to Improved Management</u>
   1. interception during chum fishery
   2. incidental catch of juvenile fish

G.S. COHO



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	155,000	201,000	100,000	400,000
CATCH	630,000	567,000	400,000	600,000
EXPLOITATION RATE	.80	.74	.80	.60

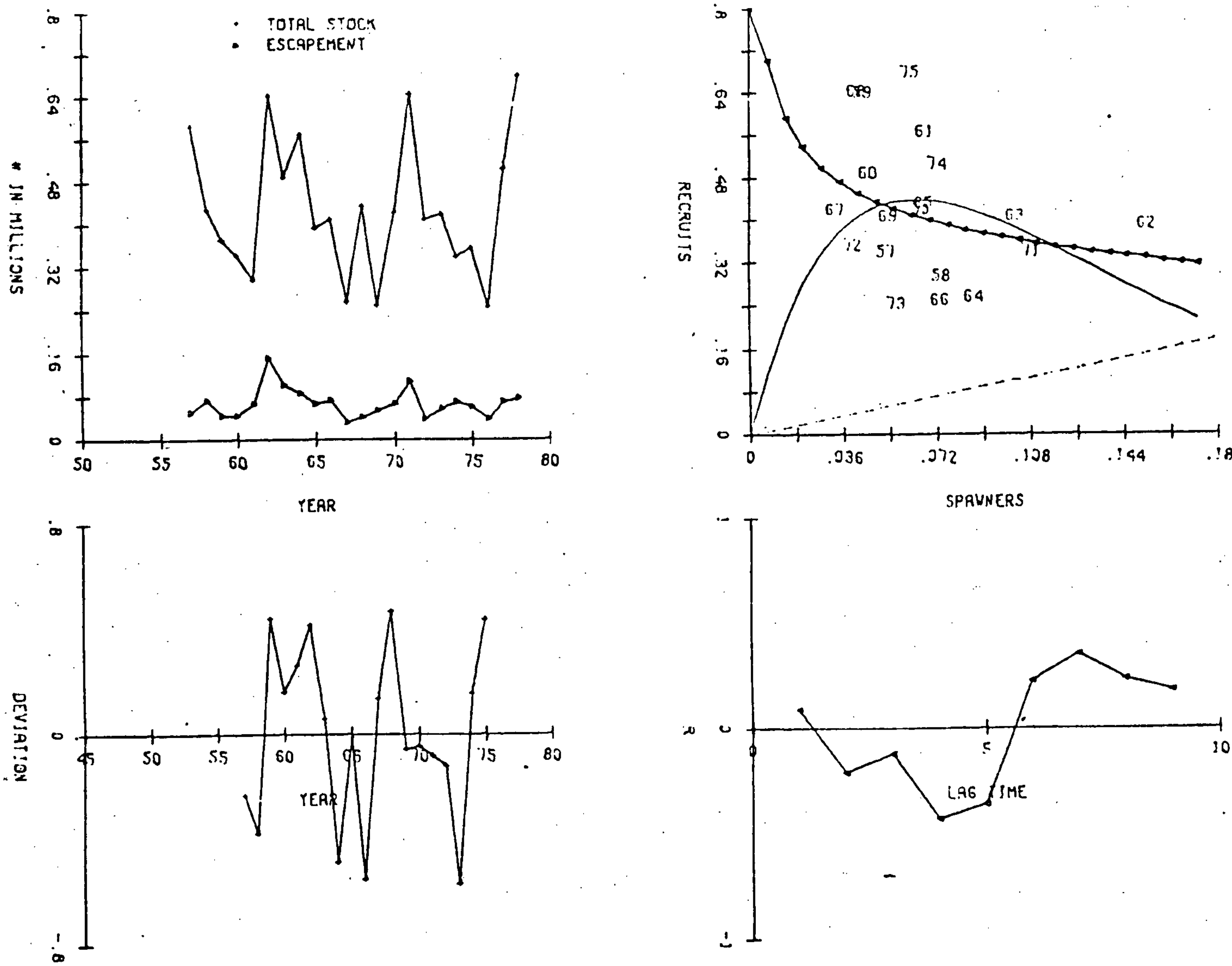
I. Major Uncertainties in Analysis

1. uncertainty in sports fishing estimates
2. uncertainty in the contribution of Washington produced fish
3. increasing hatchery output in recent years

II. Impediments to Improved Management

1. interception by Big Qualicum chum fishery
2. large sports fishing activities
3. incidental catch of juvenile fish

FRASER COHO



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	61,000	54,000	20,000	100,000
CATCH	380,000	406,000	370,000	400,000
EXPLOITATION RATE	.86	.88	.95	.80

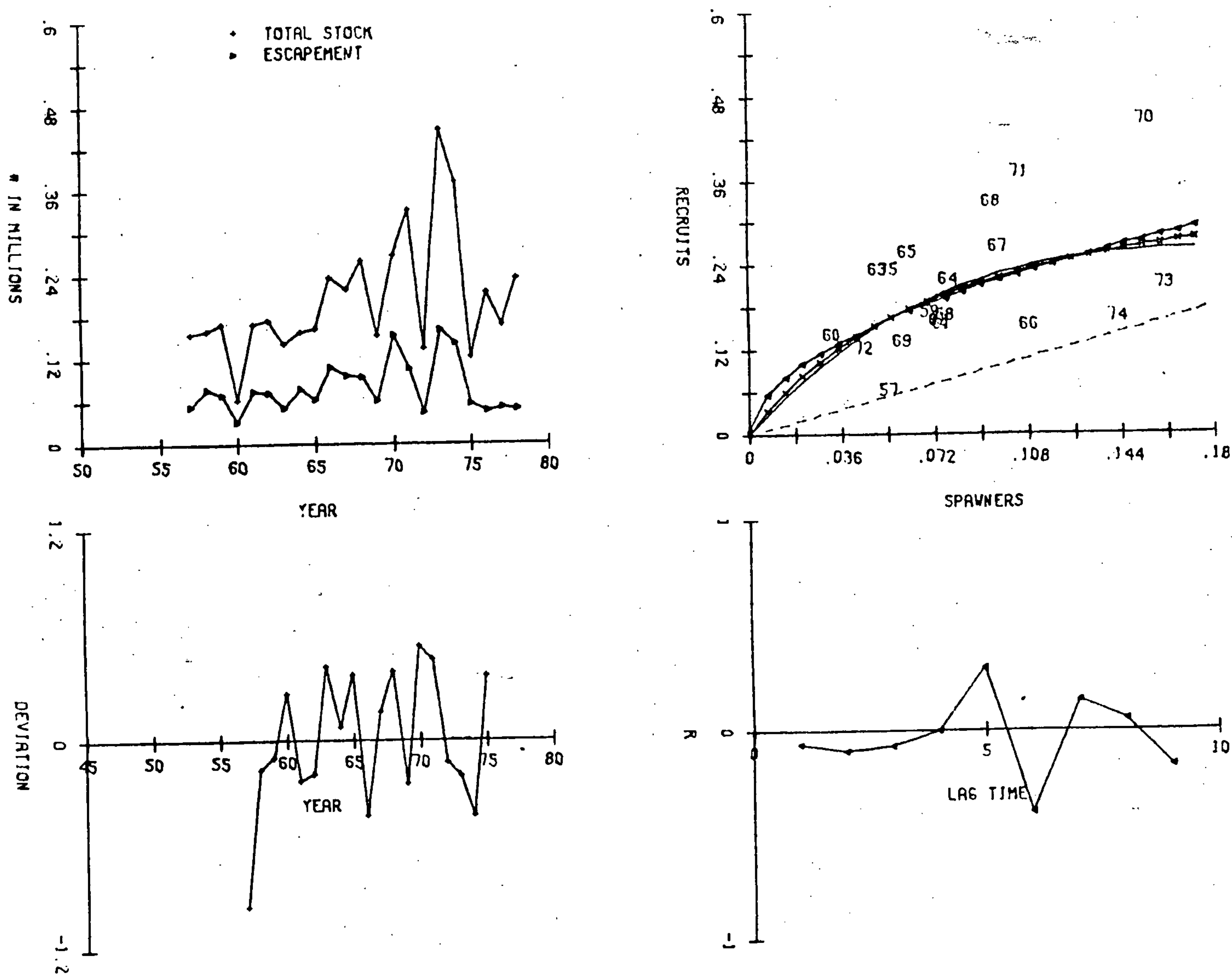
I. <u>Major Uncertainties in Analysis</u>

1. uncertainty in sports fishing estimates
2. increased effort in escapement counts in recent years
3. large uncertainty in catch allocation
4. uncertainty in the contribution of Washington produced fish

II. <u>Impediments to Improved Management</u>

1. mixed stock problem with chum and pink fishery
2. interception by Point Roberts fishery

S.W.V.I. COHO

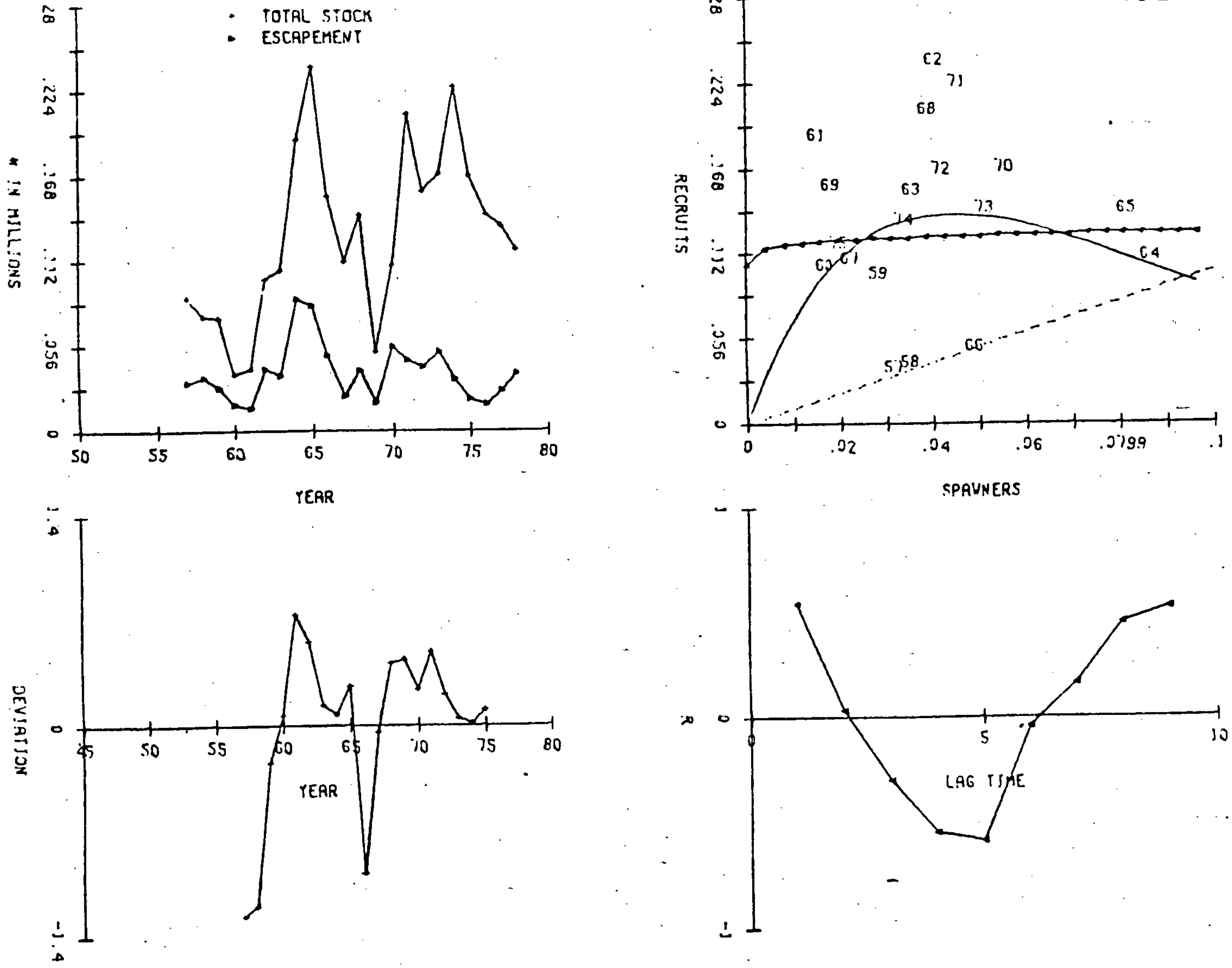


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	48,000	100,000	50,000	200,000
CATCH	135,000	150,000	100,000	160,000
EXPLOITATION RATE	.74	.60	.67	.44

I. <u>Major Uncertainties in Analysis</u>
   1. large uncertainty in catch allocation
   2. uncertainty in the contribution of Washington produced fish

II. <u>Impediments to Improved Management</u>
   1. West coast troll fishery

N.W.V.I. COHO

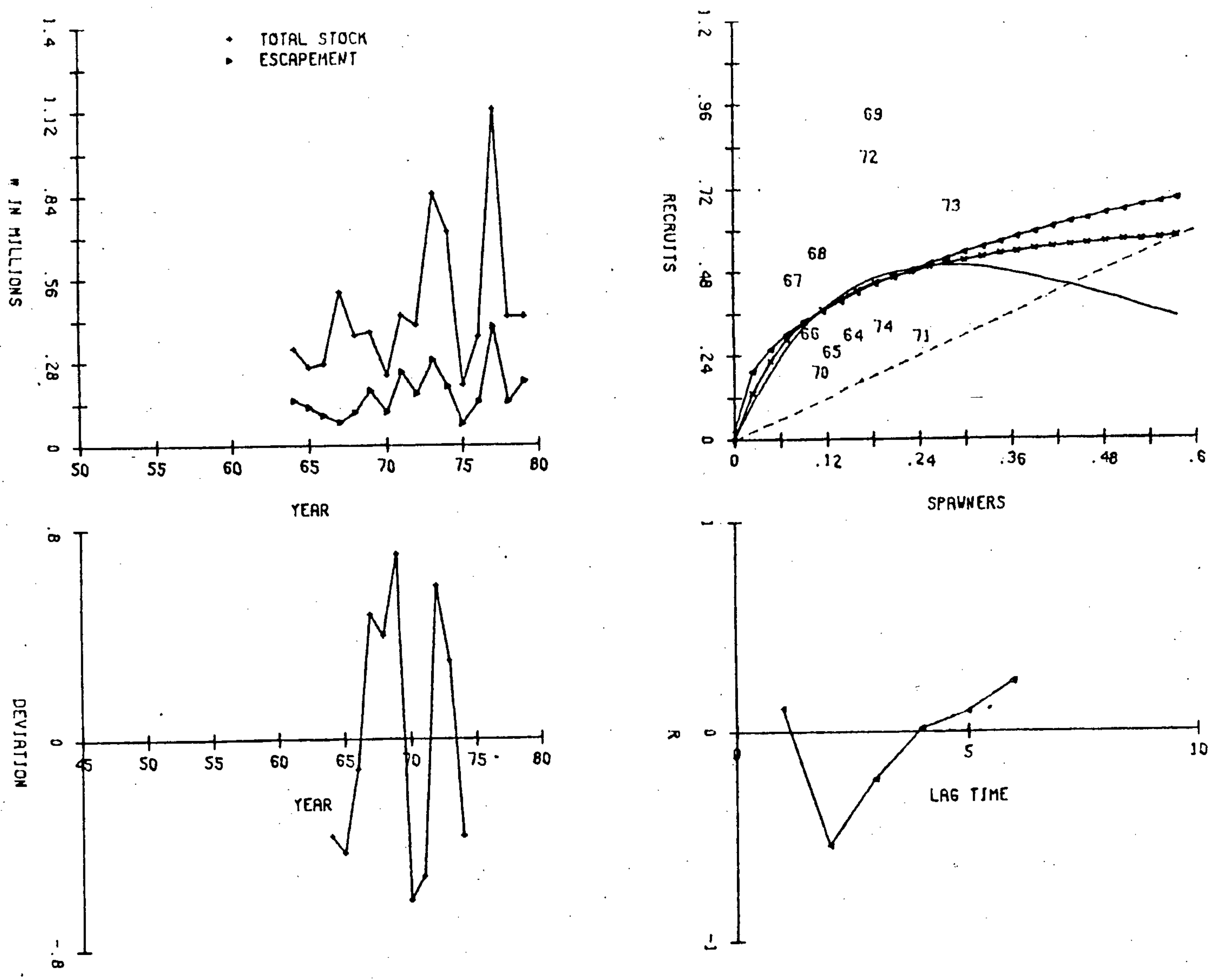


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	27,000	35,000	20,000	50,000
CATCH	116,000	125,000	100,000	125,000
EXPLOITATION RATE	.81	.78	.83	.71

I. Major Uncertainties in Analysis
   1. large uncertainty in catch allocation
   2. uncertainty in the contribution of Washington produced fish

II. Impediments to Improved Management
   1. West coast troll fishery

NASS SOCKEYE

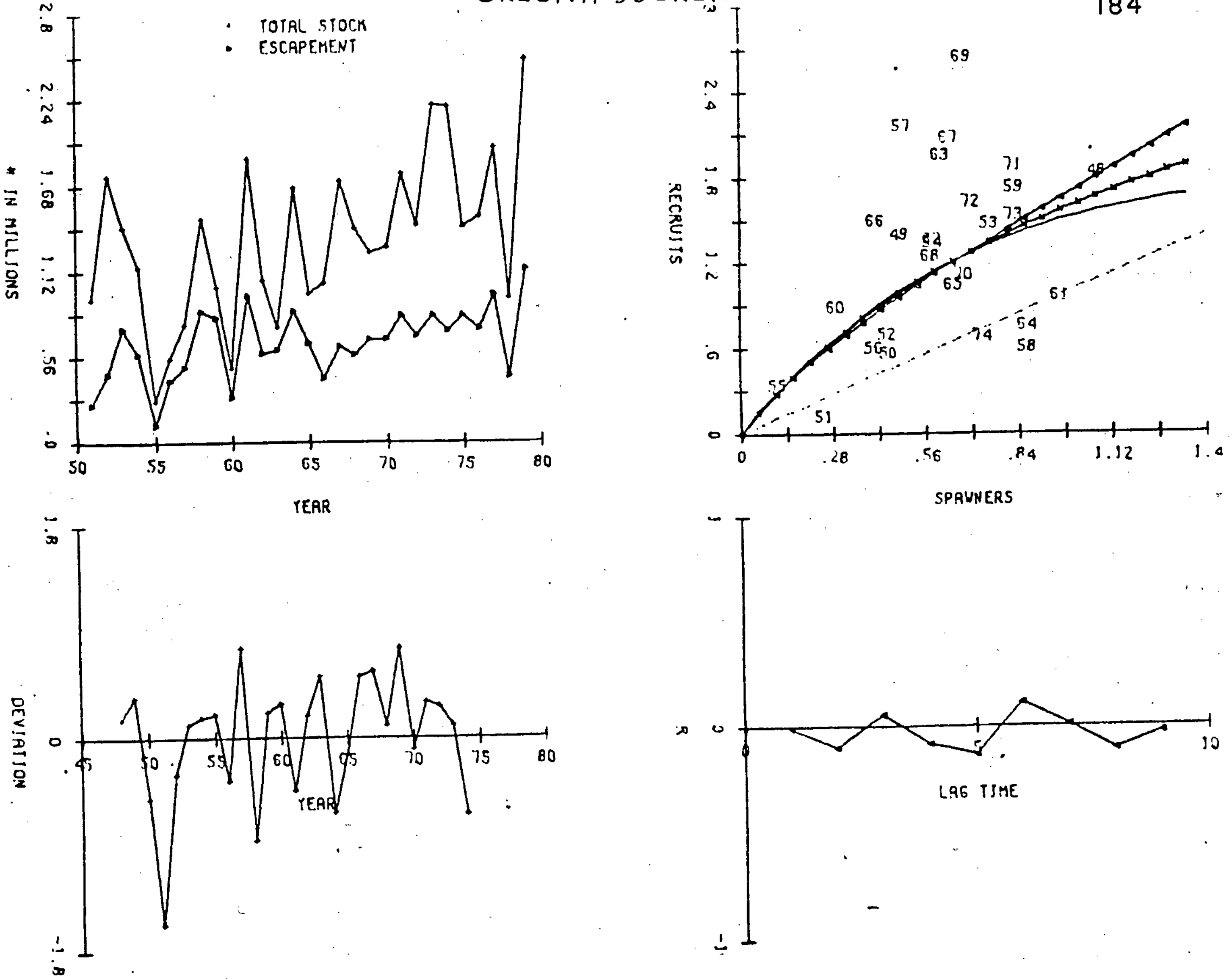


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	195,000	181,000	120,000	360,000
CATCH	317,000	350,000	240,000	360,000
EXPLOITATION RATE	.62	.66	.67	.50

I. <u>Major Uncertainties in Analysis</u>
   1. escapement counts before 1964 are unreliable
   2. uncertainty in catch allocation of Skeena and Nass fish
   3. Alaska interception not included

II. <u>Impediments to Improved Management</u>
   1. mixed fishery problem with Skeena sockeye, pink and local pink stocks
   2. interception by Alaska fishery

SKEENA SOCKEYE



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	820,000	868,000	600,000	1,500,000
CATCH	834,000	800,000	830,000	1,000,000
EXPLOITATION RATE	.50	.48	.58	.40

