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CHANGES IN S.E. ALASKA PINK SALMON (*Oncorhynchus gorbuscha*) POPULATIONS, 1914-1960

by

Marianna Alexandersdottir and O. A. Mathisen

This work was sponsored by
Salmon Processors in S.E. Alaska

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Approved

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Director

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ABSTRACT

During the period April 1, 1981 - March 31, 1982, trap catch records from six entry areas of S.E. Alaska were used to develop catch distributions for the pink salmon fishery. The daily catches were taken to represent relative daily abundance in these areas prior to removals by the fisheries in the straits and channels of S.E. Alaska. The assumption is that the catch distribution gives an estimate of the migratory time density of the runs passing through the entry areas. Some problems arose in the construction of these curves from the truncation of the data due to the opening or closing of the fisheries during the progress of the runs.

The pink salmon populations can be classified into "stocks" depending on their geographical location, spawning time, and migration route. All stocks entering S.E. Alaska through the same entry areas (e.g. Icy Strait) are classified as a run. The differences between the runs of six different entry areas of S.E. Alaska are determined by the character of the component stocks. It follows that use of migratory time densities as an in-season management tool in S.E. Alaska depends on the closeness of these assumptions to the real situation.

In the 1950's, there was a decline in the fisheries in S.E. Alaska. Overexploitation of poor year classes has been suggested as one cause (Fredin et al. 1968). A second impact discussed more fully in this report is the rigid regulatory system employed for 20 years, 1924-1944, and its effect on migratory timing and progeny survival, in addition to the removals by the fishery.

ACKNOWLEDGMENTS

This study was supported by funds provided by salmon processors in S.E. Alaska for the period April 1, 1981 to March 31, 1982.

The data base consisted largely of trap catch records microfilmed from company records in earlier years by the Fisheries Research Institute. Published and unpublished reports prepared by Federal and State agencies provided important data points; but, in addition, extremely valuable oral communications were received from some individuals, especially Dr. Elizabeth Vaughan Holmes, Mr. Vance Sutter, Whitney-Fidalgo Seafoods, Inc., Mr. Paul T. Macy, Dr. R. Van Cleve, and Dr. R. E. Nakatani, who freely shared their knowledge and experience of the early S.E. Alaska salmon fisheries and past research programs.

Dr. W. Hershberger reviewed those parts dealing with trunk selection and the genetic structure of the pink salmon stocks.

To all these individuals we extend our hearty thanks and appreciation.

INTRODUCTION

The S.E. Alaska pink salmon fishery dates back to 1878, when the first cannery was built in that region; but the fishery for pink salmon did not expand until the turn of the century. In the pre-World War II years, catches averaged about 30 million (Fig. 1). Peak catches occurred in the late 1930's and early 1940's and subsequently declined during the following decade. This occurred concurrently with an increase in fishing effort (Fig. 2). Traps, which dominated the fishery and accounted for 50-75 percent of the catch, remained at a steady level of about 260, while seine boats increased to about 500 units.

Several factors need to be considered in a discussion of possible causes for the observed decline of these populations. Natural causes include, for instance, climatic conditions in the freshwater and ocean environments. Harsh winters or severe floods can cause failure of an incubating or emerging brood year; pink salmon spend a larger percentage of their lifespan at sea than most other salmon species, and oceanic conditions are also highly important in survival of a year class.

The impact of man and his activities must also be considered. Logging, an important industry in S.E. Alaska, can frequently cause degradation of the stream environment to the detriment of spawning salmon populations. Still, the pink salmon fishery has probably been the major factor in the decline of the S.E. Alaska pink salmon populations. The effect of the fishery cannot be measured just by the number of fish removed but the type of fish removed must also be assessed to evaluate the effect of "regulatory selectivity" of the fishery which consistently exposed the same section

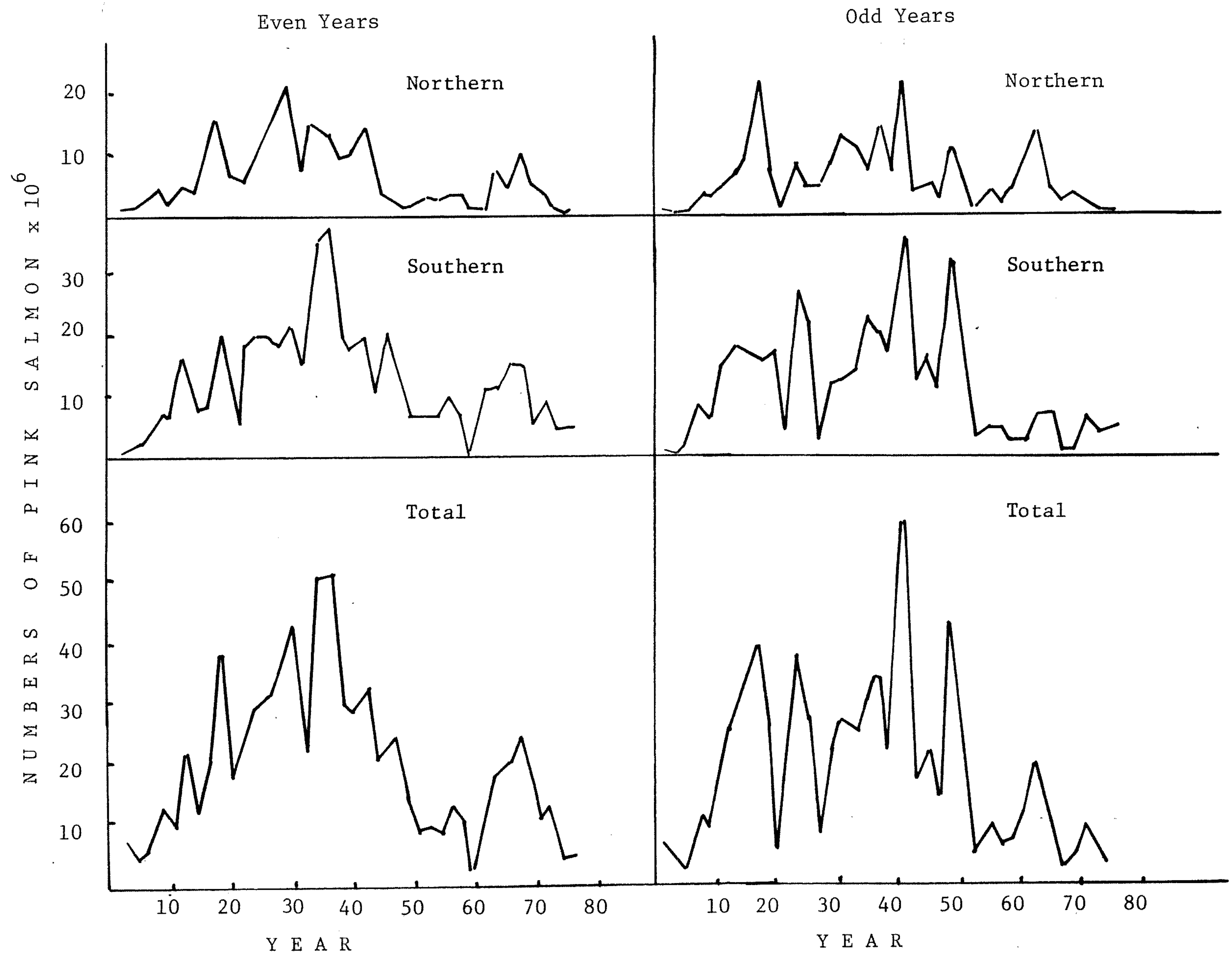

Figure 1. Catches of pink salmon in S.E. Alaska, 1900-1976 for northern and southern districts and total area, for even and odd lines separately (data from Thorsteinsson 1950 and I.N.P.F.C. Bull. No. 39, 1979).