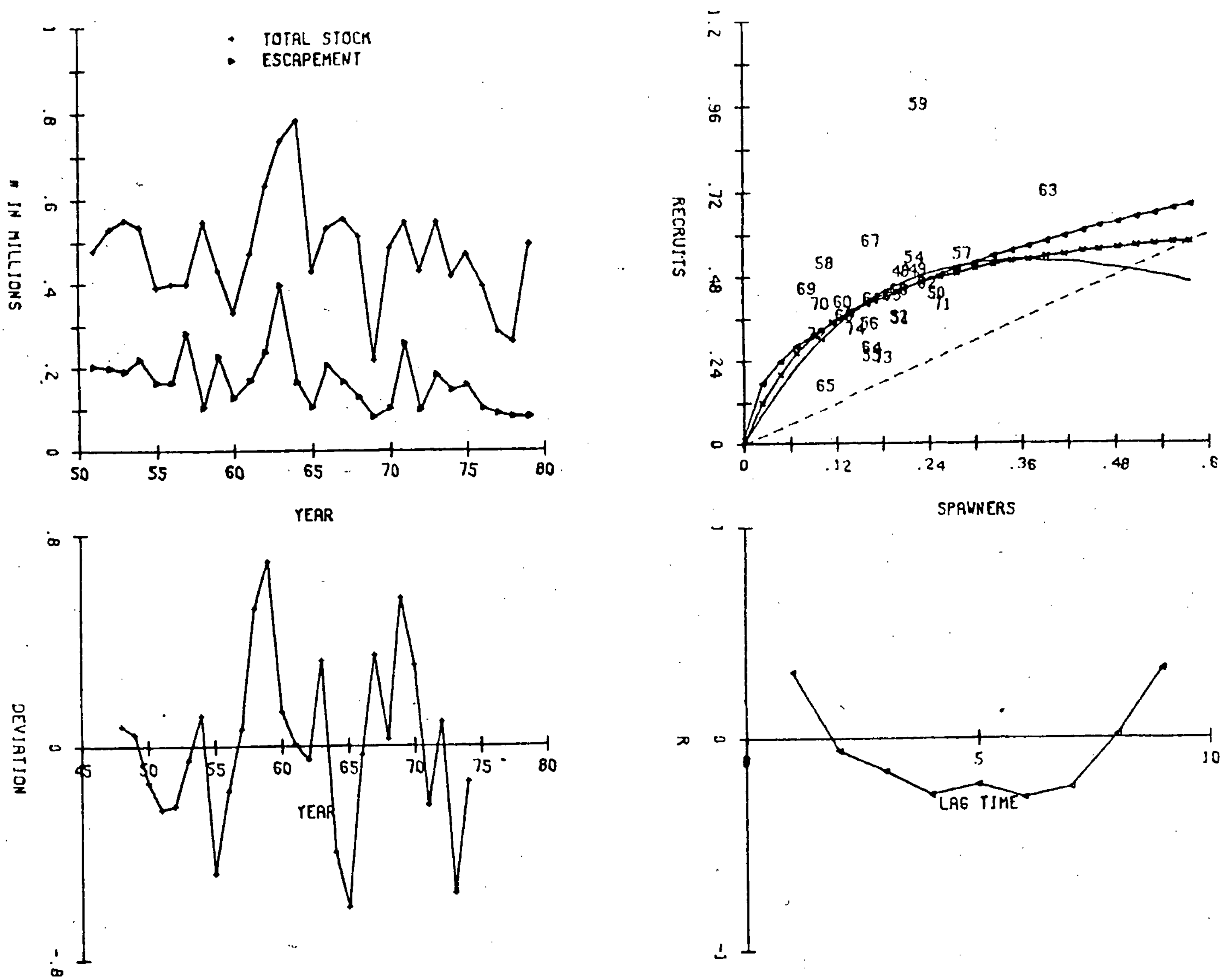
I. <u>Major Uncertainties in Analysis</u>

1. substock composition is changing rapidly to predominantly enhanced stocks
2. effects of substantial increase of smolt output from spawning channels are uncertain
3. Alaska interception not included
4. uncertainty in catch allocation

II. <u>Impediments to Improved Management</u>

1. mixed fishery problem with pink and enhanced stocks
2. interception by Alaska, Q.C.I, Nass and upper C.C. fisheries

C.C. SOCKEYE

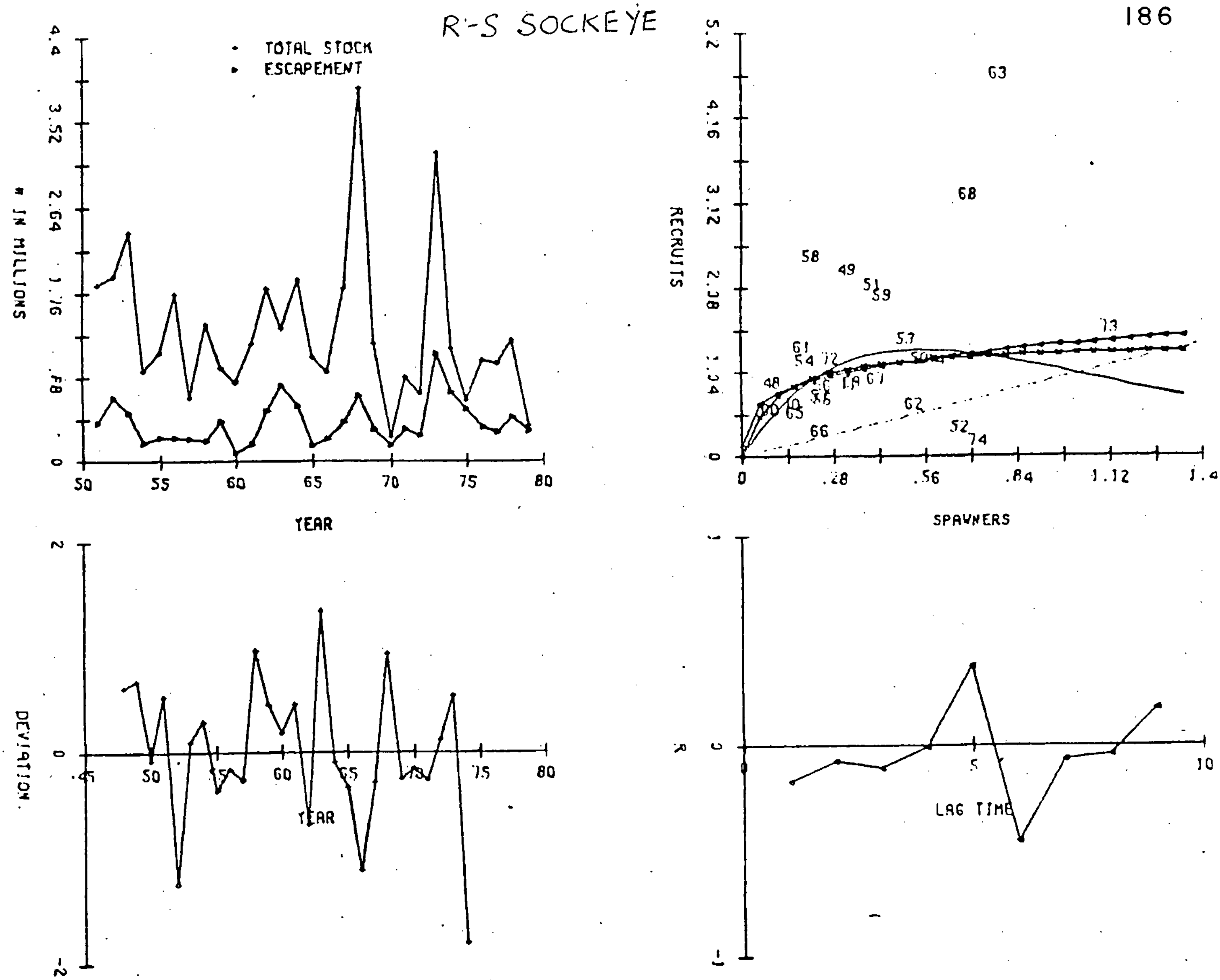


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	100,000	200,000	100,000	400,000
CATCH	280,000	283,000	220,000	350,000
EXPLOITATION RATE	.74	.59	.69	.47

I. <u>Major Uncertainties in Analysis</u>
   1. age composition data available from 1959-1972 only
   2. may include fish destined for Skeena in the catch

II. <u>Impediments to Improved Management</u>
   1. difficult to set up small terminal fisheries
   2. mixed fisheries problem with local pinks

R-S SOCKEYE

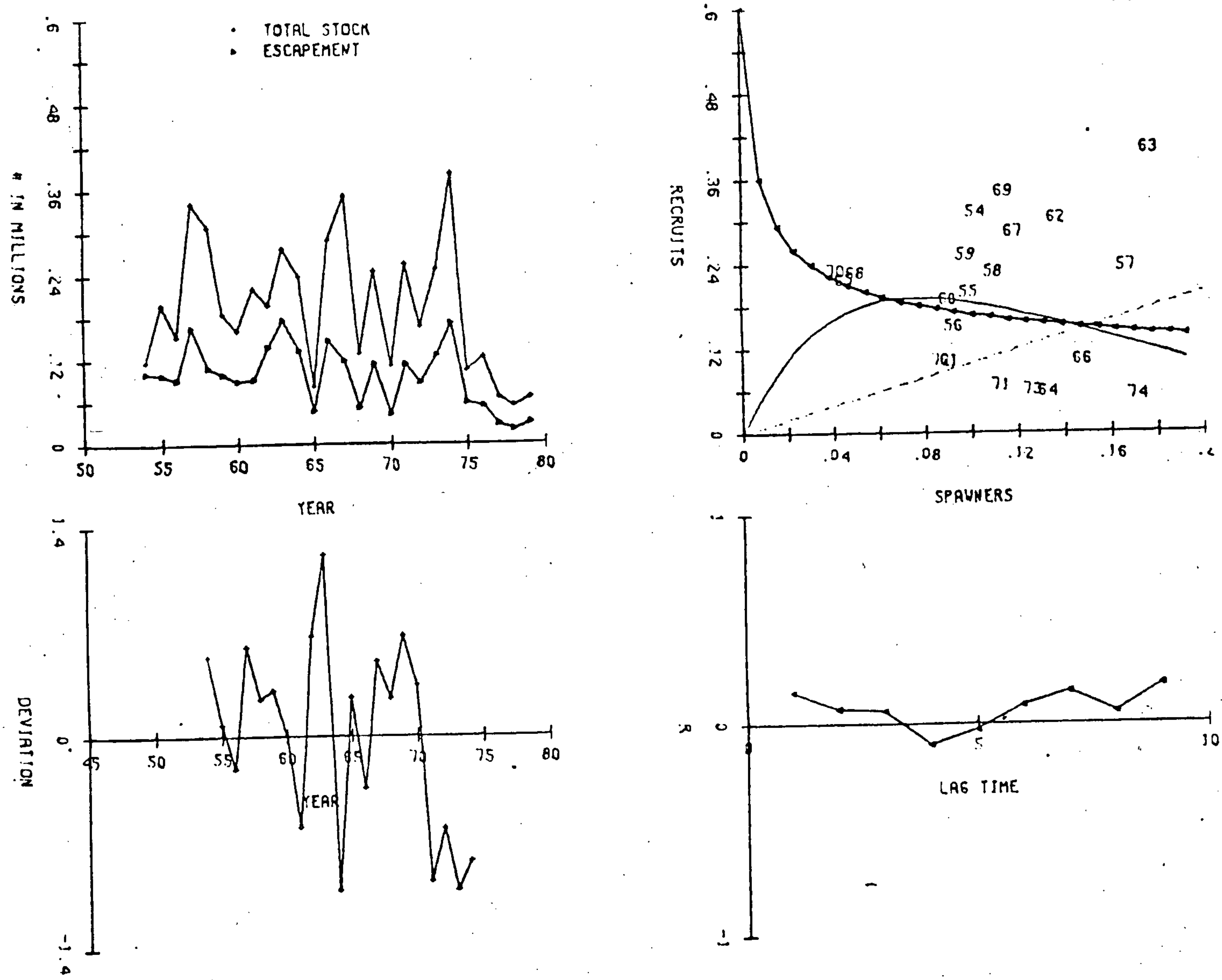


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	390,000	500,000	400,000	2,000,000
CATCH	480,000	1,200,000	1,000,000	1,500,000
EXPLOITATION RATE	.55	.71	.83	.43

I. <u>Major Uncertainties in Analysis</u>
   1. substocks not treated separately

II. <u>Impediments to Improved Management</u>
   1. mixed fishery problem with pinks

J.S. SOCKEYE

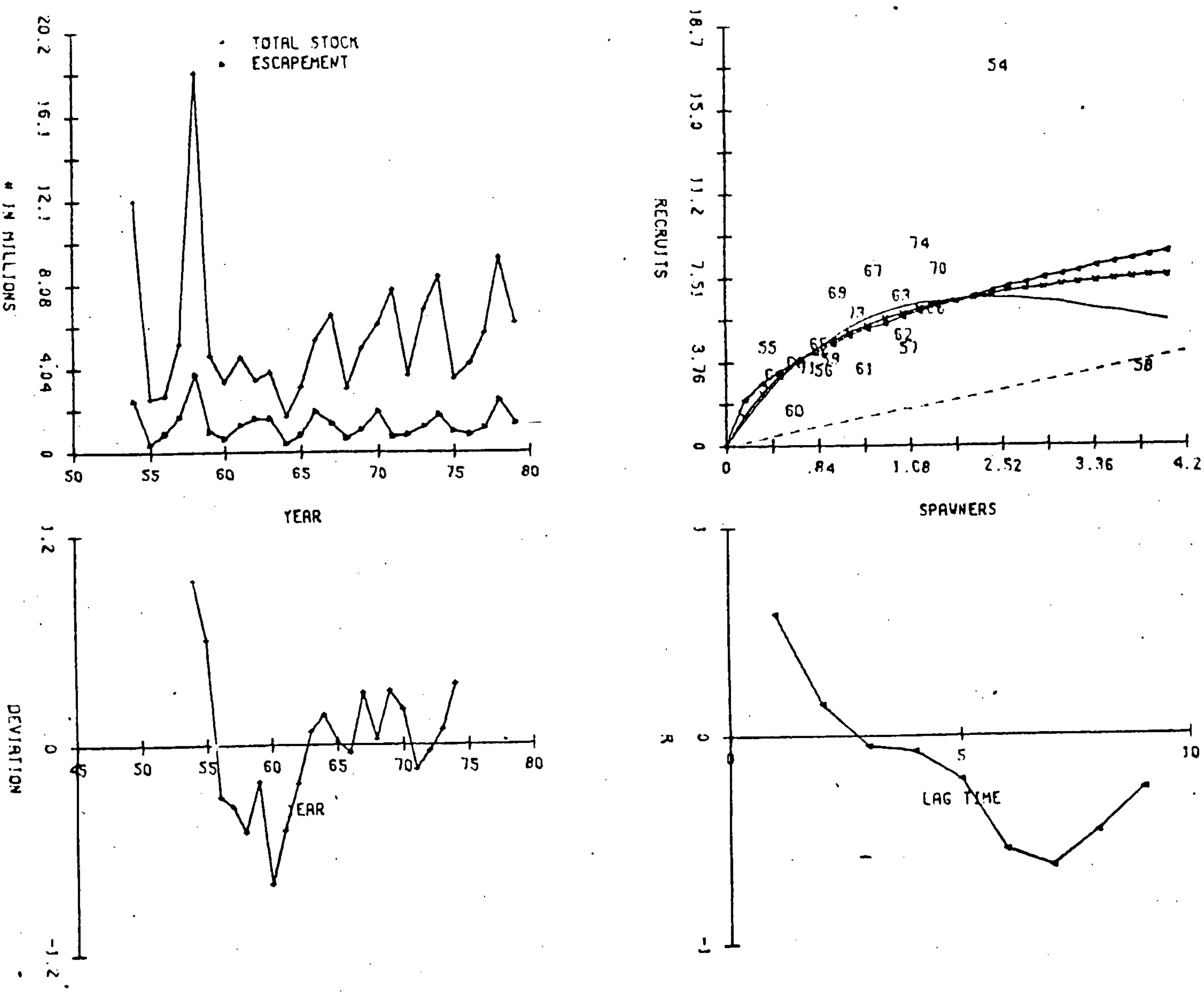


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	37,000	?	?	?
CATCH	44,000	?	?	?
EXPLOITATION RATE	.54	?	?	?

I. Major Uncertainties in Analysis
1. age composition data available from 1958-1975 only
2. native food fishery not included
3. misallocation of catches destined for the Fraser River
4. extreme uncertainty in optimal escapement estimation

II. Impediments to Improved Management
1. interception during Johnstone Strait fishery for Fraser sockeye
2. unable to move fishing boundaries due to gear allocation problem

FRASER SOCKEYE

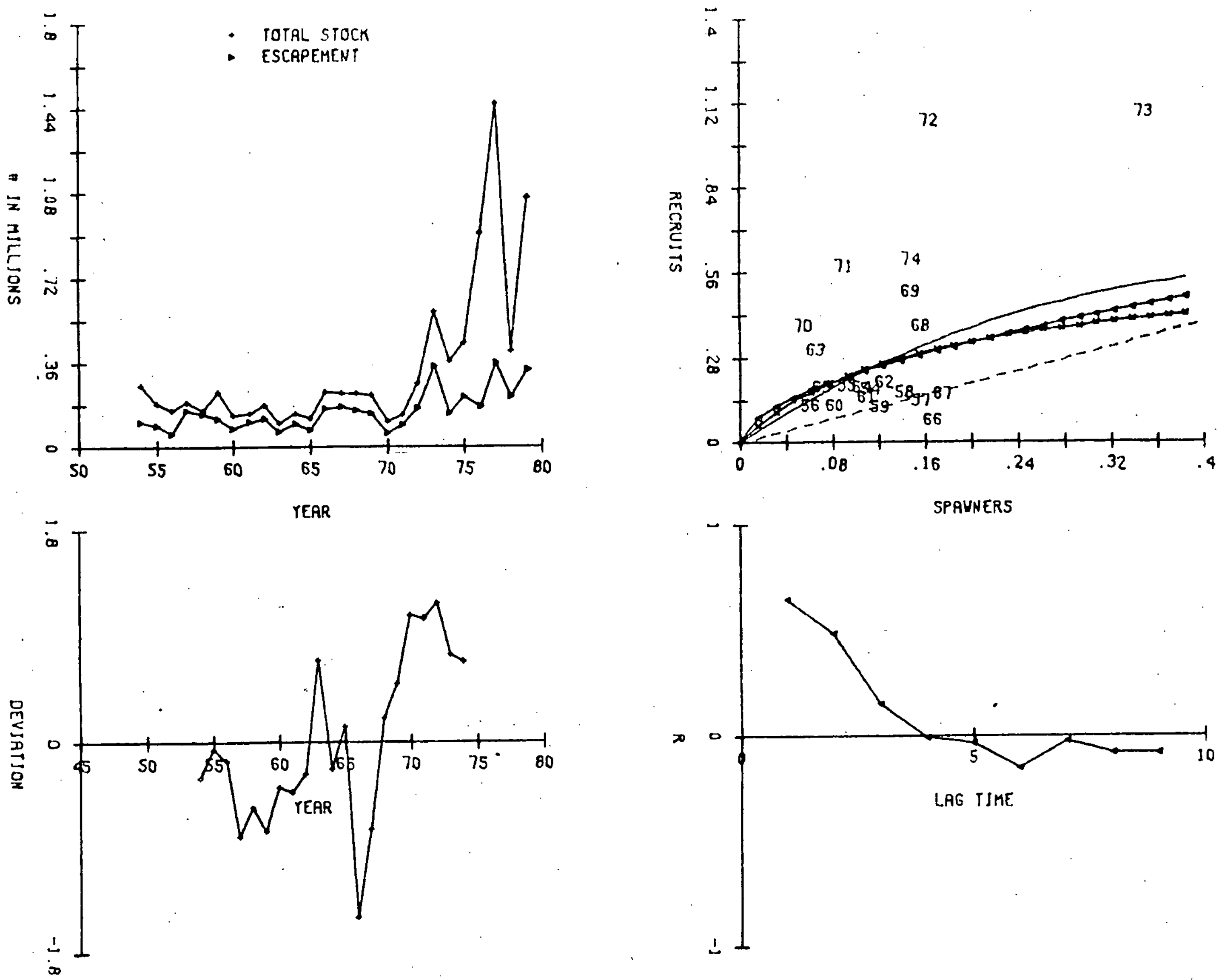


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM LOWER	UPPER
ESCAPEMENT	1,370,000	4,000,000	2,000,000	8,000,000
CATCH	4,460,000	8,000,000	7,000,000	11,000,000
EXPLOITATION RATE	.77	.67	.78	.58

I. Major Uncertainties in Analysis
   1. substocks not treated separately
   2. cyclic dominance not considered
   3. in 1958 only 2 million fish allowed to spawn in Adams River

II. Impediments to Improved Management
   1. allocation of equal share to U.S. and Canadian fishermen
   2. interception by Johnstone Strait net fishery and W.V.I. troll fishery
   3. potential disease problem in rebuilding high spawning densities
   4. substock mixed fishery problem

S.W.V.I. SOCKEYE



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	260,000	300,000	100,000	1,000,000
CATCH	600,000	500,000	150,000	1,000,000
EXPLOITATION RATE	.70	.63	.60	.50

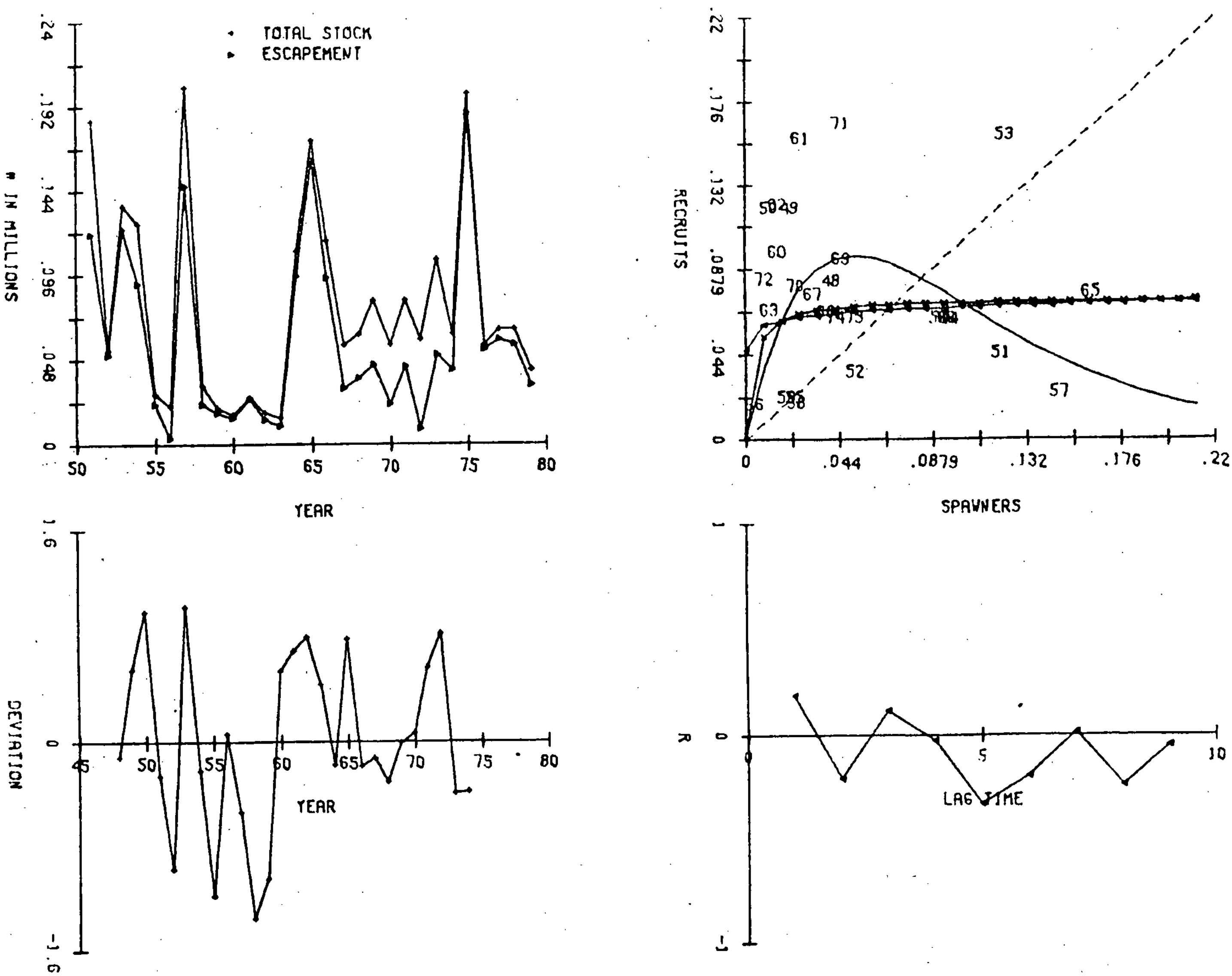
I. <u>Major Uncertainties in Analysis</u>

1. fertilization of Great Central Lake increased production in recent years
2. age composition data available from 1960-64 and 1967-72
3. 1970-74 S-R data has a totally different pattern than previous years
4. current upward production trend occurred before fertilization (note upward trend residuals began in 1968)

II. <u>Impediments to Improved Management</u>

1. limited geographical area for terminal fishery
2. impact of lake fertilization on the long term production of sockeye is still uncertain

Q.C.1 CHUM



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	78,000	?	?	?
CATCH	8,000	?	?	?
EXPLOITATION RATE	.10	?	?	?

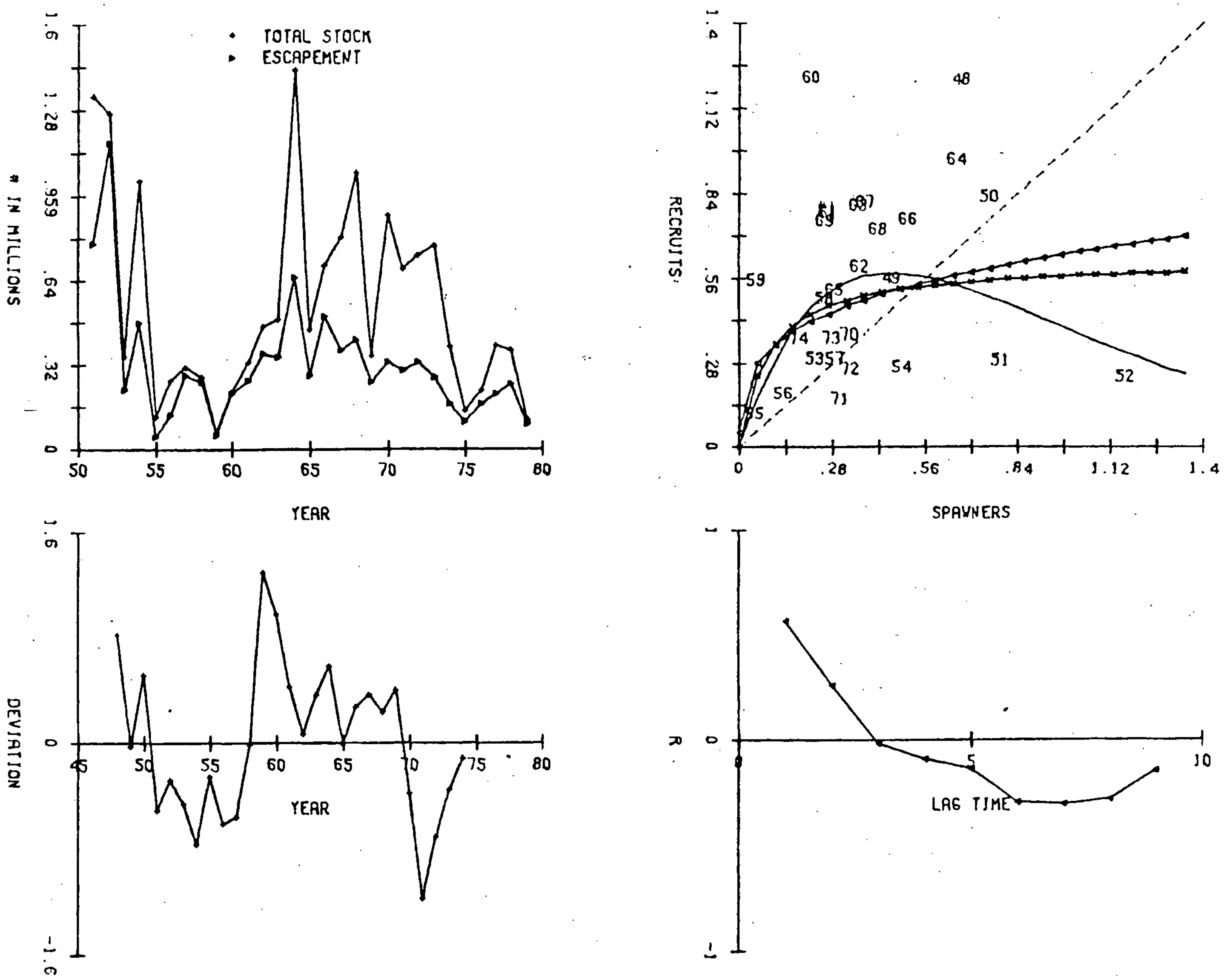
I. <u>Major Uncertainties in Analysis</u>

1. age composition data not available
2. extreme uncertainty in optimal escapement estimation

II. <u>Impediments to Improved Management</u>

1. difficulty in setting up terminal fishery

Q.C.2 CHUM

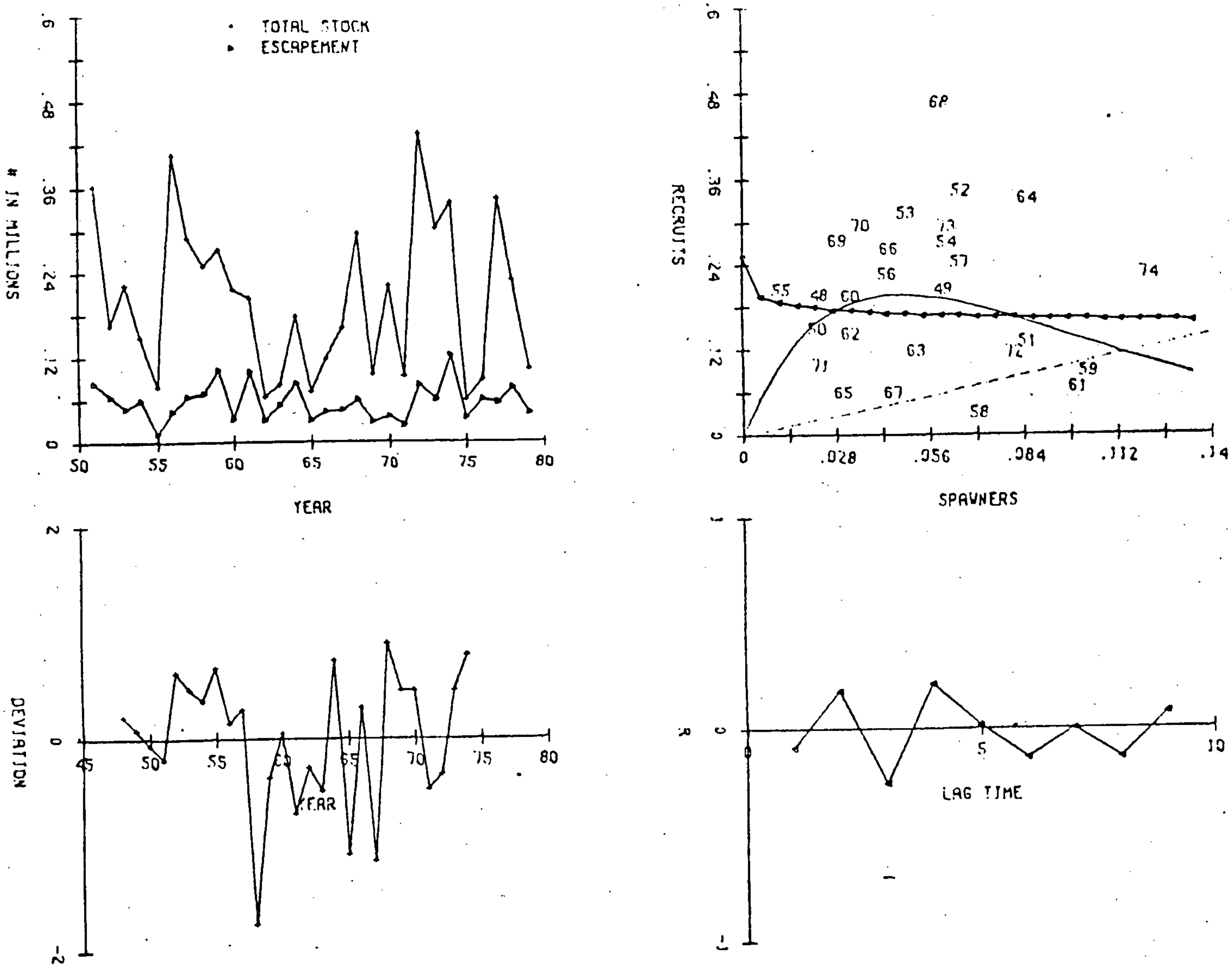


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	155,000	600,000	206,000	1,000,000
CATCH	85,000	200,000	100,000	300,000
EXPLOITATION RATE	.34	.25	.33	.23

I. Major Uncertainties in Analysis
   1. age composition data available in 1961, 1964-65 and 1971-1976
   2. poor escapement estimate in 1956, 1959
   3. early 50's data did not account for Japanese high seas interception

II. Impediments to Improved Management
   1. difficulty in setting up terminal fishery

NASS CHUM

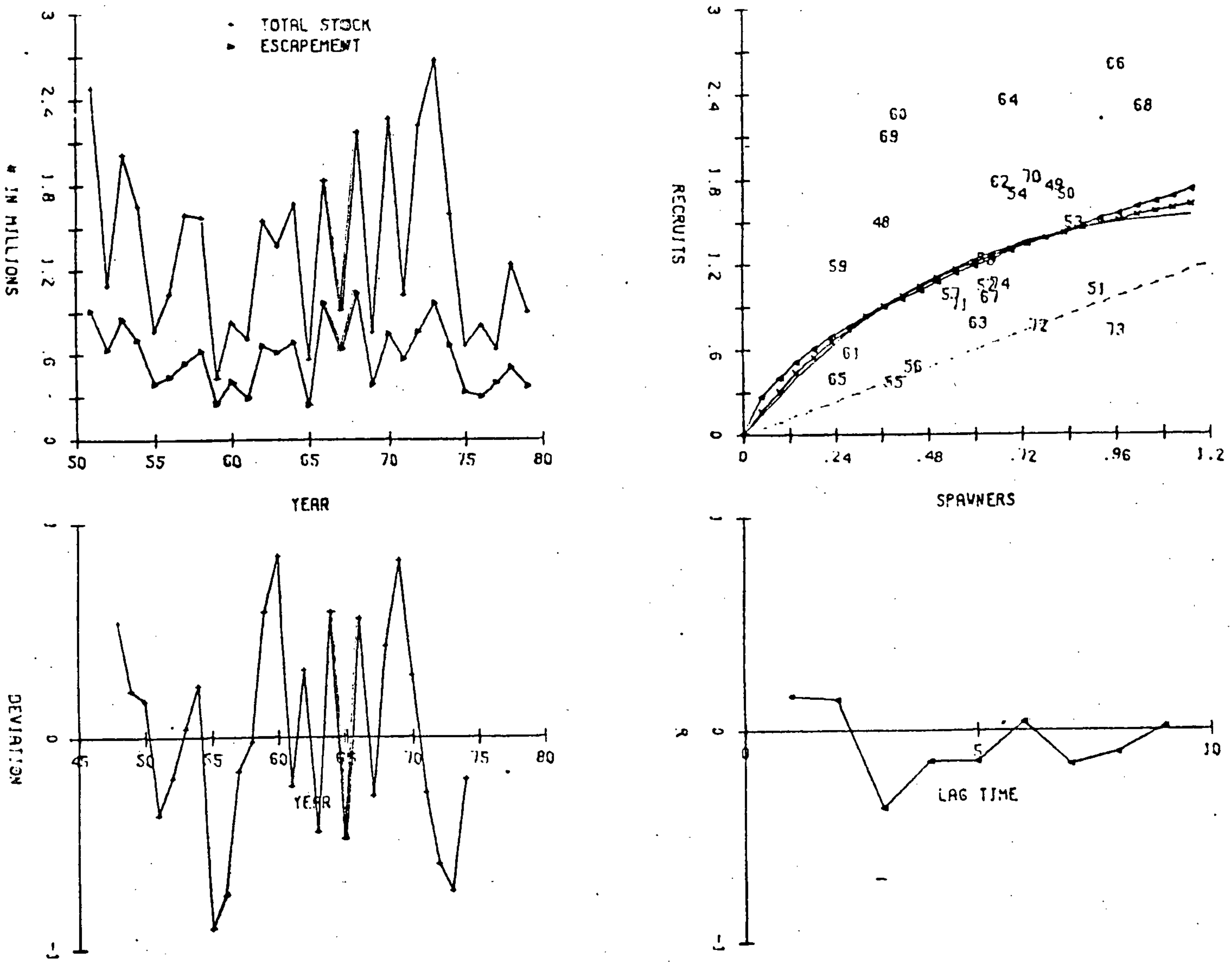


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	53,000	?	?	?
CATCH	112,000	?	?	?
EXPLOITATION RATE	.68	?	?	?

I. Major Uncertainties in Analysis
  1. age composition data available from 1957-72 only
  2. included unknown, but significant number of Alaska chum in the catch
  3. extreme uncertainty in optimal escapement estimation

II. Impediments to Improved Management
  1. interception of Alaska chum
  2. mixed fishery problem with Skeena and local pinks

C.C. CHUM

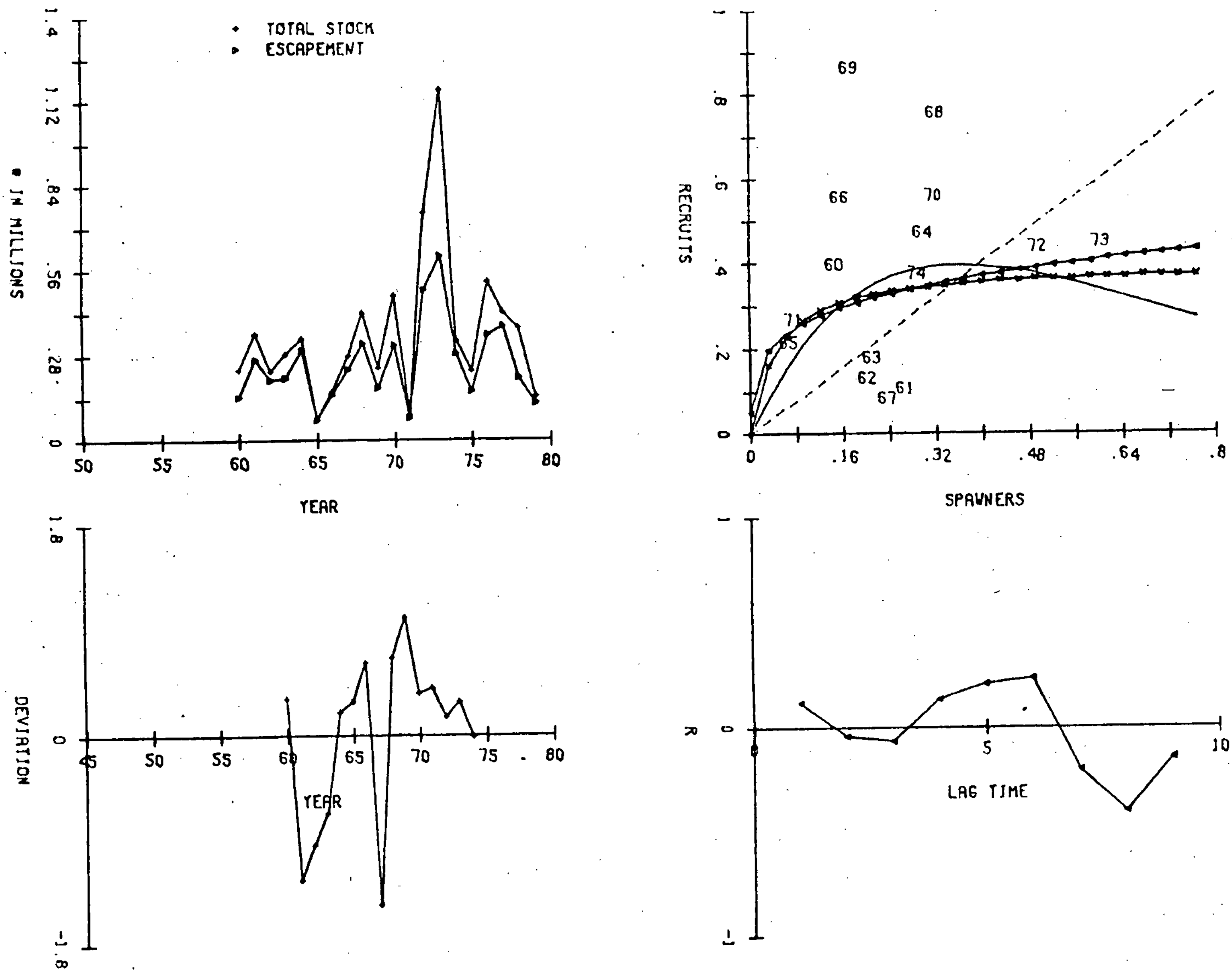


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	380,000	684,000	400,000	1,000,000
CATCH	470,000	808,000	400,000	800,000
EXPLOITATION RATE	.55	.54	.54	.44

I. <u>Major Uncertainties in Analysis</u>
   1. age composition data available from 1957-72 only
   2. decline of productivity in recent years may indicate habitat deterioration

II. <u>Impediments to Improved Management</u>
   1. mixed stock fishery with local pinks

J.S. CHUM

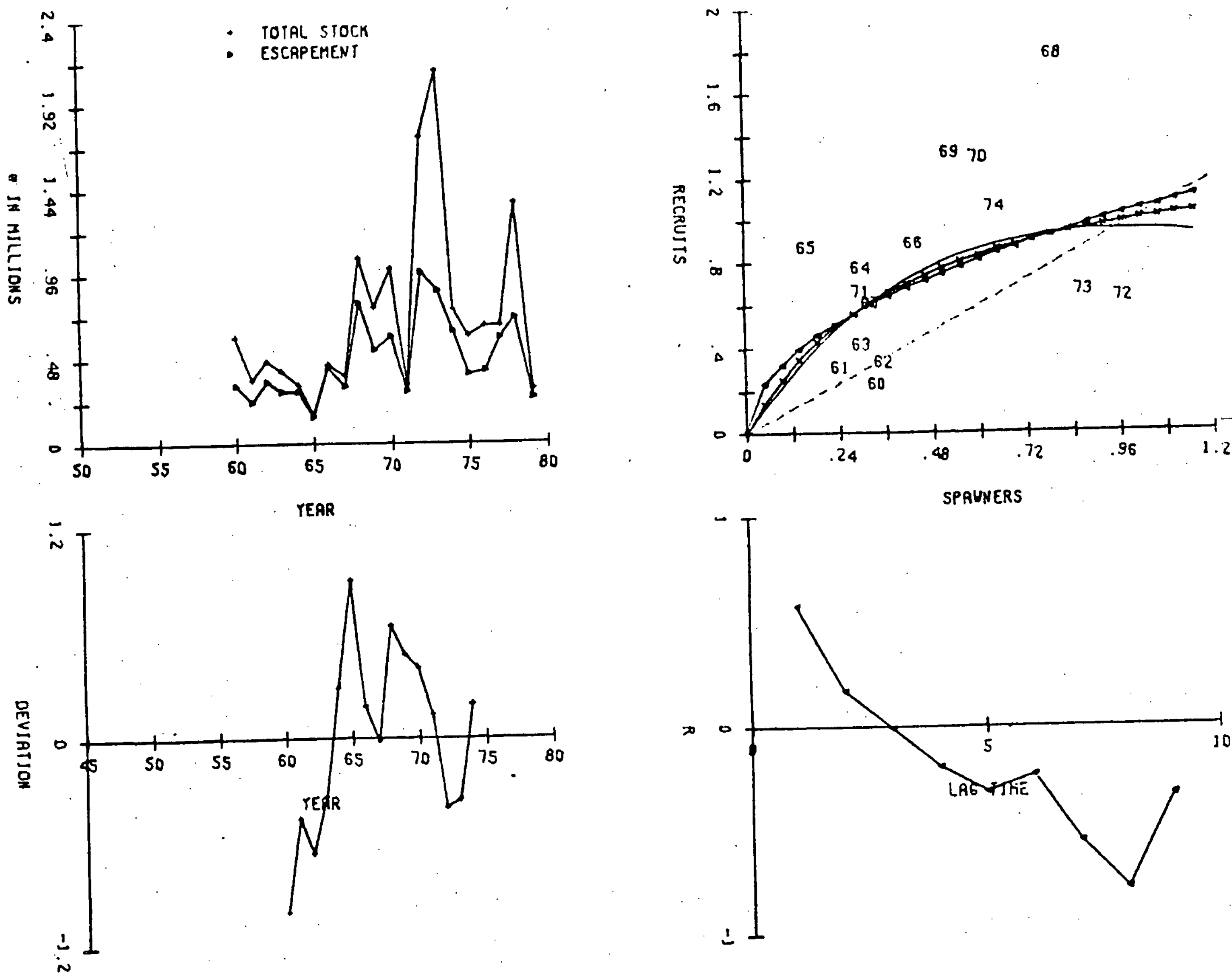


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	242,000	210,000	150,000	350,000
CATCH	94,000	250,000	150,000	250,000
EXPLOITATION RATE	.28	.54	.50	.42