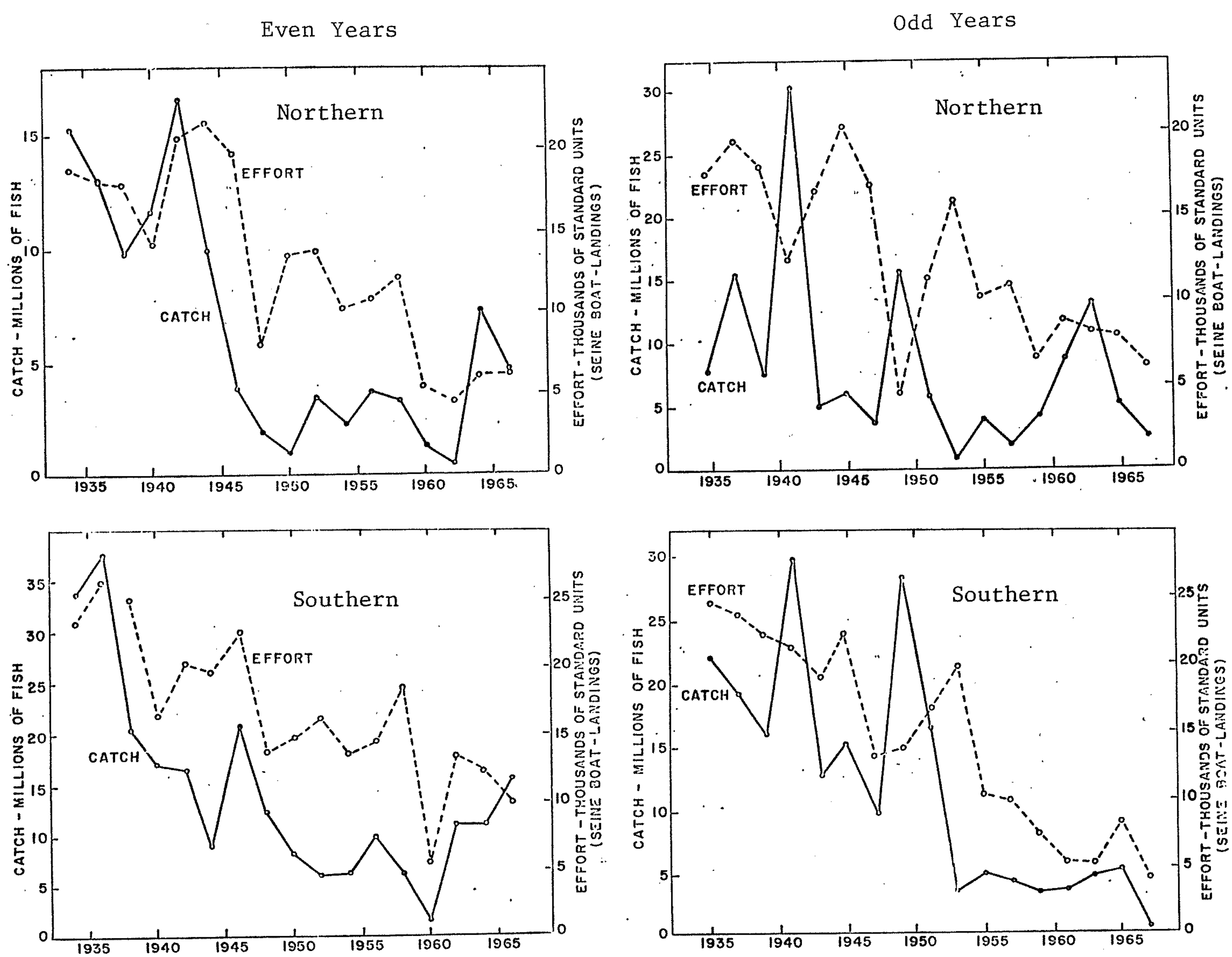

Figure 2. Pink salmon catch and effort for northern and southern districts, S.E. Alaska, odd and even lines, and seine-boat effort.

of the pink salmon runs to exploitation and perhaps an excessive one.

Catch and effort data were analyzed, and, in particular, trap catch records were used, as these reflect both abundance and timing of the pink salmon passing each trap location. The results of this analysis showed that the early runs had been consistently and intensively fished from 1926 to 1944 and were systematically depleted, as evidenced by later and later appearance of the run. Subsequently, during the period 1945-1953, the seasons were set later (Table 1), and with an increasing number of purse seines and intense effort, middle and late runs also deteriorated, leading to the drastic depression of the pink salmon populations in S.E. Alaska in the 1960's.

Life History

Pink salmon have a life history uniquely different from that of the other salmonid species. They spawn and die in their second year of life, so two lines, odd and even, exist which rarely interbreed. Altukhov and Salmenkova (1981) found sufficient genetic differences between these two lines to imply isolation between them. Pink salmon are also considered to have less-developed homing (Aspinwall 1974) than other salmon species, and Altukhov and Salmenkova (1981) found less interpopulation heterogeneity in pink salmon than in chum or sockeye. Straying may be an important component in the demographic strategy of the pink salmon. The species inhabits a variety of stream types with harsh environments and, in the case of a failure of a year-class due to environmental factors (e.g. low winter temperatures or excessive flooding), it lacks the buffer of a multi-age population structure. Recolonization by strays from adjacent

Table 1. Fishing seasons in Southeast Alaska, 1924-1953 (from Thorsteinsson 1950).

Year	Icy and Upper Chatham Open	Icy and Upper Chatham Close	Lower Chatham Open	Lower Chatham Close	Frederick Sound Stephens Passage Open	Frederick Sound Stephens Passage Close	Stikine Open	Stikine Close	Sumner Open	Sumner Close	Clarence Open	Clarence Close	Southern Open	Southern Close	South Prince of Wales Open	South Prince of Wales Close
1924		8/11		8/11		8/20				8/25		8/20		8/20		8/25
1925		8/06		8/11		8/11				8/22		8/18		8/18		8/22
1926		8/06		8/11		8/18				8/22		8/18		8/18		8/22
1927		8/06		8/11		8/13				8/18		8/13		8/13		8/18
1928	6/15	8/06	6/15	8/06	6/20	8/18			7/15	8/27	6/25	8/22	6/25	8/18	7/15	8/22
1929	6/15	8/03	6/15	8/10	6/25	8/14	6/30	9/30	7/10	8/20	7/05	8/20	7/05	8/16	7/10	8/24
1930	6/15	8/03	6/15	8/10	6/25	8/14	6/30	9/30	7/10	8/20	7/05	8/20	7/05	8/16	7/10	8/24
1931	6/15	8/03	6/15	8/10	6/25	8/14	6/25	9/23	7/10	8/20	7/05	8/20	7/05	8/16	7/10	8/28
1932	6/15	8/03	7/05	8/17	6/25	8/17	6/26	9/23	7/15	8/26	7/15	8/26	7/05	8/19	7/15	8/30
1933	6/15	8/10	7/05	8/22	6/25	8/23	6/26	9/23	7/15	8/29	7/15	8/29	7/05	8/22	7/15	9/02
1934	6/20	8/03	7/05	8/18	6/25	8/16	6/26	9/23	7/10	8/22	7/10	8/28	7/05	8/18	7/15	8/27
1935	6/20	8/03	7/05	8/18	6/25	8/18	6/26	9/23	7/10	8/22	7/10	8/28	7/05	8/18	7/15	8/27
1936	6/20	8/04	7/05	8/19	6/25	8/18	6/26	9/23	7/10	8/22	7/10	8/28	7/05	8/18	7/15	8/29
1937	6/20	8/04	7/05	8/18	6/25	8/18	6/26	9/23	7/10	8/22	7/10	8/27	7/05	8/18	7/15	8/29
1938	6/20	8/04	7/05	8/20	6/25	8/20	6/26	9/23	7/10	8/22	7/10	8/31	7/05	8/20	7/15	9/02
1939	6/20	8/04	7/05	8/18	7/05	8/18	6/26	9/23	7/10	8/22	7/20	8/27	7/15	8/16	7/25	8/29
1940	6/20	8/05	7/05	8/18	7/05	8/19	6/23	9/23	7/10	8/23	7/25	8/29	7/15	8/19	7/25	8/29
1941	6/20	8/04	7/05	8/20	7/05	8/20	6/23	9/23	7/10	8/22	7/25	8/27	7/15	8/16	7/25	9/01
1942	6/20	8/04	7/05	8/21	7/05	8/22	6/23	9/23	7/10	8/22	7/20	8/29	7/15	8/20	7/15	9/02
1943	6/20	8/04	7/05	8/23	7/05	8/20	6/23	9/23	7/10	8/22	7/20	9/01	7/15	8/18	7/20	8/31
1944	6/20	8/04	7/05	8/23	7/05	8/18	6/28	9/23	7/10	8/22	7/20	8/30	7/15	8/18	7/25	9/01
1945	6/25	8/05	7/05	8/21	7/05	8/23	6/25	9/15	7/10	8/23	7/20	8/29	7/15	8/18	7/25	8/31
1946	7/01	9/07	7/15	9/07	7/15	9/11	6/25	9/20	7/10	9/07	7/20	8/31	7/15	9/11	7/25	9/14
1947	7/14	8/16	7/28	9/06	7/28	9/06	6/25	9/20	8/11	9/06	8/04	9/06	7/28	9/03	8/18	9/06
1948	8/09	9/03	8/09	9/03	8/09	9/03	6/25	9/20	8/09	9/03	8/09	9/07	8/09	9/03	8/09	9/07
1949	8/15	9/03	8/15	9/03	8/09	9/03	6/25	9/20	8/09	9/08	8/15	9/03	8/15	9/03	8/15	9/03
1950	6/25	9/03	8/15	9/03	8/15	9/09	5/01	9/20	8/15	9/03	8/15	9/03	8/15	9/03	8/15	9/03
1951	6/25	9/01	8/01	9/01	8/01	9/01	5/01	9/20	8/01	9/01	8/15	9/01	8/03	9/01	8/06	9/01
1952	6/18	8/30	7/24	8/30	7/28	8/30	5/01	9/20	7/24	8/30	8/04	8/30	8/01	8/30	8/04	8/30
1953	6/24	8/22	6/24	8/22	6/24	8/29	5/04	9/30	7/20	8/29	8/05	9/02	7/20	8/22	7/20	9/02

streams is probably important in the survival of the populations, with strays from closer streams of similar environmental type the most likely to be successful. Populations from adjacent streams may then act as buffers to each other and function as an extended population group.

This important point is generally overlooked in contemporary discussion of the effect of industrial development, these either being hydroelectric dam projects, exploitation of mineral deposits or logging of virgin forests. Impact statements fall short on two counts. By only considering the present production, the potential production is underestimated where the effect of excessive fishing or faulty regulations has been removed. Next, the species can only overcome population changes by the buffering actions of numerous producing sub-units. If any of these are removed or seriously impacted by any of the above-mentioned developments, there is a ripple effect in addition to the direct measurable loss to the total production of a single stream.

Altukhov (1981) discusses the importance of regulating fisheries on the basis of the population-genetic structure of the species. Altukhov and Salmenkova (1981) define two levels of population hierarchy:
1) population systems, collections of elementary populations which may be spatially isolated but are genetically stable. The stability depends on a balance between selection, random genetic drift, and gene migration;
2) elementary populations, which are traditionally considered the unit of any evolutionary process. They are often highly variable and less isolated than a population system. In a fishery management model, the population systems could be defined as "local stocks," where the component elementary populations contribute to the general gene pool. Definition of

these local stocks then becomes necessary for rational fishery management, which must also take note of the internal organization of the stock or population system and distribute fishing and management efforts evenly over all its components.

For the purpose of clarification in the following discussion certain definitions need to be made:

1. Population — spawning group, spawning together in a defined area, equivalent to the elementary population.
2. Stock — groups of populations occurring within defined geographical boundaries, equivalent to Altukhov's population system.
3. Run — collection of stocks migrating along a particular pathway en route to their spawning grounds.

For example, in Bristol Bay, the sockeye salmon run would be the total collection of sockeye salmon entering Bristol Bay; stocks are the different sub-groups of the run destined for separate river systems (e.g. Nushagak River); and populations are the separate groups spawning in particular tributaries or sections of the river. Equivalently, in S.E. Alaska, a run is a collection of stocks entering through the same entry portal and being exploited by the same fishery. There are several runs in S.E. Alaska, each of which is separated geographically along its migration route, at least until terminal areas are reached. For instance, runs entering through Icy Strait and Lower Chatham Strait both arrive in Frederick Sound. A stock is a group of populations destined for streams within a geographical area and having similar spawning times, and populations are the separate stream populations.

In S.E. Alaska the pink salmon populations separate in time and space. A natural geographic division occurs between the southern and northern areas as demonstrated by various tagging experiments (Rich and Suomela 1930, Verhoeven 1952). The pink salmon populations are also separated according to time of spawning. The usual classification divides the populations into three major groups: early (spawning before August 15), middle (spawning August 15 to September 15), and late (spawning after September 15). This range of spawning times results from the wide range of environments in which pink salmon spawn in S.E. Alaska. The spawning time is correlated with the temperature regime of the stream so that colder streams have earlier spawners (Sheridan 1962).

Streams located within a defined geographical area having similar climates also have populations with similar spawning times (Fig. 3). This leads to a natural division of S.E. Alaska into 16 stocks, based on place of entry and time of spawning (Table 2):

1. Thus all populations comprising a stock enter S.E. Alaska through the same entry portal, e.g., Icy Strait or Sumner Strait.
2. The same populations have spawning times falling within a specified range, i.e., early, middle, or late.

As the separate population components of these stocks all occur in streams located within a defined geographical area and have spawning times similar to each other, the suggestion is that they fulfill some of the characteristics of a genetically stable population system. Straying certainly occurs between such close populations, and the success of spawning of strays is likely, as they are adapted to similar environments and have similar spawning times. They are thus acting as buffers against wide