I. Major Uncertainties in Analysis
   1. age composition data available from 1958-72 only
   2. uncertainty in catch allocation

II. Impediments to Improved Management
   1. mixed fishery with Big Qualicum, Fraser and Washington fish
   2. terminal fishery produce poor quality fish

G.S. CHUM

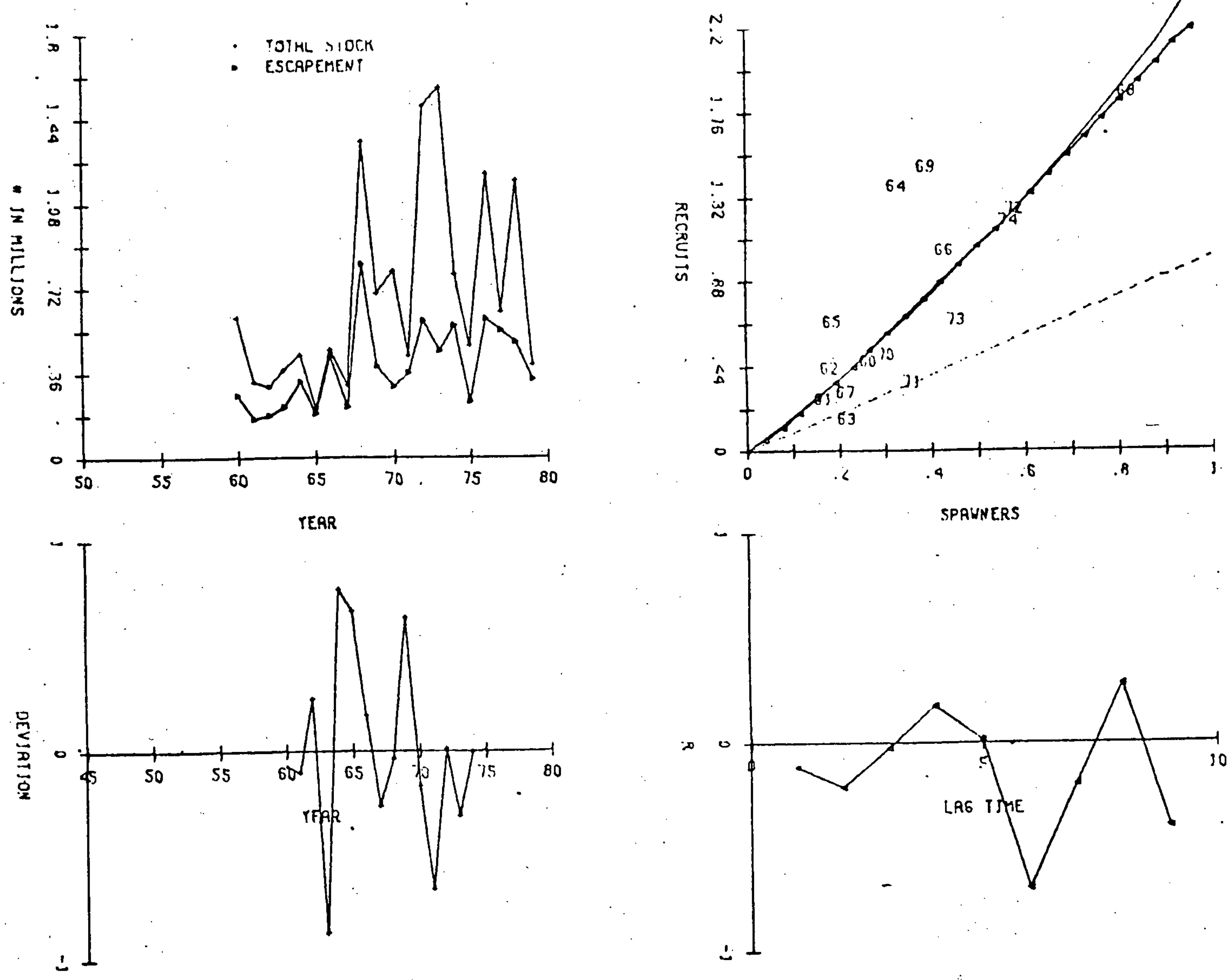


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	472,000	415,000	300,000	500,000
CATCH	246,000	488,000	200,000	500,000
EXPLOITATION RATE	.34	.54	.40	.50

I. Major Uncertainties in Analysis
1. age composition data available from 1958-64 only
2. Big Qualicum enhancement in recent years
3. uncertainty in catch allocation

II. Impediments to Improved Management
1. mixed fishery with Big Qualicum, Fraser and Washington fish

FRASER CHUM

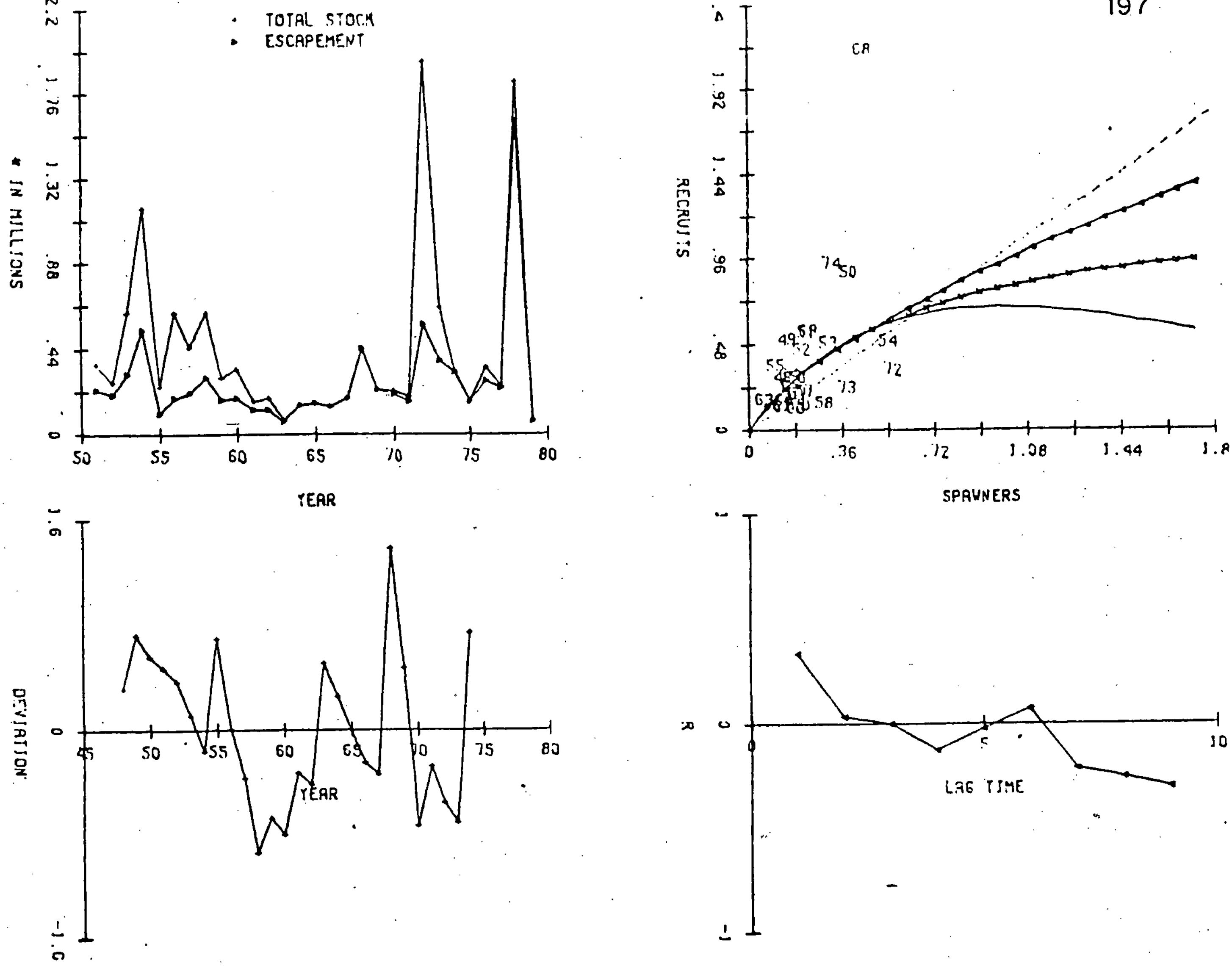


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	435,000	1,000,000	600,000	3,000,000
CATCH	341,000	1,200,000	600,000	2,000,000
EXPLOITATION RATE	.44	.55	.50	.40

I. <u>Major Uncertainties in Analysis</u>
   1. uncertainty in catch allocation
   2. difficulty in setting upper bound for optimal escapement

II. <u>Impediments to Improved Management</u>
   1. interception by Point Roberts fishery

S.W.V.I. CHUM



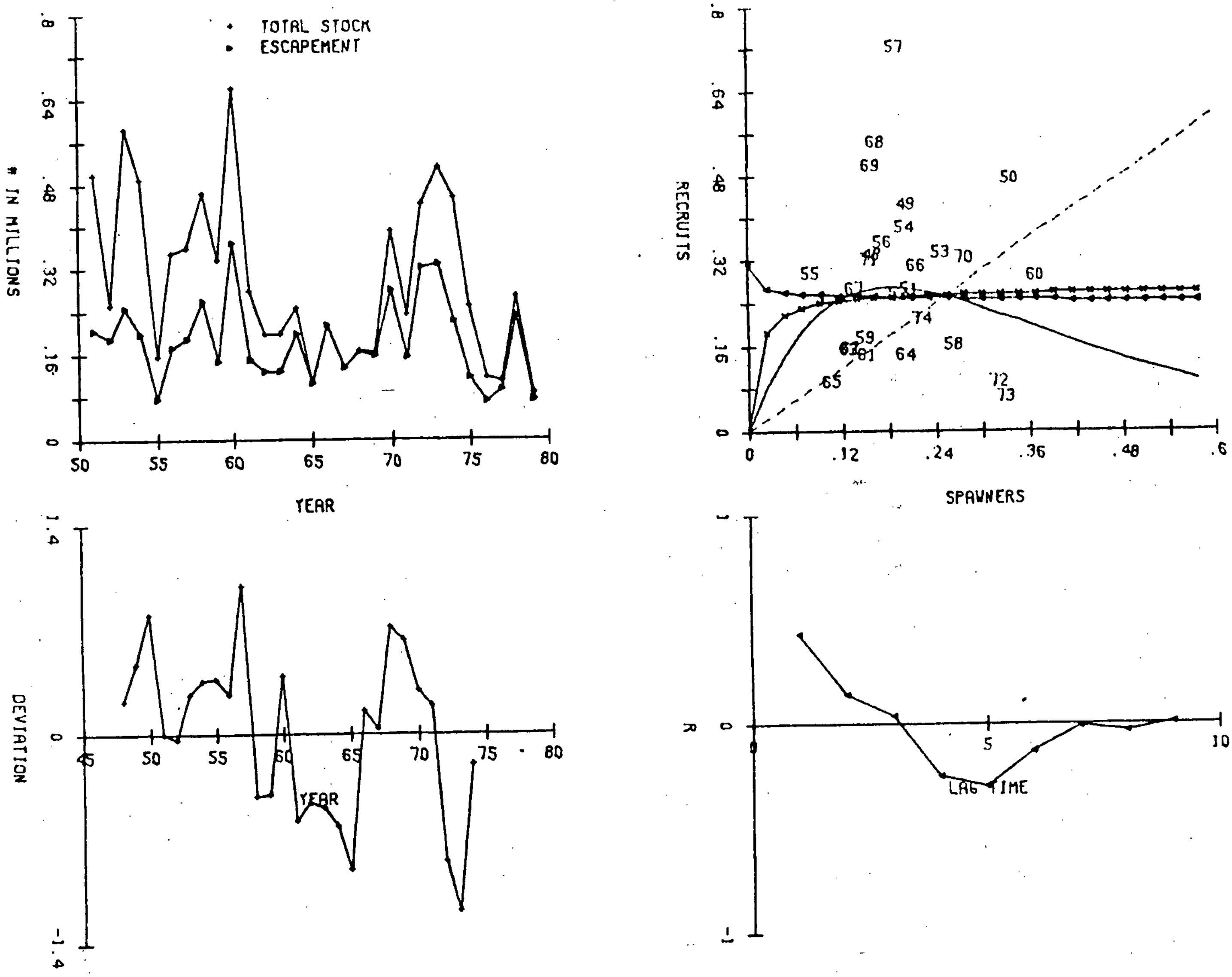
	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	471,000	372,000	300,000	500,000
CATCH	58,000	217,000	150,000	300,000
EXPLOITATION RATE	.11	.37	.33	.38

I. Major Uncertainties in Analysis

1. age composition data available from 1959-63, and 1969-78

II. Impediments to Improved Management

N.W.V.I. CHUM



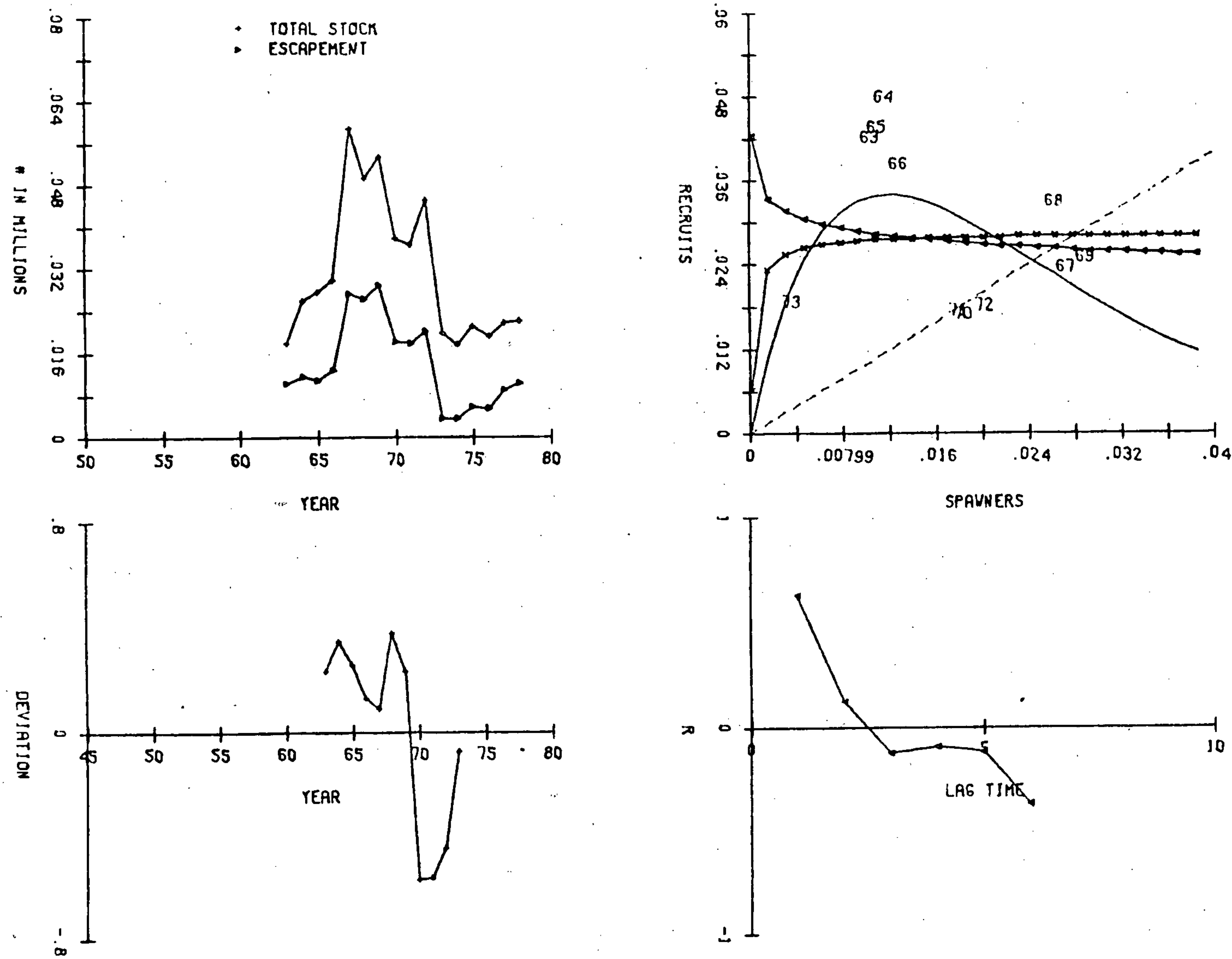
	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	117,000	150,000	100,000	200,000
CATCH	48,000	100,000	80,000	120,000
EXPLOITATION RATE	.29	.40	.44	.38

I. Major Uncertainties in Analysis

1. age composition data available from 1959-64, and 1969-77

II. Impediments to Improved Management

NASS SPRING

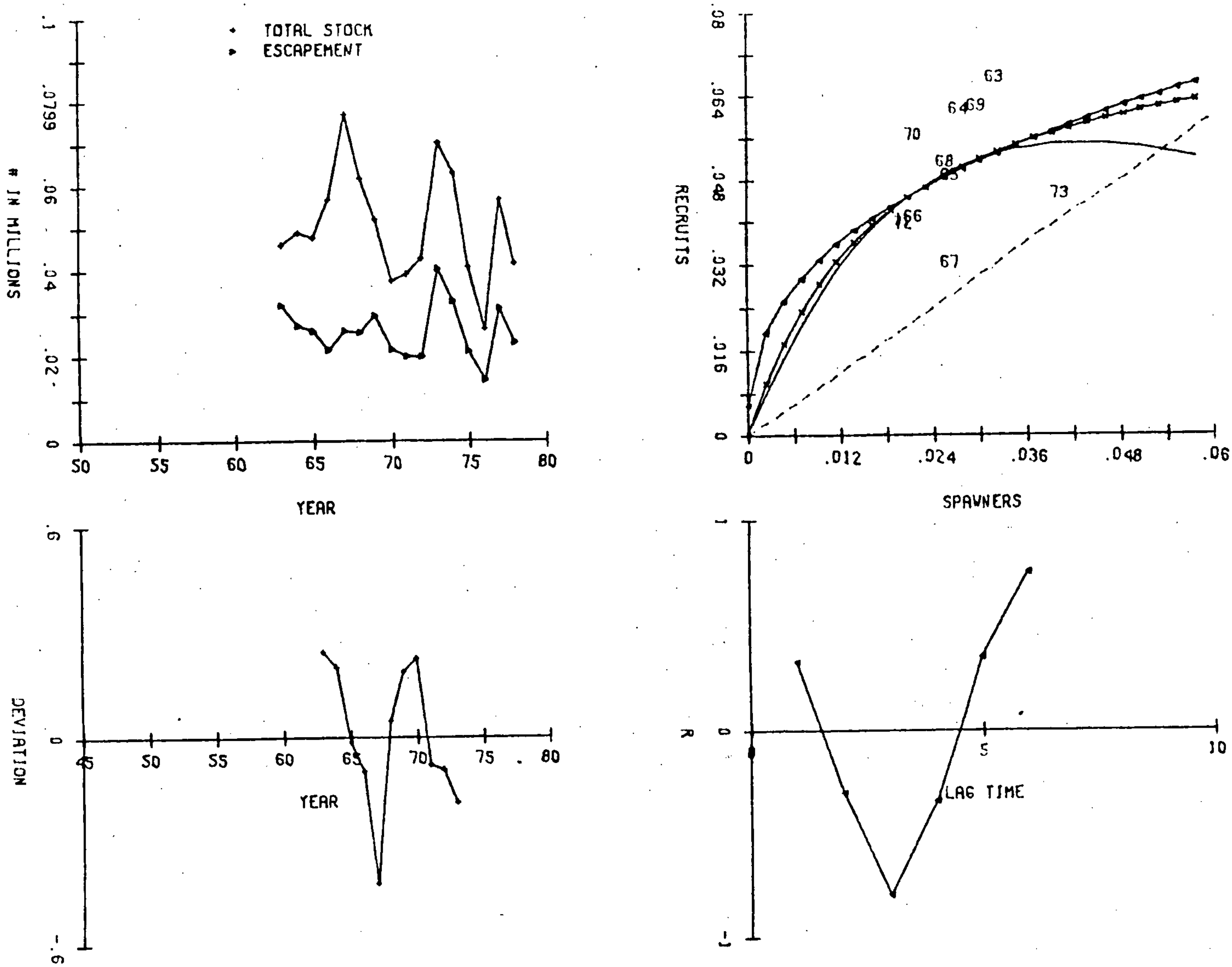


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	7,000	8,300	6,000	10,000
CATCH	13,000	27,000	20,000	26,000
EXPLOITATION RATE	.65	.76	.77	.72

I. Major Uncertainties in Analysis
   1. fish intercepted by Alaska fisheries not included
   2. time specific age structure not available
   3. large uncertainty in catch allocation