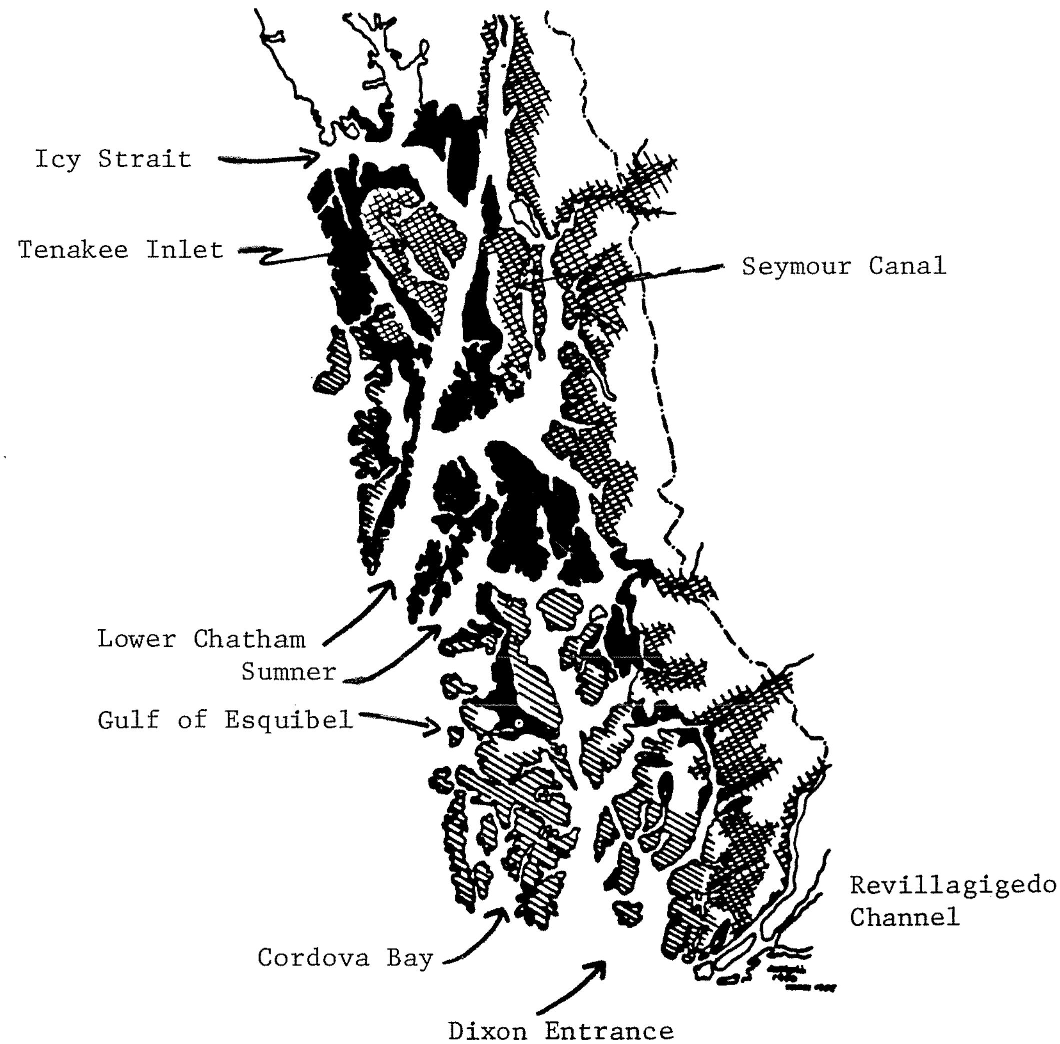

Figure 3. Spawning time of pink salmon stocks in S.E. Alaska. Entry points indicated by arrows.

Spawning times: Late(after Sept. 15)
Middle (Aug.15-Sept.15)
Early(Prior to Aug. 15)

Table 2. Runs and stock areas for pink salmon in S.E.Alaska.

Entry area	Spawning time	Unit No.	Unit location
Icy Strait	Early	1	Mainland from Taku south to Stikine and Seymour Canal
		2	Lynn Canal to Taku River
		3	Tenakee Inlet
	Middle	4	Chichigof and mainland coasts of Icy Strait
		5	West coast of Admiralty Island and east Baranof south to Frederick Sound
Lower Chatham Strait	Middle	6	South Baranof, Kinu Island and Kupreanof Island Coasts of Chatham Strait and Frederick Sound
Sumner Strait	Early	7	Ernest Sound
	Middle	8	Wrangell
		9	Kuiu and Kupreanof Islands
		10	Upper Clarence Strait
Dixon Entrance	Early	11	Upper Behm Canal Mainland
	Late	12	Revillagegido Channel and west Behm Canal
		13	East coast Prince of Wales
		14	Cordova Bay
Outer areas	Middle	15	Northern Prince of Wales
	Late	16	Central Prince of Wales

fluctuations in numerical abundance of a population system.

Treatment of these groups as stocks in a fishery assumes that the populations concerned have been affected similarly by the fisheries in the past, and all have the same vulnerability to fishing pressure during their migration. Thus the important components of the S.E. Alaska fisheries are

1. S.E. Alaska can be divided into districts, depending on the point of entry of the migrating stocks which the fisheries in the district exploit (Fig. 3). There are four main points of entry into S.E. Alaska: Icy Strait and Lower Chatham Strait in the northern section and Sumner Strait and Dixon Entrance in the southern section. In addition, there are stocks migrating to outer island and fisheries in outer areas, e.g., in Salisbury Sound.
2. Fisheries in these districts are exploiting more than one stock in general.
3. Probable entry into a particular fishery of a stock depends on
   a. time of spawning of the stock;
   b. distance to the spawning stream; and
   c. oceanic conditions, which affect the time of departure from feeding grounds and arrival at the entry portals.

The objective of this study was to develop a historical data base using trap catch records from entry areas into S.E. Alaska for the purpose of examining the migratory entry patterns of S.E. Alaska pink salmon runs as described by the catch distributions in the trap fisheries in the separate entry areas. In this report, changes over time within districts and in S.E. Alaska as a whole will be examined, and the implications of these changes with regards to the decline of the fishery in the 1950's are discussed.

METHODS AND MATERIALS

The first Director of the Fisheries Research Institute, Dr. W. F. Thompson, organized a microfilming of catch records from the major fishing companies in the 1950's. While similar records from Bristol Bay date back to the first years of fishing, those from S.E. Alaska are not as consistent due to changing ownership of the canneries and often loss of records by transfers. However, they offer a valuable source of daily trap catches for a period of almost 40 years and represent a historical data base which can be used for studying the pink salmon fishery and populations during those years. Nakatani et al. (1975) summarized some of these records from the years 1938-1945 from northern S.E. Alaska in their report on tagging experiments during those years. Two other publications were also of great use in the statistical reviews of the fishery in S.E. Alaska for the period 1900-1950, one by E. Vaughan of the U.S. Fish and Wildlife Service (1942) and a second by F. V. Thorsteinson of the Fisheries Research Institute (1950).

In this study, the catches of selected traps (Table 3) were analyzed under the assumption that

1. The daily catches of traps located in the outer areas of S.E. Alaska where the pink salmon first enter the fishery represent a relative measure of the daily entrance of new fish to the fishery.
2. Since other of the selected traps were placed along the major migration routes of pink salmon, the records of daily catches were representative of the passage of fish along these routes.

Table 3. Trap catches used in pink salmon analysis.

Area	Trap No.	Trap Names
1. Icy Strait I (1916-1950)	10	Three Hill Island
	20	North Island
	30	Inian Island
	50	Gull Cove
	60	Lesmurier
	80	Pt. Adolphus
	90	Eagle Point
2. Icy Strait II (1916-1950)	100	Pleasant Island No. 1
	110	Pleasant Island No. 2
	111	Porpoise Island
3. Chatham Straits (Frederick Sound) (1936-1950)	420	Pt. Brightman
	440	Deepwater No. 4
4. Sumner Straits (1936-1950)	701	Beauclere-Pt. Amelius
	702	Totem Bay trap
	703	Point Baker
	704	Pt. Colpoys
5. Prince of Wales Isl. Northern West Coast (1924-1947)	769	Tranquil Pt.
	772	Red Buoy
6. Prince of Wales Isl. Southern West Coast (1922-1947)	765	Pt. Webster
	766	Sukkwan Isl.
7. Revillagigedo Channel (1914-1948)	704	Slate Isl. No. 3
	751	Breakwater Nth.

Traps were also chosen if they provided a long time series in order to compare catch distributions from all regulatory periods. There were four of these regulatory periods. The first one up to 1925 covers the years prior to the White Act. The White Act established a 50 percent rule, which was to secure 50 percent escapement of a run regardless of time of appearance in the fishery. This rule was in effect during the second (1926-1940) and third (1941-1944) periods, and the prevailing management strategy was basically to allow harvest on what was considered the first 50 percent of the runs, and then to close the fishery. Thus during periods II and III, only the earlier part of the runs was exploited, while later arrivals were protected. The only difference between periods II and III lies in the weekend closures, which were 36 hours during period II but increased to 60 hours in 1941. Period IV, after 1945, saw the switching around of seasons which opened and closed later and were more variable than in the previous 20 years. The opening and closing dates of the seasons for 1924-1953 are listed in Table 1.

The cannery records present some problems in their use in migratory entry pattern analysis. The data record the number of fish brailed on a specific day. But, as all traps in a district were not necessarily brailed daily, an artificial difference between traps was introduced. In order to develop a daily catch distribution, the average daily catch per trap ($\overline{C}_i$) was calculated for each entry area and each year according to

$$C_i = \frac{\sum_{j=1}^{n} C_{ij}}{n}$$

where

i = day i

j = trap j

C_{ij} = catch on day i in trap j

n = number of traps

A daily catch proportion (P_{ik}) could then be estimated by

$$P_{ik} = \frac{C_i}{\sum_{i=1}^{d} C_i}$$

where

d = number of days in season k

k = year

The set of daily catch proportions through a season $\{P_{1k}, P_{2k}, \ldots, P_{dk}\}$ describes the catch distribution for that year's pink salmon run.

Average catch distributions for a run were calculated separately for odd and even years for each period when the number of years was more than 3 (Appendix 1). Average daily catch proportion $\overline{P}_i$ becomes

$$\overline{P}_i = \frac{\sum_{k=1}^{m} P_{ik}}{m}$$

where

m = total number of years examined

Together they sum to one and form an empirical migratory density function.

However, such functions could only be calculated for the pink salmon trap catches during period I (1914-1924), as later years' regulations introduced truncation of the data due to early closures or late openings.

RESULTS

The southern section of S.E. Alaska historically produced higher catches with the exception of a few years, but the trends were similar in both sections during the years 1900-1960 (Fig. 1). These two sections can subsequently be divided into two or more areas depending on the runs exploited in the fisheries of each area.

The trap data were summarized for 6 areas of S.E. Alaska (Fig. 3). In northern S.E. Alaska, Icy Strait and Lower Chatham Strait are the two main entry points for pink salmon runs. Southern S.E. Alaska was divided into 4 areas: Sumner Strait and Revillagigedo Channel, through which pink salmon runs pass that are destined for mainland and inner channel streams; Gulf of Esquibel off the northwest coast of Prince of Wales Island and Cordova Bay to the southwest. The two latter areas have runs destined for west Prince of Wales Island and for the outer islands off its coast, Dall, Sukkwan, and Noyes Islands, among others.

The series of records was complete in four areas of the six. Trap records for Sumner Strait were located for 1936-1950. In Lower Chatham Strait, records could be found for only a few years, but on the recommendation of an industry member, two traps in Frederick Sound were summarized, as these generally had catch patterns similar to Chatham Strait traps (Vance Sutter, personal communication). It should also be noted that a seventh major migratory route into Clarence Strait from Dixon Entrance is not represented by these data.

The cumulative catch proportions were plotted for each area and period (Appendix 1).

Northern Section

Icy Strait (Appendix 1a-d)

This is the northernmost point of entry into S.E. Alaska, and the run here is composed of several stocks. The run starts in June, earlier than in any other area of S.E. Alaska. The mainland stocks arrive first (Fig. 3), since they have the longest distance to migrate of all S.E. Alaska stocks, and they spawn by mid-August. Middle and some late stocks that follow result in the Icy Strait run being of longest duration in S.E. Alaska, about 2.5 to 3 months.

Chatham Strait (Appendix 1e)

The runs entering this area are mainly bound for Frederick Sound and Lower Chatham streams. Early records are not available for this area, but catch distributions from 1937-1945 suggest that the runs start later than the Icy Strait runs. The duration of the run cannot be determined from the catches, but it probably extends into September as many Lower Chatham streams are late run streams (Fig. 3).

Southern Section

Sumner Strait (Appendix 1f)

As in Chatham Strait, no early records were found. Tagging studies indicated that early runs bound for Ernest Sound enter here (Elling and Macy 1981). The fishing season did not start here until mid-July, and the catch curves for period II are probably truncated at both ends, as early races may be expected to start arriving before that time.

Outer Islands Off Prince of Wales Island, Cordova Bay, and Gulf of Esquibel (Appendix 1g-j)

In both of these areas a few years of early records were available, and the catch distributions indicate late runs of short duration in both places. The runs intercepted at these points are late runs from west Prince of Wales Island and the outer islands. These are the only areas which can probably be regarded as having one stock.

Revillagigedo Channel (Appendix 1k-l)

A long series of records from 1914-1947 is available. The run entering here bound for Behm Canal streams is one of the earliest of the southern section runs, starting in early July and lasting until September, as Behm Channel has streams with early, middle, and late spawners. The fishery after 1925 also opened earlier here than in any other area in southern S.E. Alaska, and truncation of the catch curve probably only occurs at the latter end of the season.

Differences Between Periods

Catch and Effort

Traps were the dominant gear type during periods I-IV (1914-1950's) although after 1930 the number of purse seines increased while trap numbers remained steady (Fig. 4). Despite the increase in purse seiners, their CPUE remained low. In the late 1950's, however, traps were banned in most areas and purse seines took about 90 percent of the pink salmon catch. As traps were removed and management restricted seine boats to some degree, effort decreased into the late 1950's and 1960's, and the decreased catches