II. Impediments to Improved Management
   1. interception by Alaska troll

SKEENA SPRING

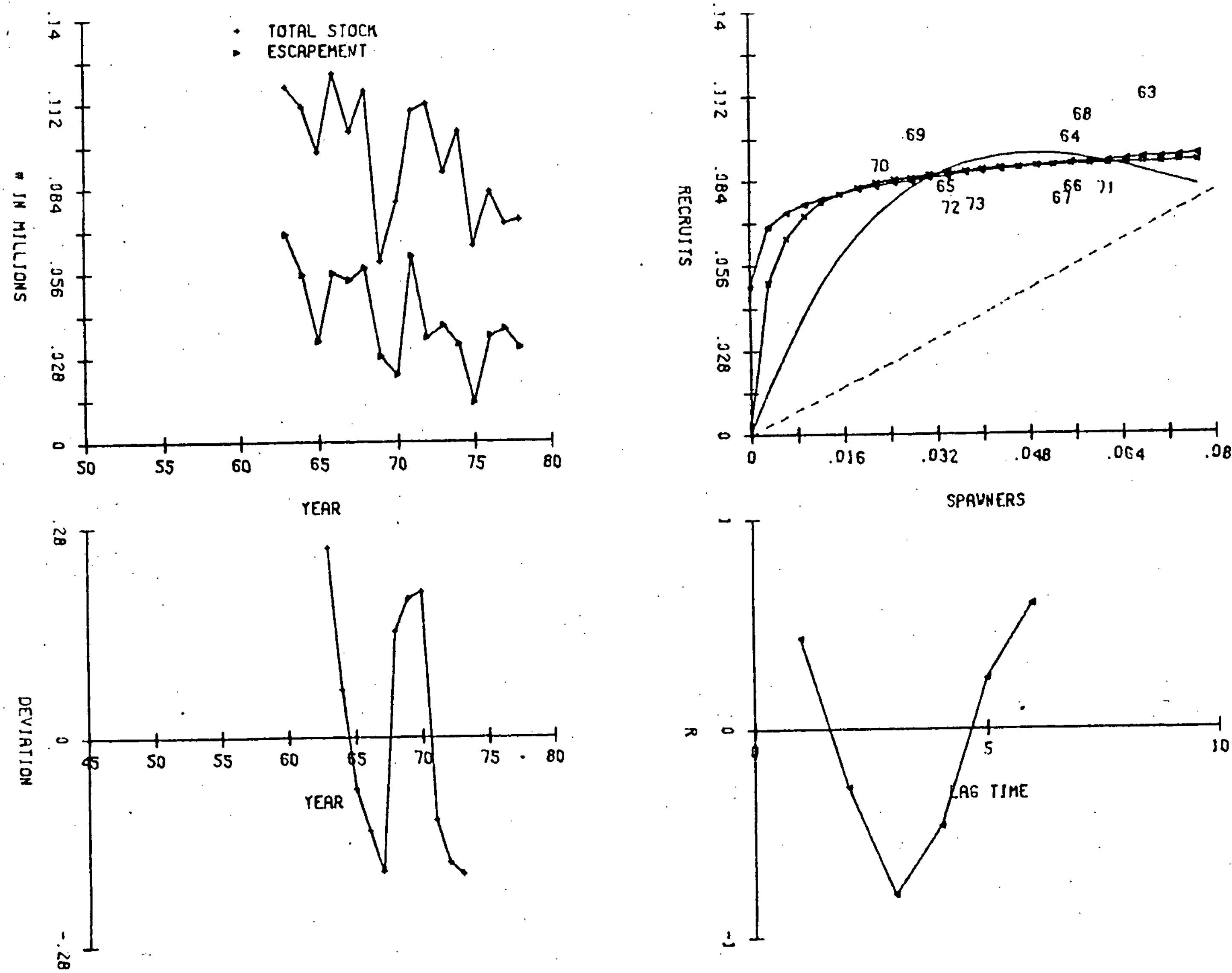


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	22,000	22,000	20,000	50,000
CATCH	19,000	25,000	20,000	30,000
EXPLOITATION RATE	.46	.53	.53	.38

I. <u>Major Uncertainties in Analysis</u>
1. fish intercepted by Alaska fisheries not included
2. native food fishery not included
3. time specific age structure not available
4. large uncertainty in catch allocation

II. <u>Impediments to Improved Management</u>
1. increasing native food fishery demands
2. interception by Alaska troll

C.C. SPRING

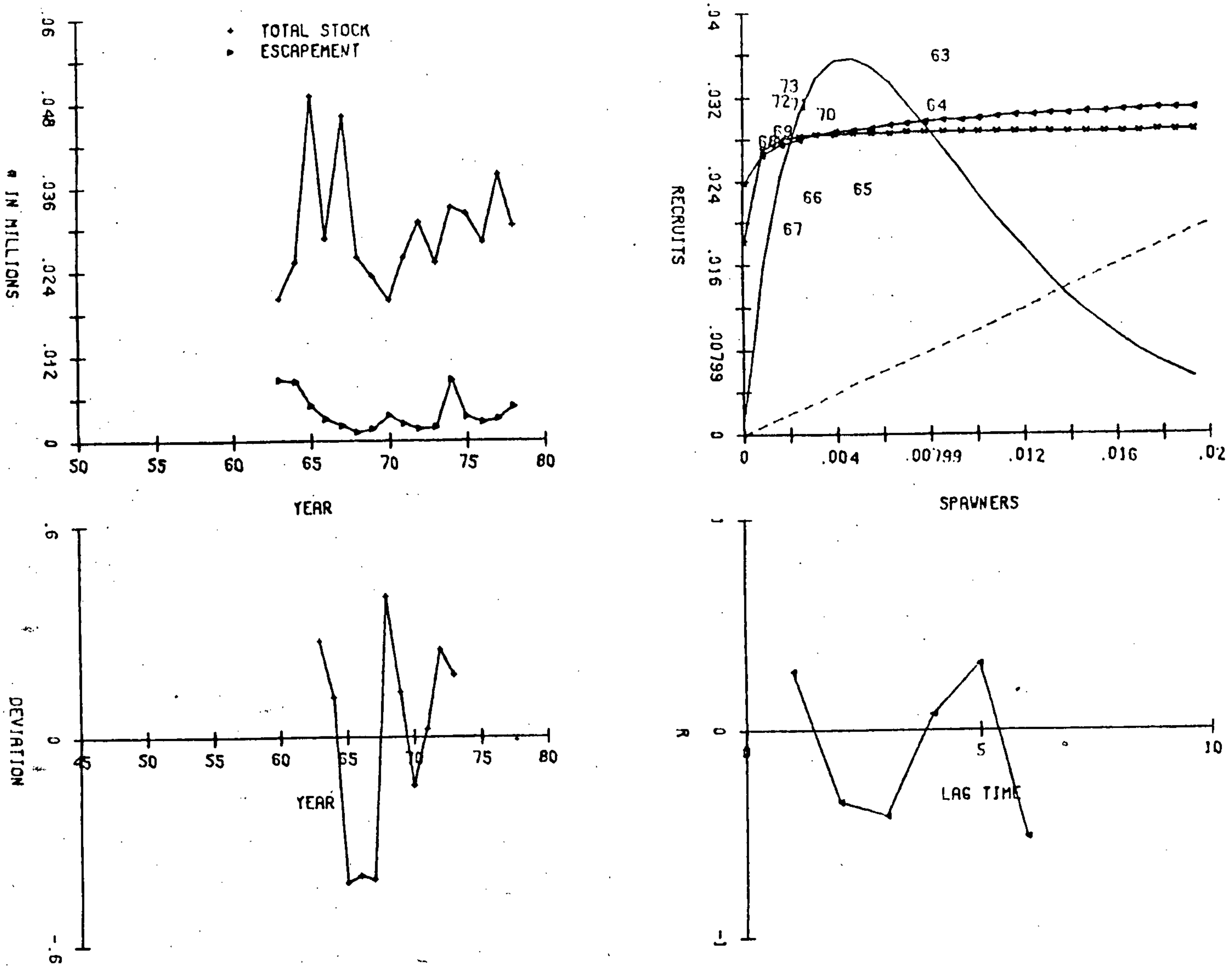


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	29,000	30,000	16,000	50,000
CATCH	44,000	56,000	50,000	50,000
EXPLOITATION RATE	.60	.65	.76	.5

I. Major Uncertainties in Analysis
1. fish intercepted by Alaska fisheries not included
2. time specific age structure not available
3. large uncertainty in catch allocation

II. Impediments to Improved Management
1. interception by Alaska troll

R-S SPRING

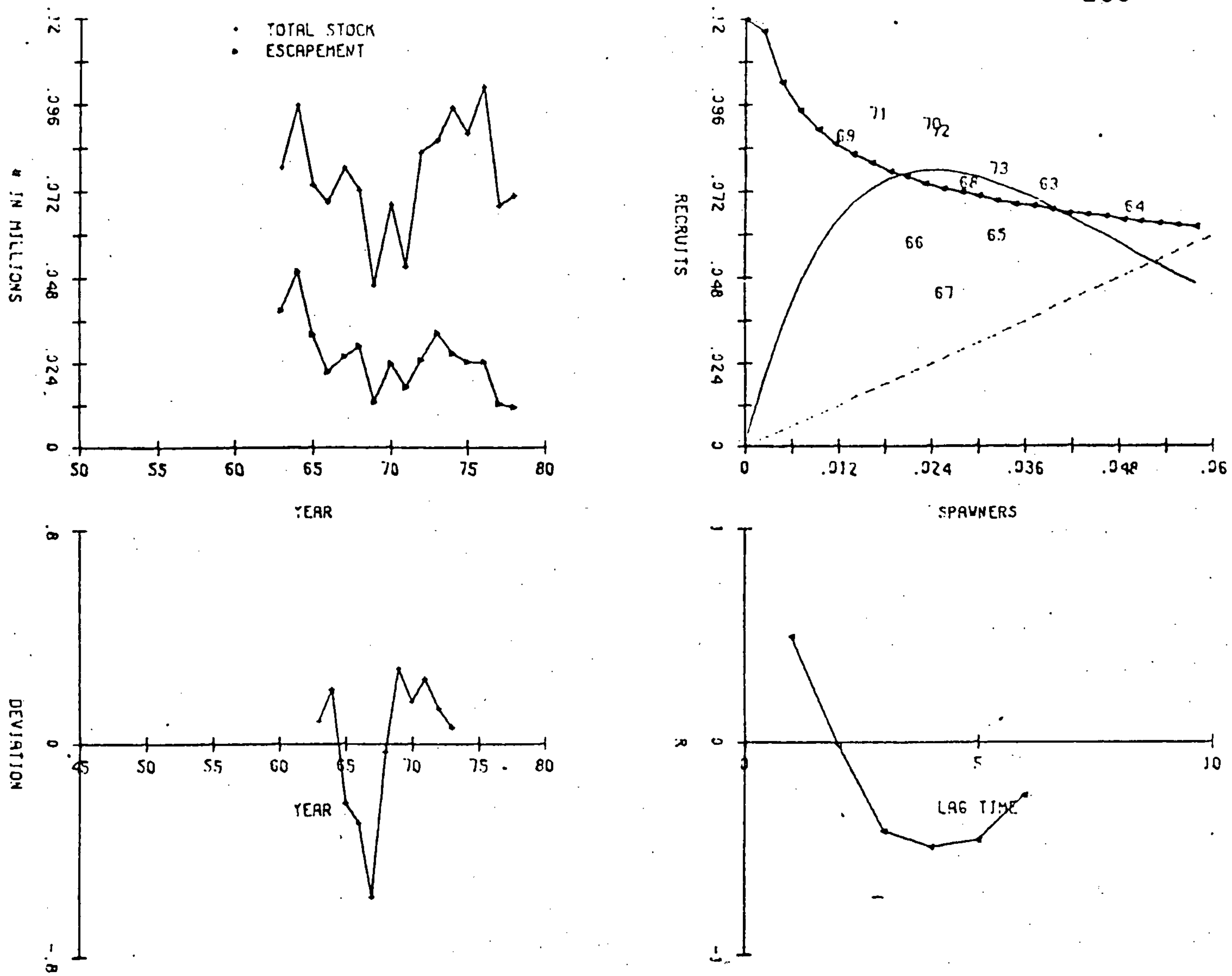


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	3,000	4,000	3,000	8,000
CATCH	29,000	33,000	30,000	25,000
EXPLOITATION RATE	.91	.89	.91	.76

I. Major Uncertainties in Analysis
   1. fish intercepted by Alaska fishery not included
   2. time specific age structure not available
   3. large uncertainty in catch allocation

II. Impediments to Improved Management
   1. increasing sports fishing activities
   2. interception by Alaska troll

J.S. SPRING



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	17,000	18,000	10,000	30,000
CATCH	64,000	61,000	60,000	50,000
EXPLOITATION RATE	.79	.77	.86	.63

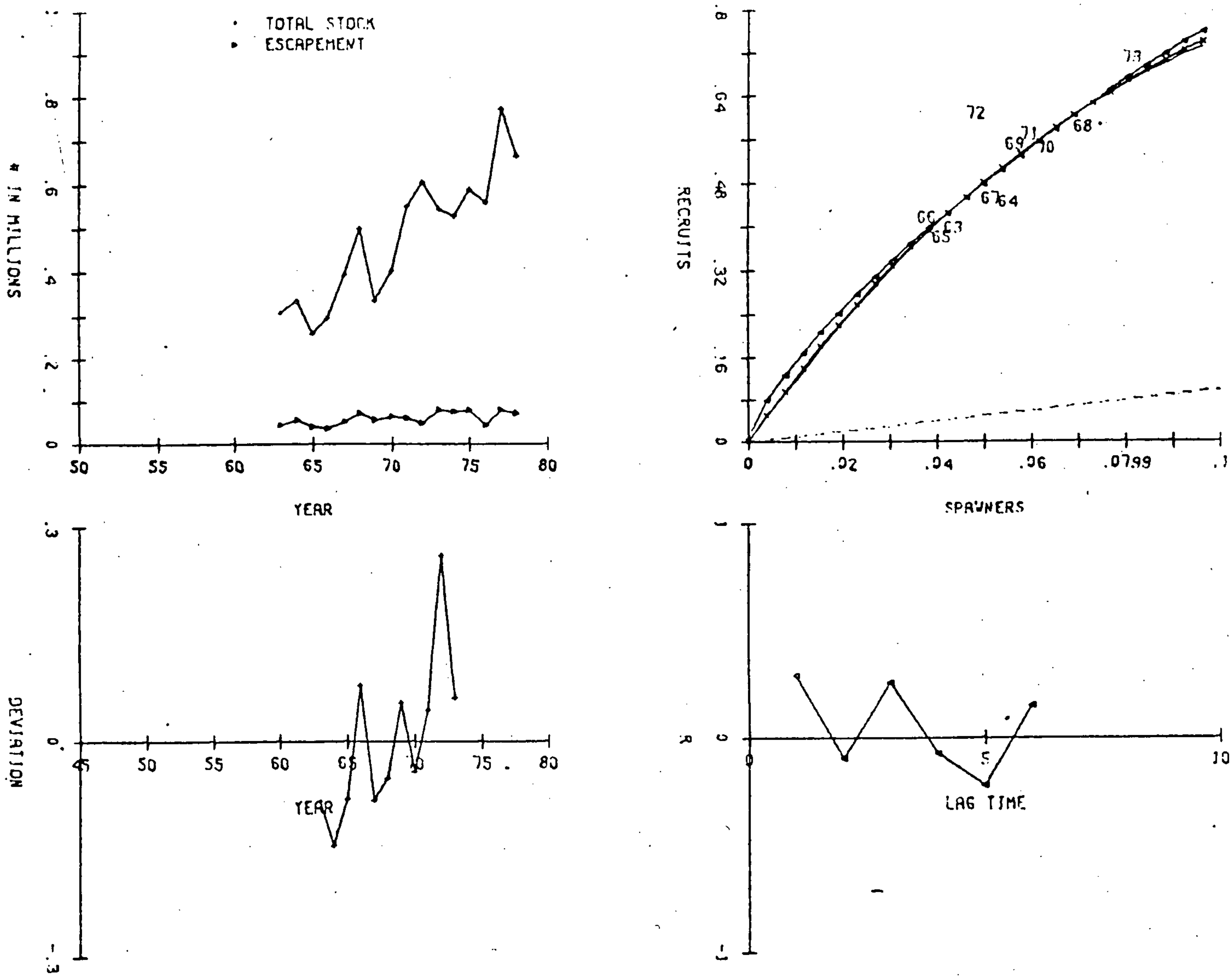
I. Major Uncertainties in Analysis

1. fish intercepted by Alaska fisheries not included
2. large uncertainty in catch allocation
3. time specific age structure not available
4. uncertainty in sports fishing estimates
5. uncertainty in the contribution of Washington produced fish

II. Impediments to Improved Management

1. incidental catch of juvenile fish
2. interception by Alaska troll

FRASER SPRING

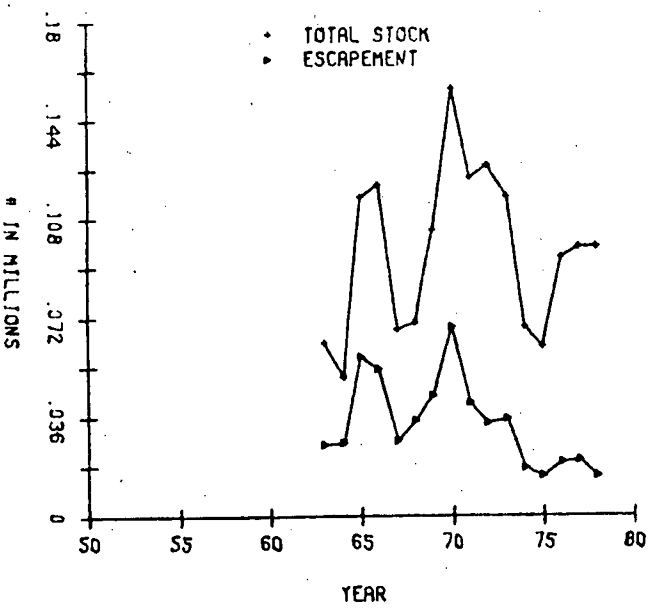


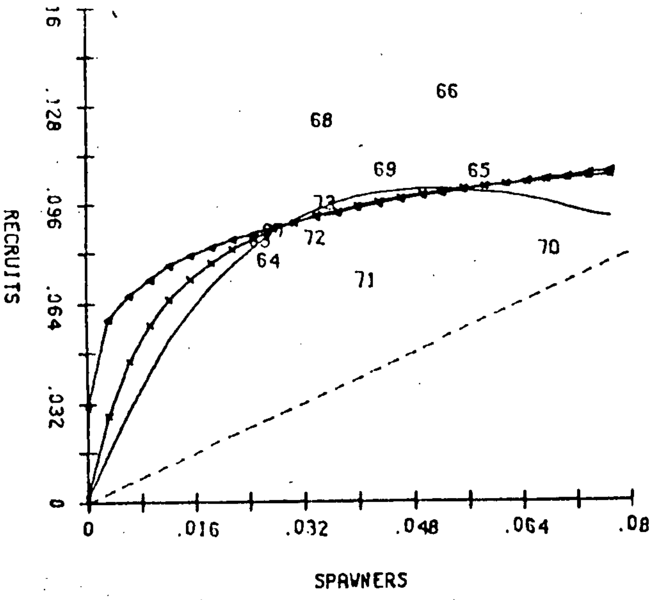
	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	68,000	200,000	100,000	400,000
CATCH	578,000	788,000	700,000	1,200,000
EXPLOITATION RATE	.89	.80	.88	.75

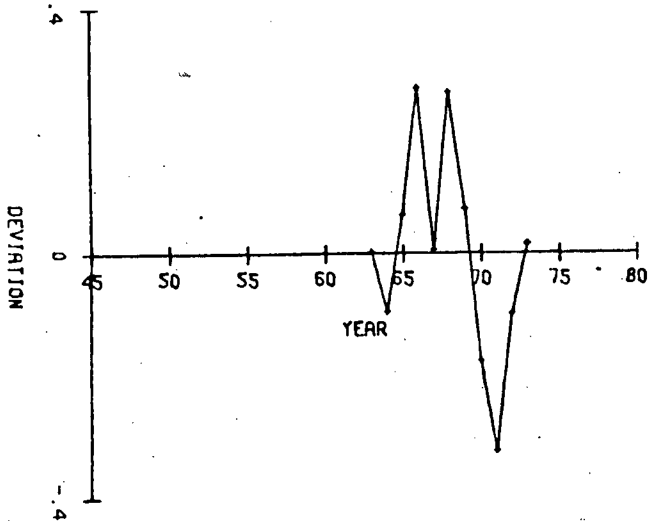
I. Major Uncertainties in Analysis
1. large uncertainty in catch allocation
2. fish intercepted by Alaska fisheries not included
3. time specific age structure not available
4. uncertainty in sports fishing estimates
5. uncertainty in the contribution of Washington produced fish

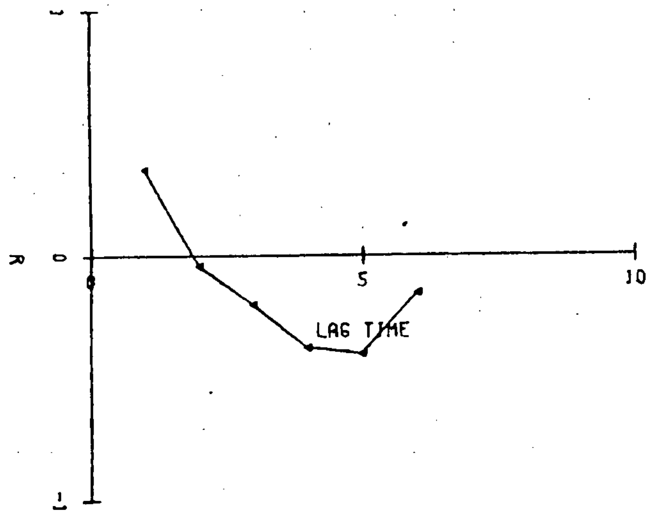
II. Impediments to Improved Management
1. mixed fishery problem with local sockeye, pink and chum fishery
2. uncertainty in the mechanisms and extent of "resident" verses "ocean" type behavior
3. interception by Alaska troll

G.S. SPRING







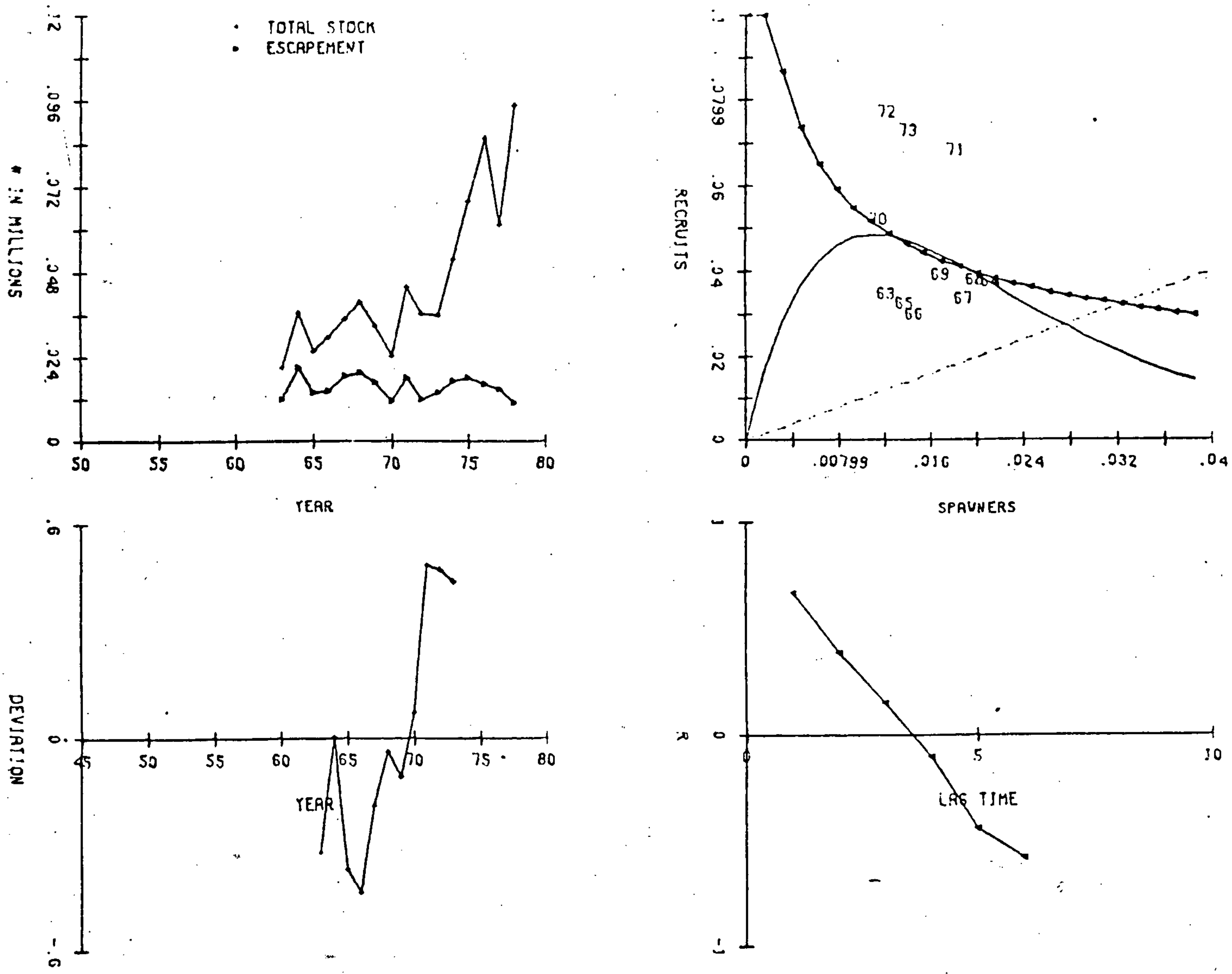


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	19,000	32,000	20,000	50,000
CATCH	70,000	62,000	40,000	50,000
EXPLOITATION RATE	.79	.66	.67	.50

I. Major Uncertainties in Analysis
1. fish intercepted by Alaska fisheries not included
2. uncertainty in the contribution of Washington produced fish
3. time specific age structure not available
4. uncertainty in sports fishing estimates
5. increasing output from local hatcheries
6. large uncertainty in catch allocation

II. Impediments to Improved Management
1. incidental catch of juvenile fish
2. uncertainty in the mechanisms and extent of "resident" verses "ocean" type behavior
3. interception by Alaska troll

S.W.V.I. SPRING

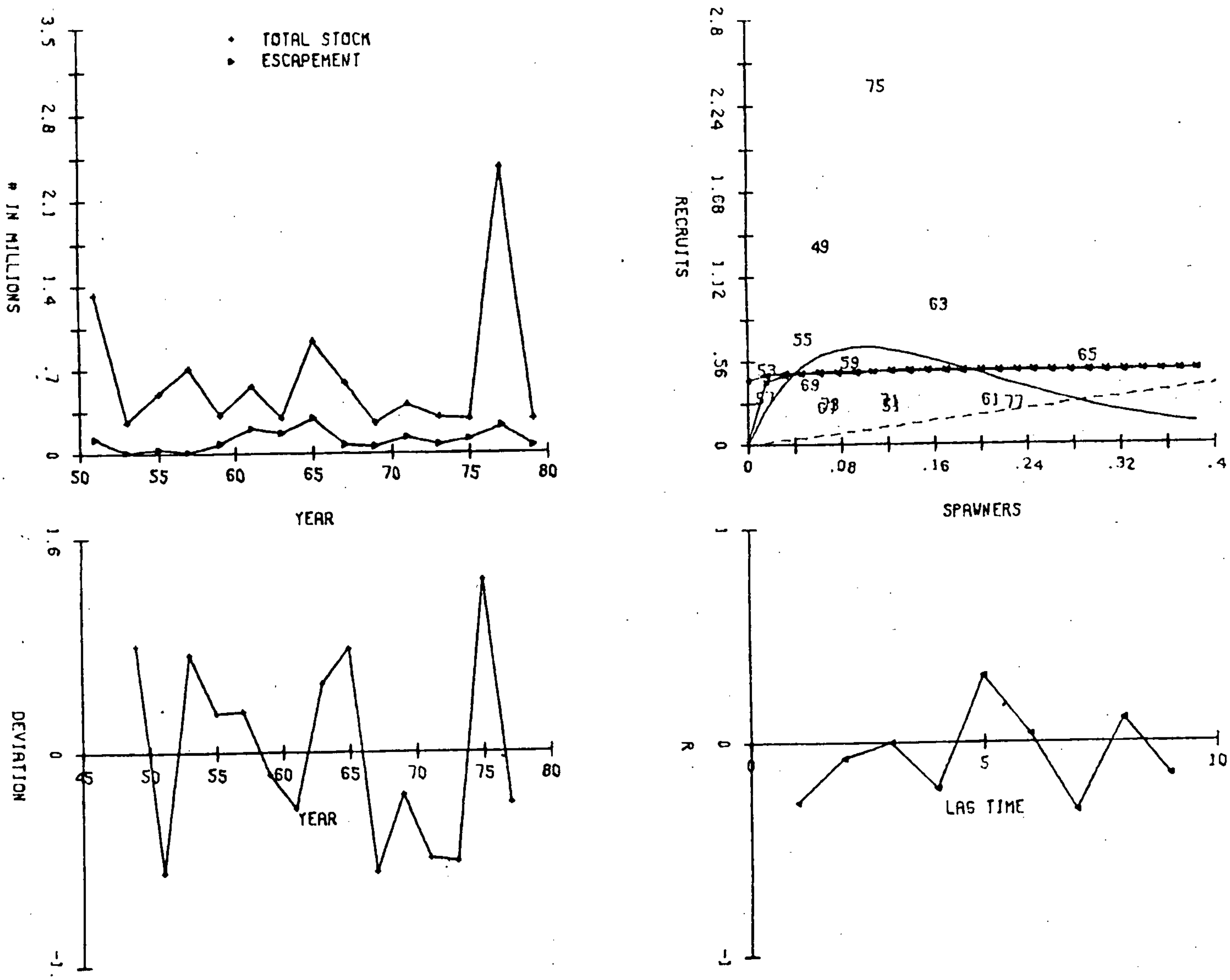


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	15,000	?	?	?
CATCH	62,000	?	?	?
EXPLOITATION RATE	.81	?	?	?

I. Major Uncertainties in Analysis
1. large uncertainty in catch allocation
2. fish intercepted by Alaska fisheries not included
3. uncertainty in the contribution of Washington and Columbia River produced fish
4. time specific age structure not available
5. extreme uncertainty in optimal escapement estimation
6. increasing output from local hatchery

II. Impediments to Improved Management
1. incidental catch of juvenile fish
2. interception by Alaska troll
3. West coast troll fishery

NASS ODD PINK



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	130,000	?	?	?
CATCH	844,000	?	?	?
EXPLOITATION RATE	.87	?	?	?

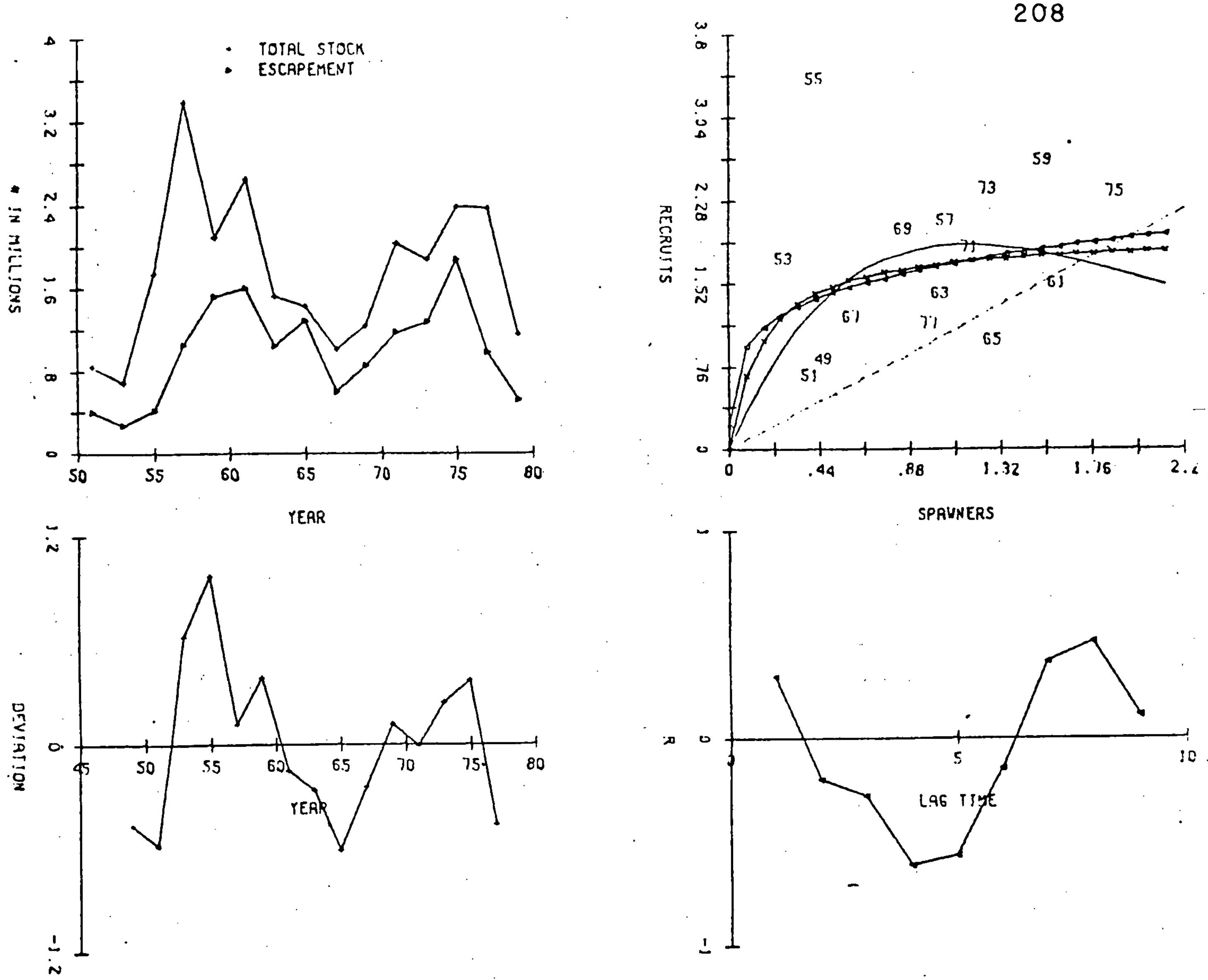
I. Major Uncertainties in Analysis

1. included substantial number of intercepted fish of unknown origin
2. escapement counts before 1963 are less reliable
3. extreme uncertainty in optimal escapement estimation

II. Impediments to Improved Management

1. lack of information on the origin of fish caught in this area

SKEENA ODD PINK

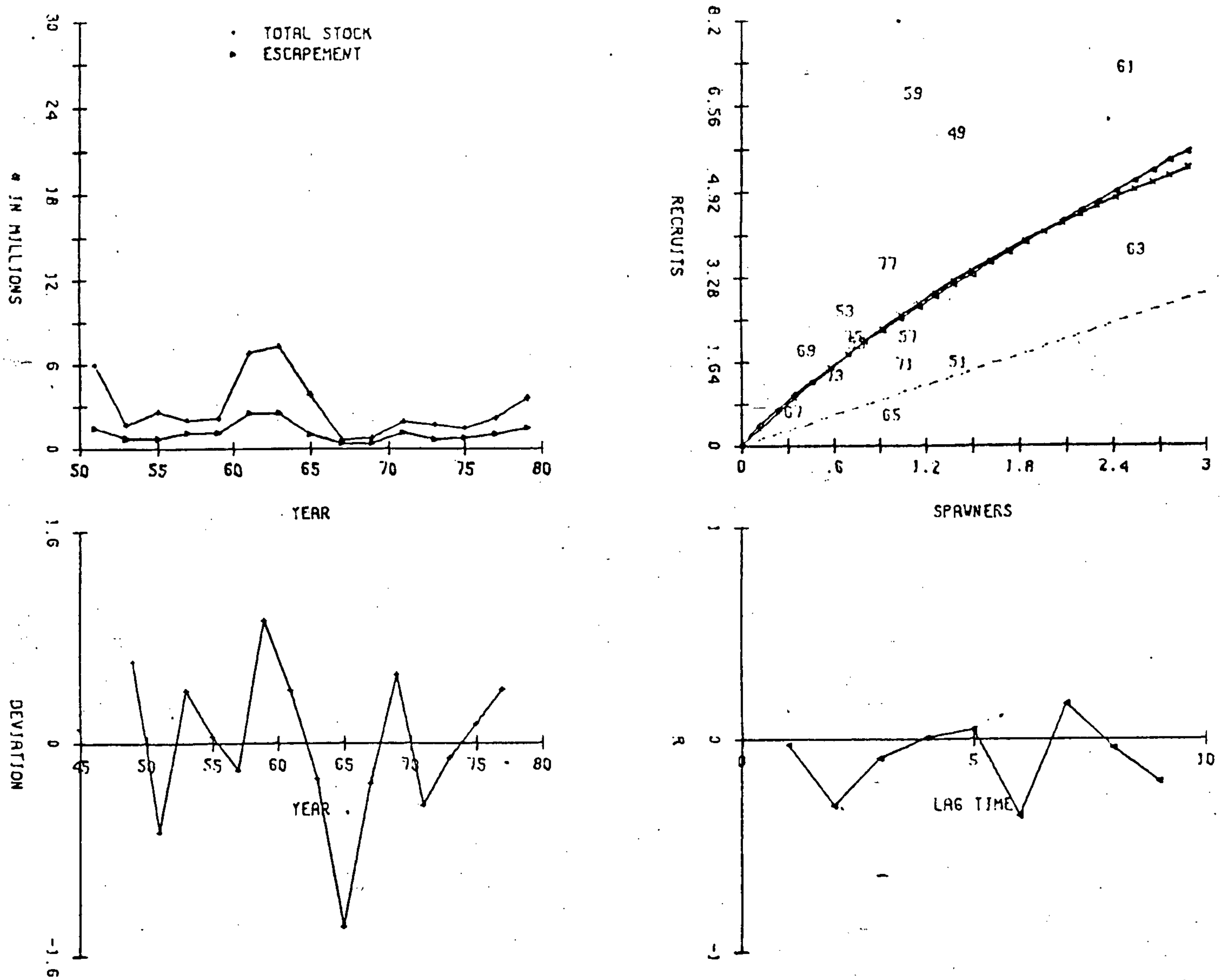


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	1,120,000	701,000	500,000	900,000
CATCH	854,000	1,220,000	1,000,000	1,000,000
EXPLOITATION RATE	.43	.64	.67	.53

I. Major Uncertainties in Analysis
   1. interception by Alaska fishery not known
   2. interception by Nass fishery not considered

II. Impediments to Improved Management
   1. mixed fishery problem with sockeye

C.C. ODD PINK

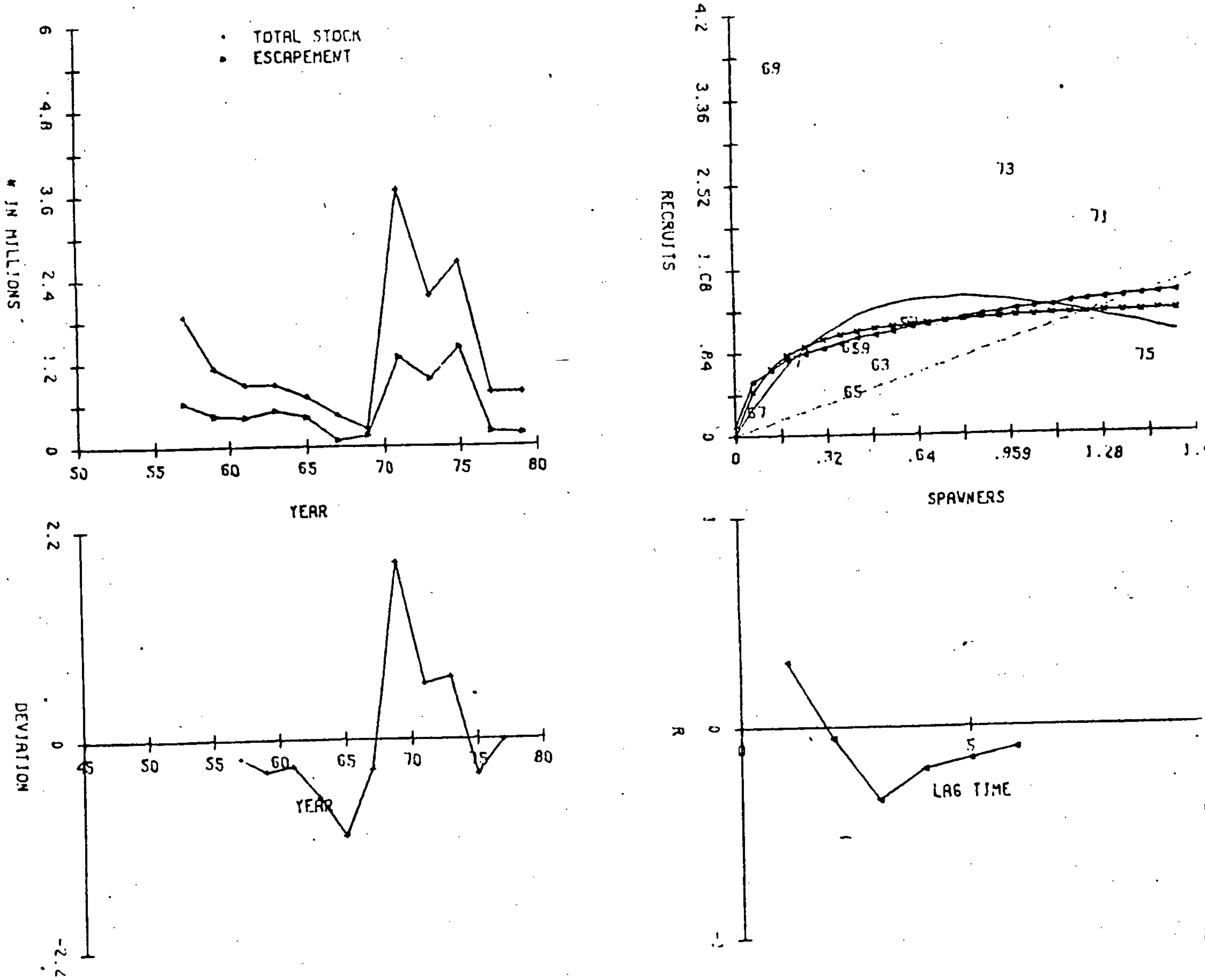


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	1,020,000	3,280,000	2,000,000	?
CATCH	1,340,000	3,650,000	2,500,000	?
EXPLOITATION RATE	.57	.53	.56	?