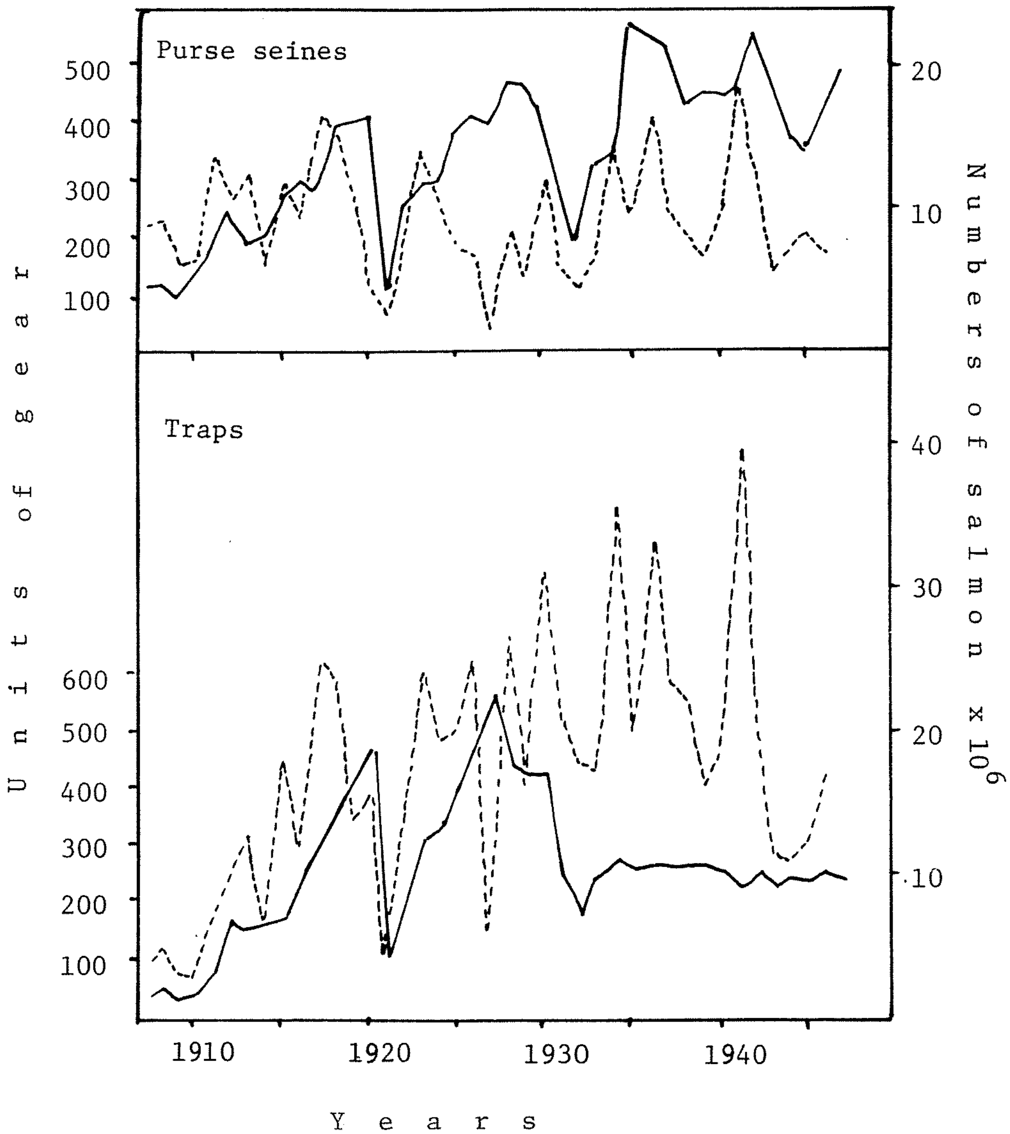

Figure 4. Catches (-----) and units of gear (———) for the trap and purse seine fisheries for pink salmon in S.E. Alaska, 1907-1946 (from Thorsteinsson 1950).

may be attributed in part to this (Fredin et al. 1968). However, a real decline was evident in the pink salmon stocks which continued into the 1960's (Fig. 2).

Catch Distribution

As discussed above, there were certain regulatory differences between periods which resulted in distortion of the migratory pattern in the fishery. Only during the first period (I — prior to 1925), when few regulations were imposed (weekend closures), can the daily catch proportions be assumed to be representative of the migratory time density of the pink salmon runs. Figures 5-7 show the daily catch proportions for Icy Strait, Cordova Bay, and Revillagigedo Channel, and Appendix 1 the cumulative daily proportions. After 1925 there is a truncation of the data in that the season closes, in some years just as the strongest section of the run is passing, and the cumulative catch distribution does not assume the tapering sigmoidal shape of period I but ends abruptly.

In order to compensate for this, some method of adjustment might be used. Vaughan (1954)[1] estimated parameters for a beta distribution from the catch data of period I and used these to expand the later years' truncated curves. However, this method, or any other, assumes that the migratory timing of the pink salmon had not changed systematically over

[1] Vaughan (1954) fitted various types of theoretical curves to the daily catch curves for the years perior to 1924 and found that the beta-distribution gave the best fit. This has the equation

$$f(x) = k(a-x)^r (x+b)^s$$

(Vaughan's notation) where the limits of the curve are -b and a (i.e., -b is the first day of catch, a the last), and the amount of skewness depends on r and s. If r and s are positive, the curve drops to zero at both terminals, a necessary condition set by Vaughan.

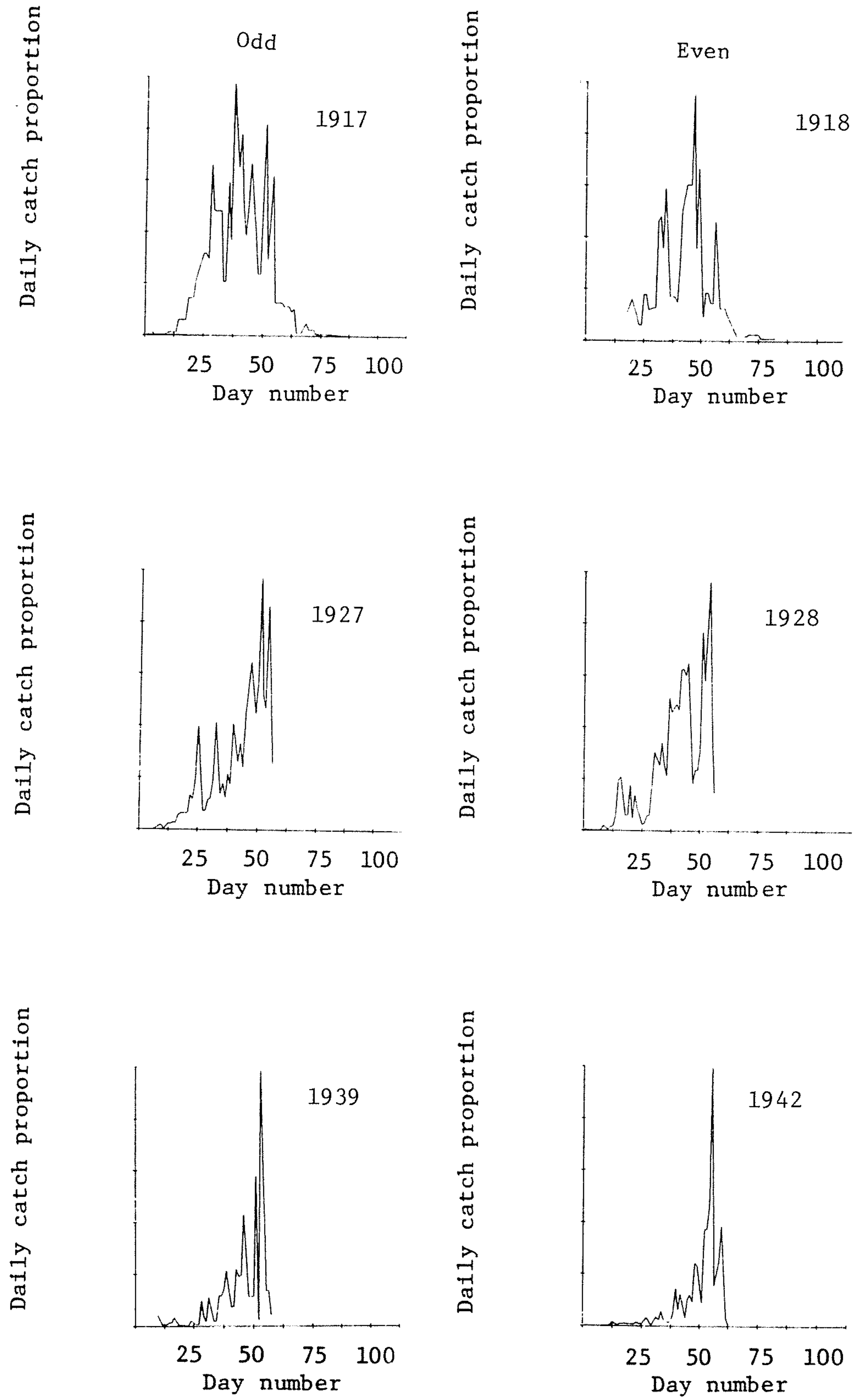

Figure 5. Daily catches of pink salmon in Icy Strait expressed as proportions of total catch. (Day 1 = June 15).

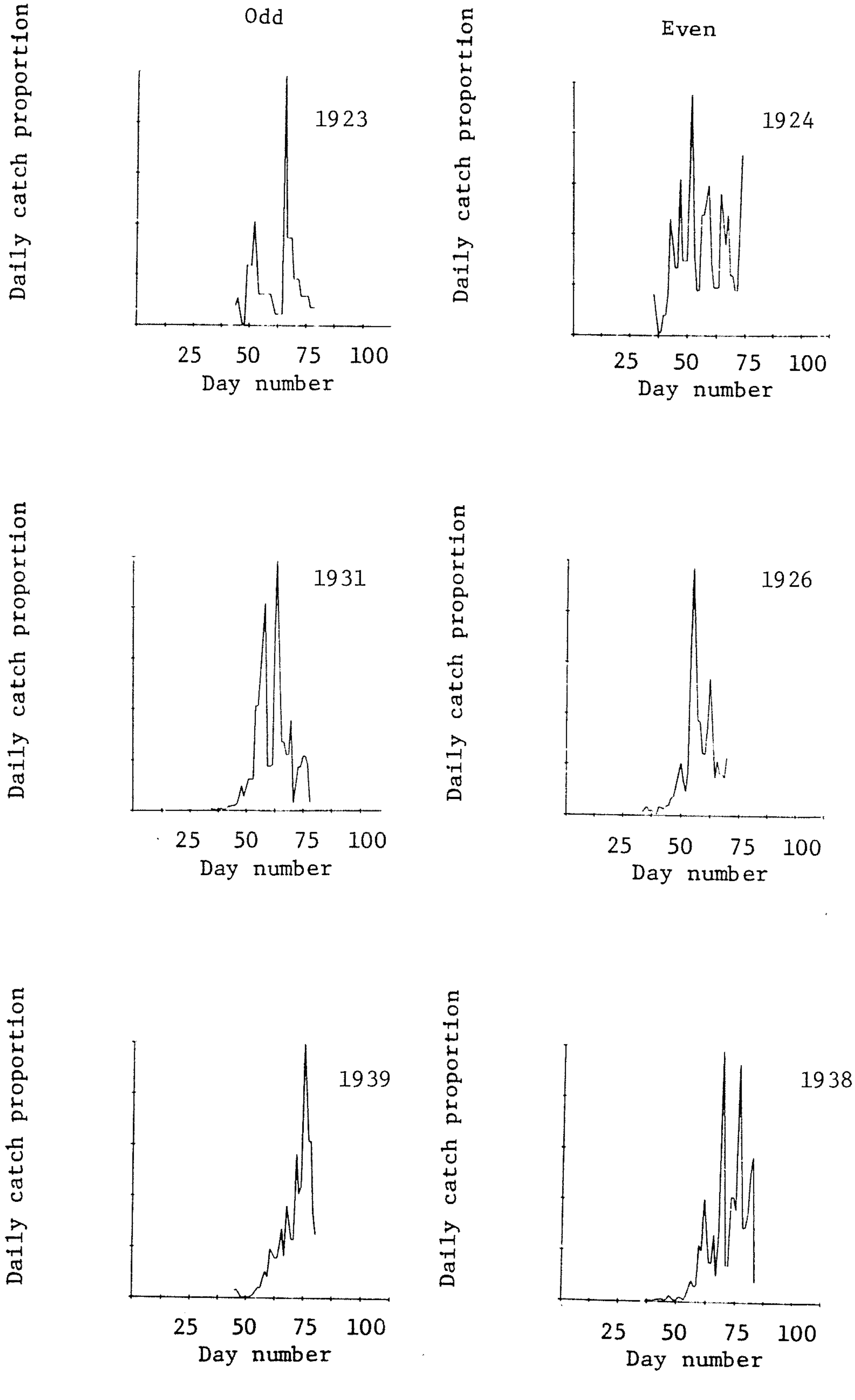

Figure 6. Daily catches of pink salmon in Cordova Bay expressed as proportions of total catch. (Day 1 = June 15).

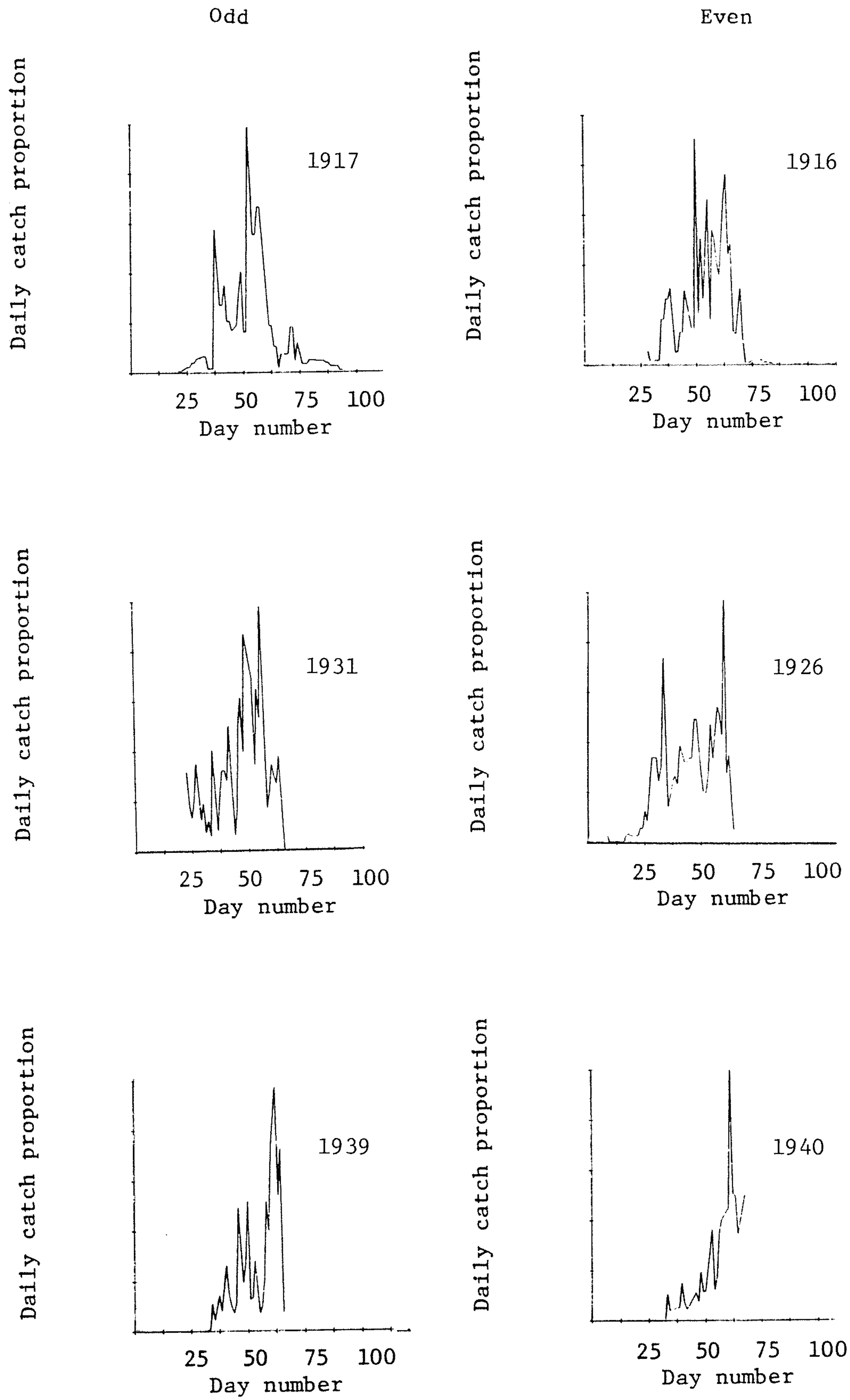

Figure 7. Daily catches of pink salmon in Revillagigedo Channel expressed as proportions of total catch. (Day 1 = June 15).

periods II and III. But Vaughan (1947) did find such a systematic trend, where the date of 75 percent catch shifted backwards during these periods (Fig. 8). A similar shift is seen in Figures 5-7 where the peak of the catches in the late 1930's and early 1940's occur in the latter half of the season. Given the change in regulations, i.e., early closures, and assuming no change in migratory timing, i.e., the underlying "true" migratory curve was conservative, any change in date of 75 percent catch should have been towards an earlier date. But, after an initial forward shift, the trend is to later dates. The implication is therefore that the actual timing of the runs is undergoing a systematic shift backwards.

During the last period (IV) after 1945, the seasons were opened later, some years up to a month later, and the seasons were allowed to extend into September. The catch distributions for this period are assumed not to be representative of the actual migrations due to excessive truncation at the front.