I. Major Uncertainties in Analysis
   1. did not account for substock effects
   2. may include some fish destined for Skeena
   3. extreme uncertainty in setting upper bound for optimal escapement

II. Impediments to Improved Management
   1. mixed fishery problem with local chums

J.S. ODD PINK



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	600,000	600,000	400,000	1,000,000
CATCH	790,000	800,000	1,000,000	1,000,000
EXPLOITATION RATE	.57	.72	.71	.5

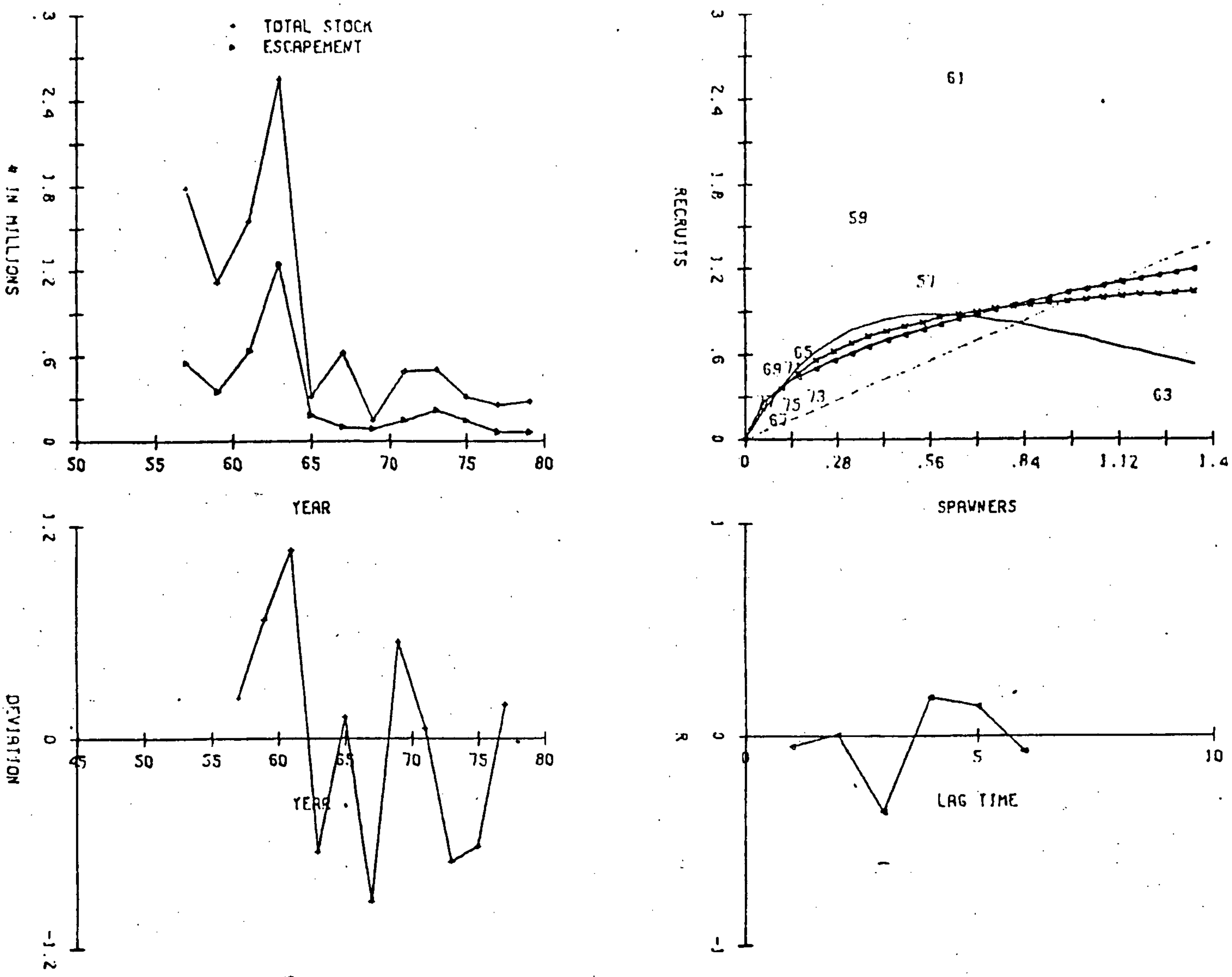
I. Major Uncertainties in Analysis

1. uncertainty in catch allocation

II. Impediments to Improved Management

1. mixed fishery problem with Georgia Strait and Fraser pinks, and Fraser sockeye

G.S. ODD PINK



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	86,000	362,000	250,000	2,000,000
CATCH	190,000	665,000	350,000	2,000,000
EXPLOITATION RATE	.69	.65	.58	.5

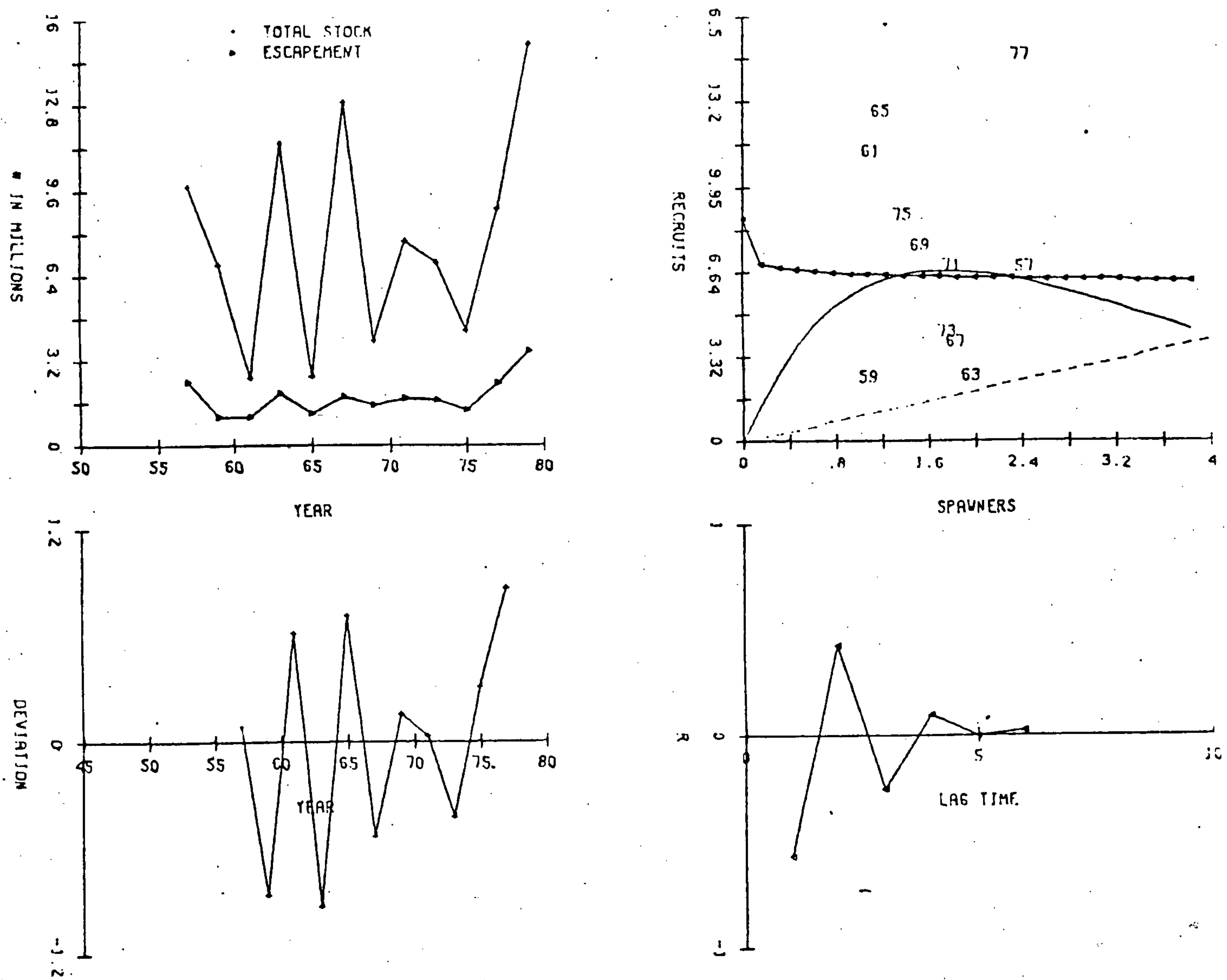
I. Major Uncertainties in Analysis

1. uncertainty in catch allocation

II. Impediments to Improved Management

1. mixed fishery problem with Fraser pink and sockeye

FRASER ODD PINK

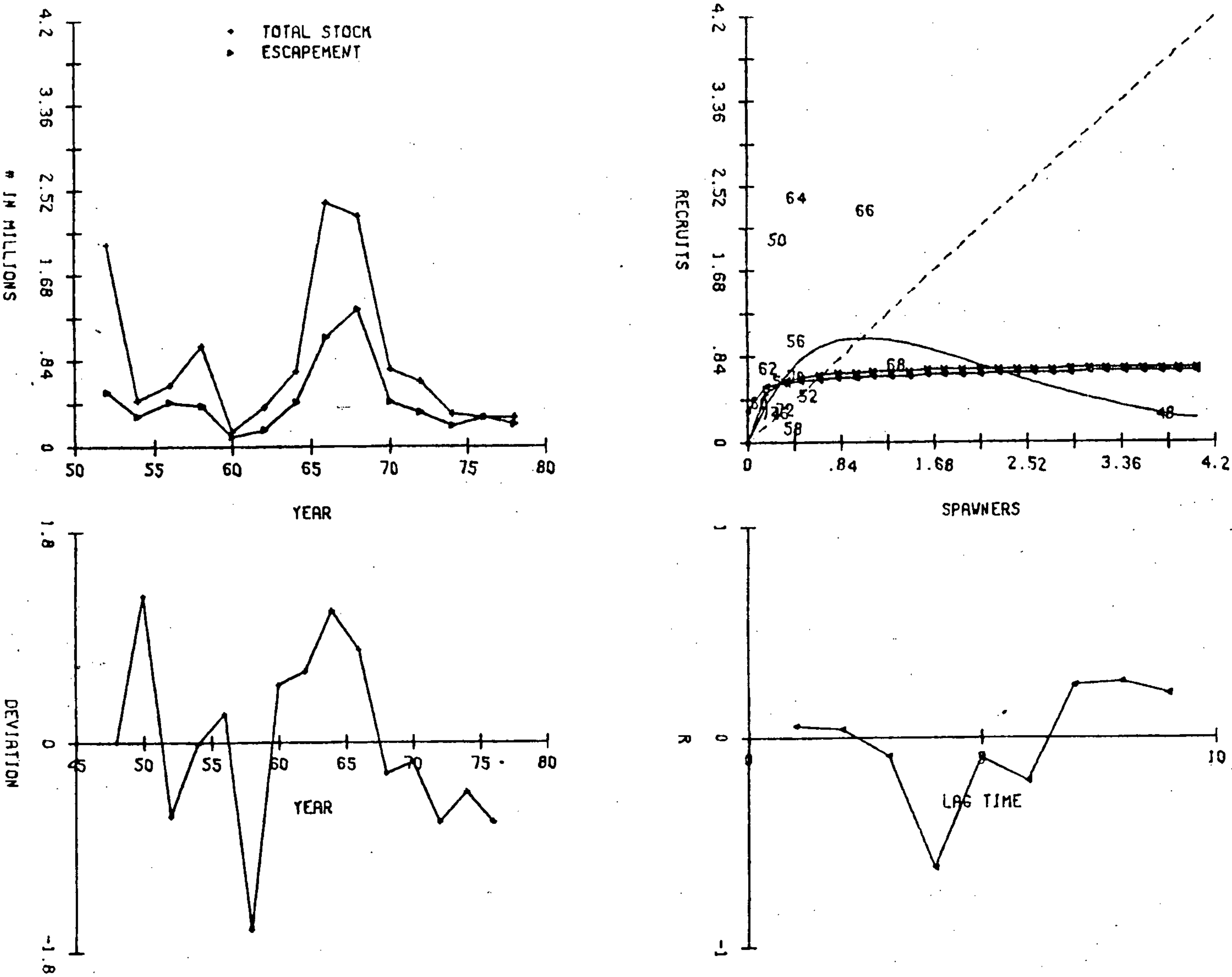


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	2,440,000	2,000,000	1,500,000	6,000,000
CATCH	7,000,000	4,000,000	3,500,000	8,000,000
EXPLOITATION RATE	.74	.67	.70	.57

I. Major Uncertainties in Analysis
   1. uncertainty in catch allocation
   2. difficulty in setting upper bound for optimal escapement

II. Impediments to Improved Management
   1. allocation of equal shares to U.S. and Canadian fishermen
   2. interception Johnstone Strait fishery
   3. mixed fishery problem with sockeye and chum

Q.C.1 EVEN PINK

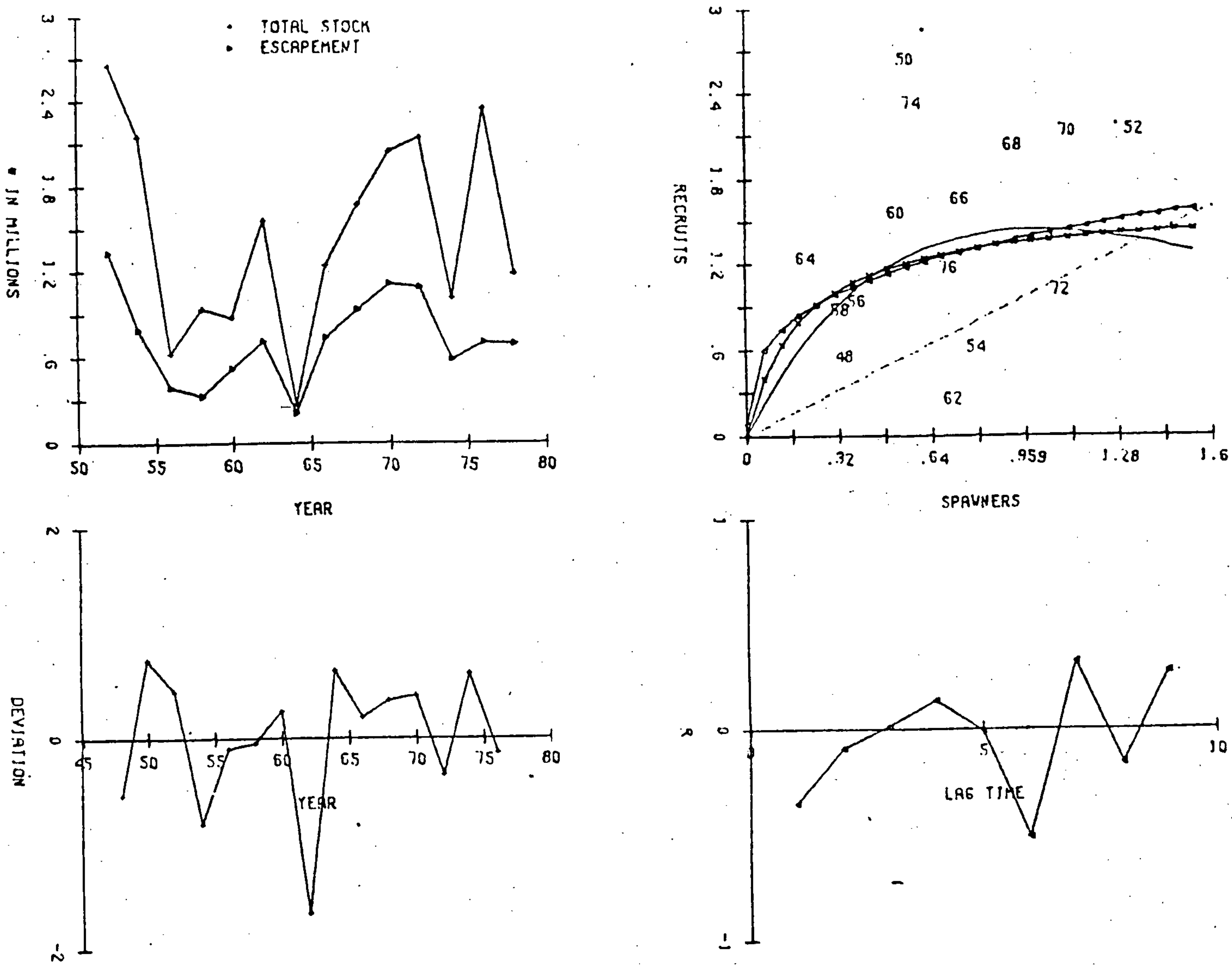


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	251,000	750,000	600,000	2,500,000
CATCH	41,000	1,000,000	900,000	2,000,000
EXPLOITATION RATE	.14	.57	.6	.44

I. <u>Major Uncertainties in Analysis</u>
   1. may include fish distined for Skeena

II. <u>Impediments to Improved Management</u>
   1. difficulty in setting up terminal fishery

Q.C.2 EVEN PINK

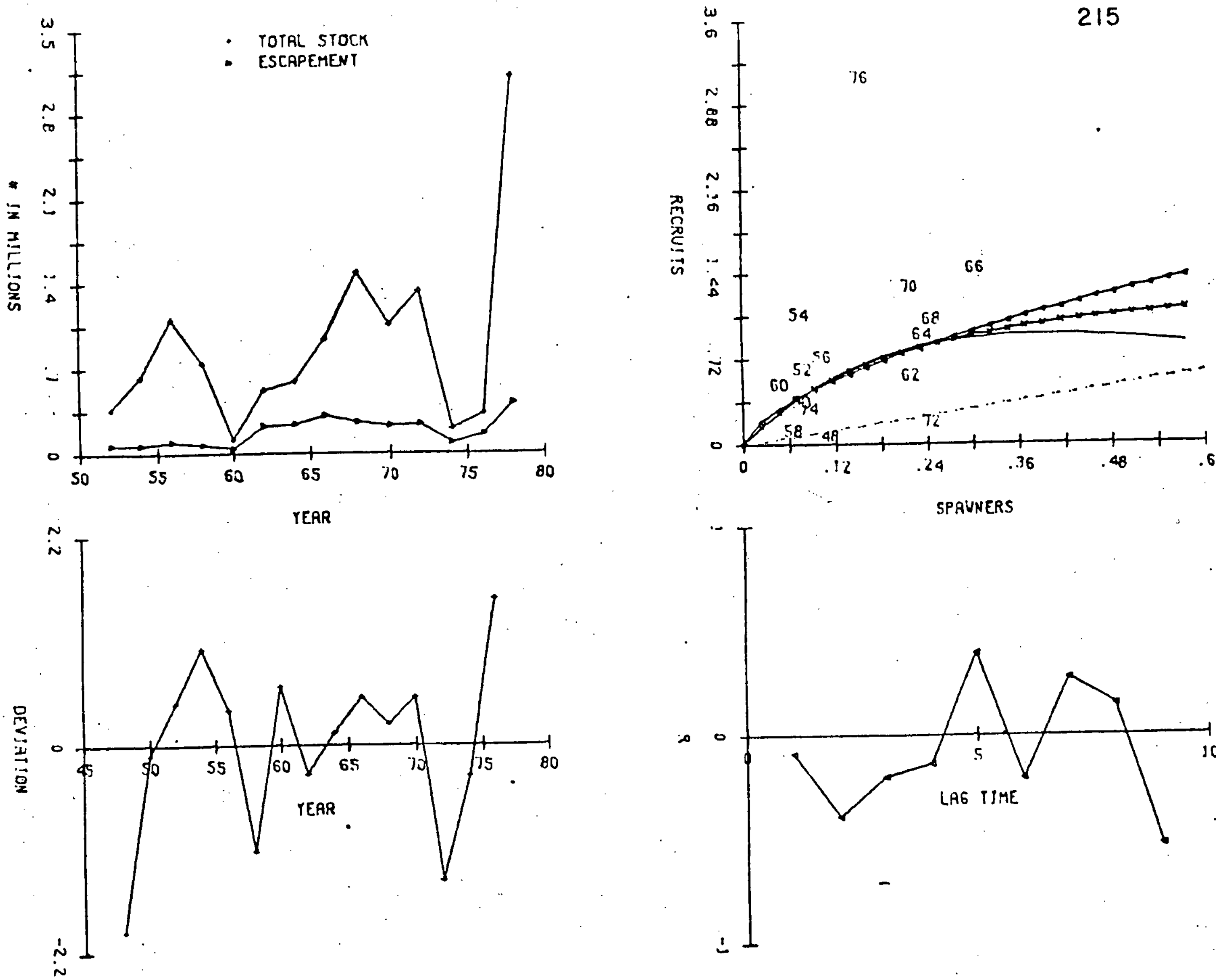


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	692,000	576,000	400,000	1,000,000
CATCH	1,065,000	1,020,000	500,000	1,100,000
EXPLOITATION RATE	.61	.64	.56	.52

I. Major Uncertainties in Analysis
1. may include fish destined for other areas

II. Impediments to Improved Management
1. difficulty in setting up terminal fishery

NASS EVEN PINK



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	278,000	?	200,000	?
CATCH	1,440,000	?	600,000	?
EXPLOITATION RATE	.84	?	.75	?

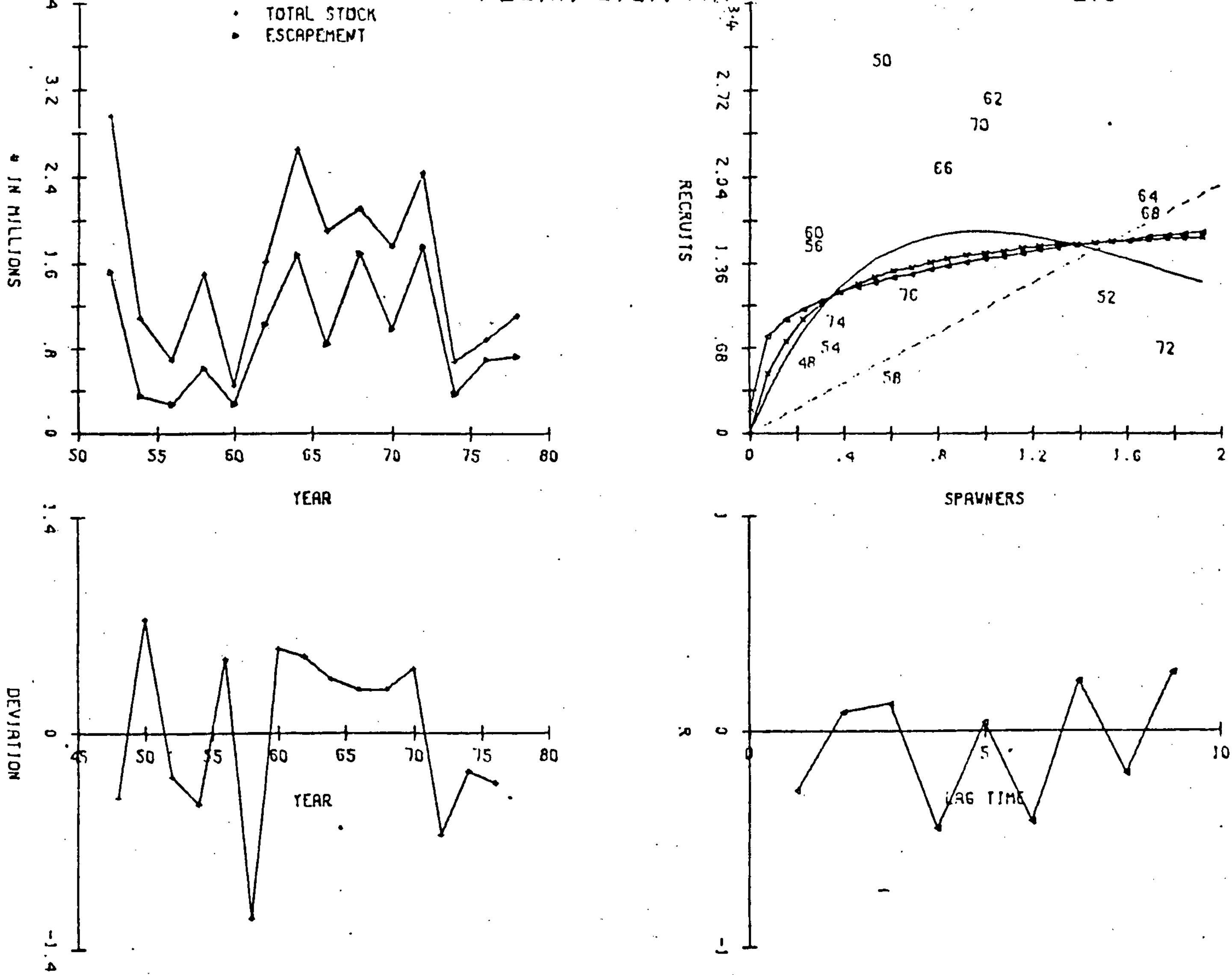
I. Major Uncertainties in Analysis

1. included substantial number of intercepted fish of unknown origin
2. escapement counts before 1964 are less reliable
3. extreme uncertainty in optimal escapement estimation

II. Impediments to Improved Management

1. lack of knowledge on the origin of fish caught in this area

SKEENA EVEN PINK

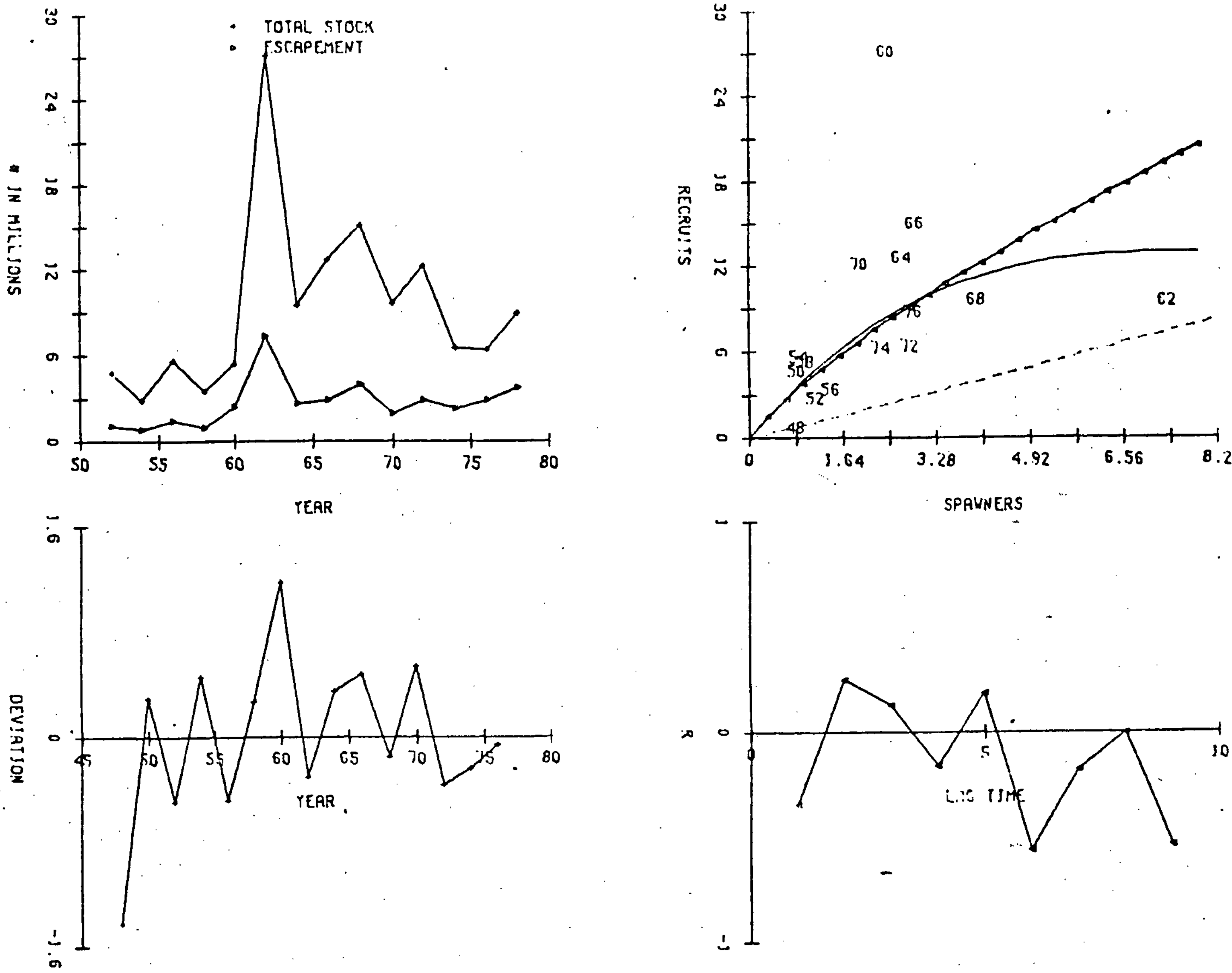


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	700,000	600,000	500,000	1,000,000
CATCH	294,000	1,140,000	1,000,000	1,000,000
EXPLOITATION RATE	.30	.66	.67	.5

I. Major Uncertainties in Analysis
   1. interception by Alaska fishery not known
   2. interception by Nass fishery not considered

II. Impediments to Improved Management
   1. mixed fishery problem with sockeye

C.C. EVEN PINK

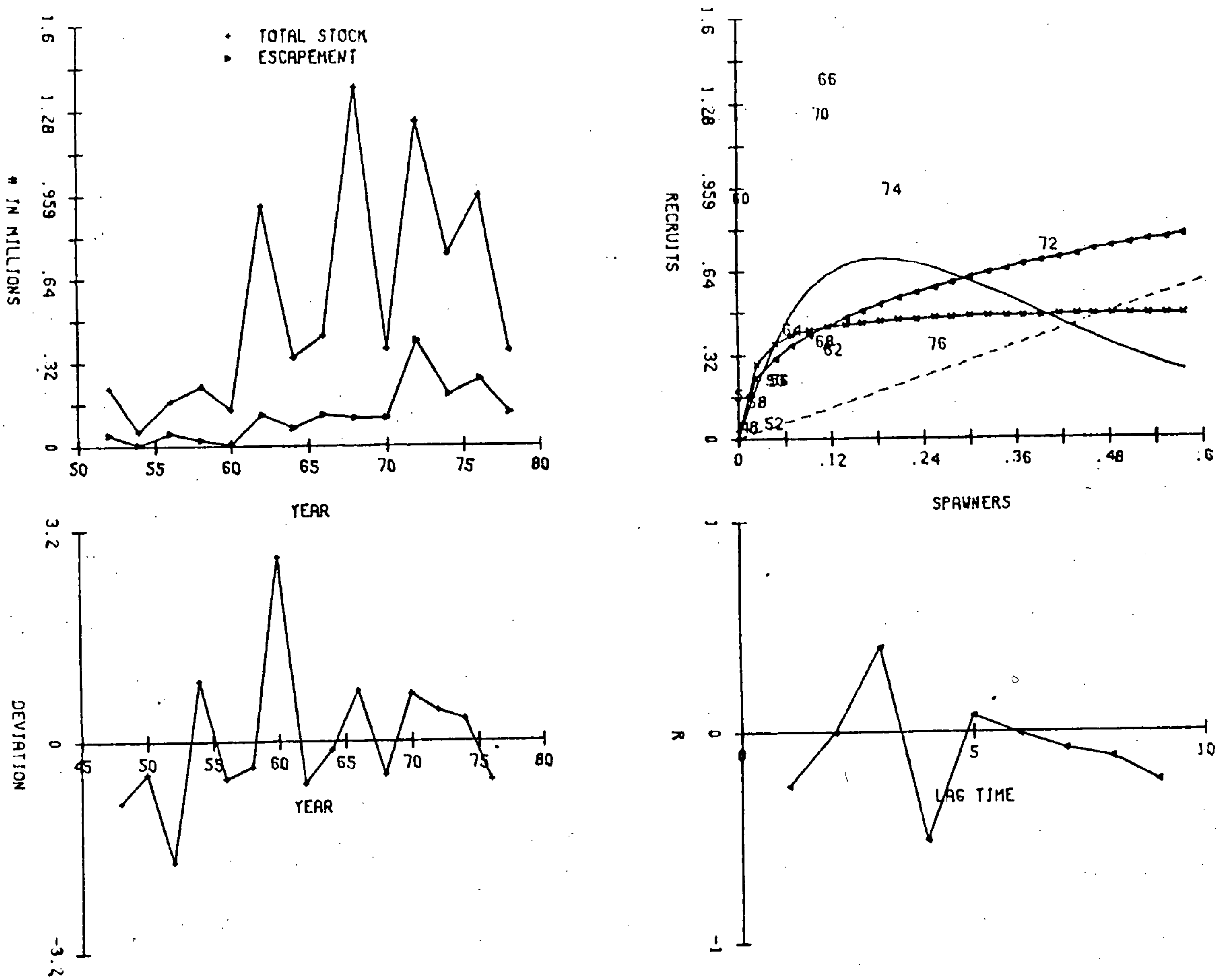


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	3,300,000	5,160,000	3,000,000	?
CATCH	4,310,000	10,100,000	8,000,000	?
EXPLOITATION RATE	.57	.66	.73	?

I. Major Uncertainties in Analysis
   1. did not account for substock effects
   2. may include some fish destined for Skeena
   3. extreme uncertainty in setting upper bound for optimal escapement

II. Impediments to Improved Management
   1. mixed fishery problem with local chums

R-S EVEN PINK

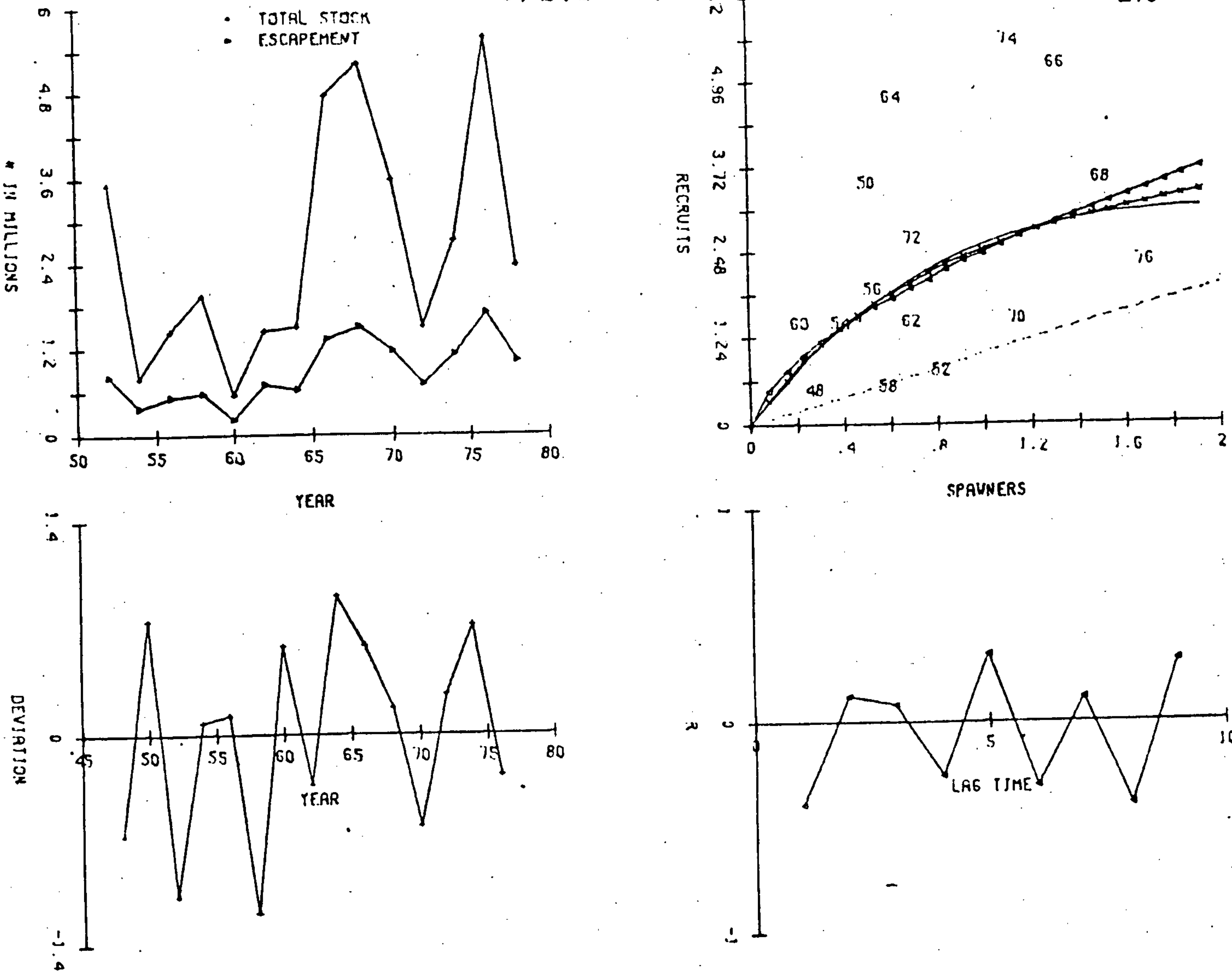


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	193,000	155,000	100,000	?
CATCH	468,000	1,120,000	600,000	?
EXPLOITATION RATE	.71	.88	.86	?

I. <u>Major Uncertainties in Analysis</u>
   1. extreme uncertainty in setting upper bound for optimal escapement

II. <u>Impediments to Improved Management</u>
   1. mixed fishery problem with local chums

J.S. EVEN PINK

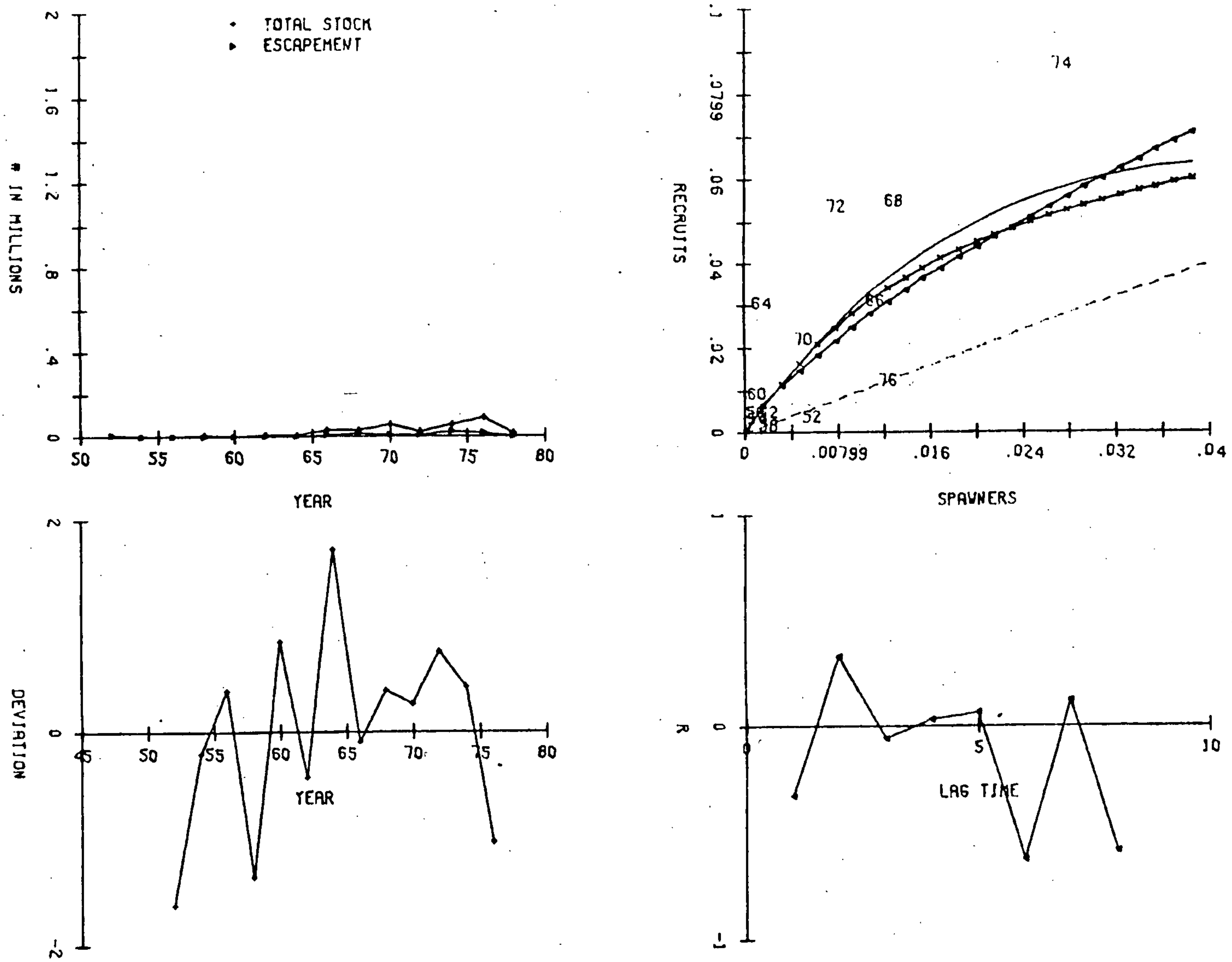


	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	1,350,000	?	1,000,000	?
CATCH	2,620,000	?	1,000,000	?
EXPLOITATION RATE	.66	?	.50	?

I. Major Uncertainties in Analysis
   1. extreme uncertainty in optimal escapement estimates

II. Impediments to Improved Management
   1. mixed fishery problem with Fraser sockeye

S.W.V.I. EVEN PINK



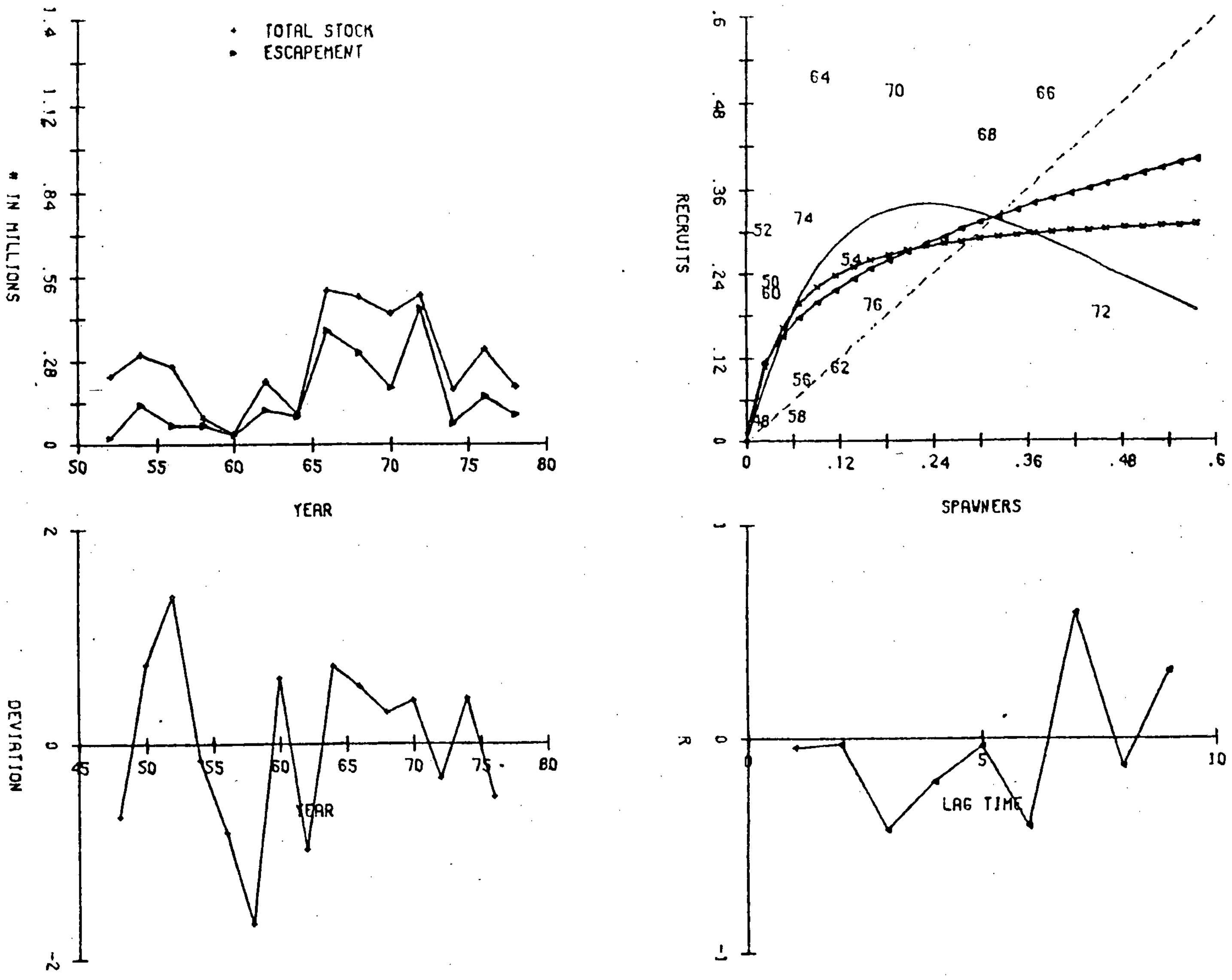
	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	7,000	?	25,000	?
CATCH	43,000	?	35,000	?
EXPLOITATION RATE	.86	?	.58	?

I. Major Uncertainties in Analysis

1. extreme uncertainty in optimal escapement estimation

II. Impediments to Improved Management

N.W.V.I. EVEN PINK



	CURRENT	OPTIMUM	PROBABLE LIMITS ON OPTIMUM	
			LOWER	UPPER
ESCAPEMENT	131,000	?	150,000	?
CATCH	128,000	?	200,000	?
EXPLOITATION RATE	.49	?	.57	?

I. <u>Major Uncertainties in Analysis</u>

1. extreme uncertainty in optimal escapement estimation

II. <u>Impediments to Improved Management</u>