DISCUSSION

Effect of Fishery on Pink Salmon Populations

The drastic decline of the pink salmon fishery in the 1950's has been attributed to a combination of overfishing relative to year-class survival, i.e., that returns from small year classes were over-exploited resulting in a general diminution of the resource (Fredin et al. 1968). Despite declining catches, effort remained high into the 1950's, which led to a collapse of the odd-year line in 1953 and a decline to an all-time low in 1960 for the even-year runs (Fig. 2). Management became more restrictive after these years in an effort to restore the resource.

In the following discussion the effect of the fishery and management will be considered with respect to the timing of the various stocks of S.E. Alaska pink salmon runs. The pink salmon migratory pattern as observed in the straits and channels where the fishery operates, is in reality the sum of the migratory patterns of several stocks which in time have been modified by the fishery. For ten generations 1924-1944, the pink salmon populations, odd and even, were subject to fishing pressure only on one particular section of the runs, that is, the opening and closing dates were consistent over this time (Table 1). The result of this pressure was an apparent retardation in the migratory timing as evidenced by later and later returns to the fishery (Fig. 8). The fact that this shift showed a steady trend towards a later and later date when 75 percent of the catch was realized suggests that it could not be the result of random annual variation around a mean return time. Rather, a steady shift toward later dates of return of the pink salmon runs is seen to be due to the systematic

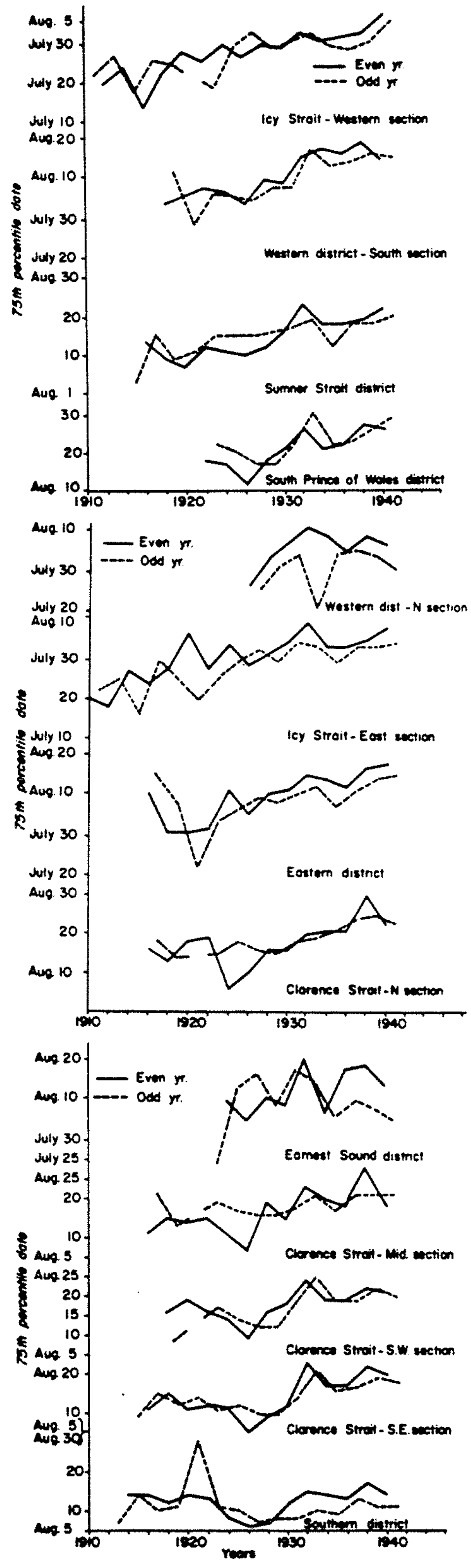

Figure 8. Date when 75% of the catch was achieved in S.E. Alaska pink salmon fishery (from Vaughan 1942).

heavier fishing pressure on the earlier stocks than on later ones.

A stock has been defined as a collection of those populations which. due to their proximity to each other in spawning time and space have similar migratory timing within defined boundaries and are considered as a population system. However, the effect of the fishery is on the individual, elementary populations. The assumption is that within a stock the majority of populations will be similarly affected as will their collective migratory pattern.

Figure 9 presents a model of the postulated effect the fishery may have on three single populations with different migratory timing with respect to a fishery. A population passing through the fisheries in its entirety (1) would be exploited equally on all segments. A second population, which would be classified as a middle-run population (2), would be partially reduced with an apparent shift in timing, and a late-run population (3) would be left untouched. All populations in a run would be affected in one of these three ways to a greater or lesser degree, and the sum of these effects, as viewed from a fishery, would be to delay the apparent time of the peak of the catch, as happened in S.E. Alaska (Fig. 9).

(1) Early-run Populations

All segments of a population passing through the fishery before closure would be equally fished upon. Early populations would be affected variously depending upon their relative strength and the fishing pressure to which they were exposed, but the overall migratory pattern would be conserved while abundance was depressed. It is probable that the earliest stocks

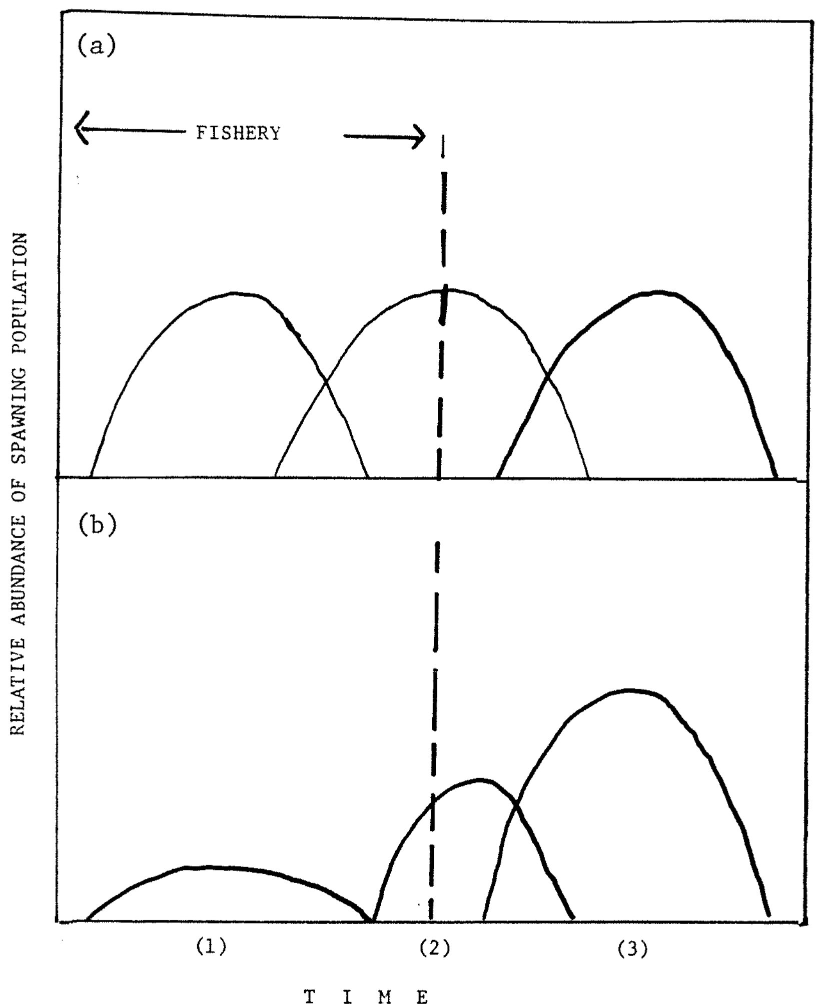

Figure 9. Postulated effect of constant fishing on one segment of a run having populations with three different times of passage through the fishery.

(a) Migratory time distribution prior to the impact of a fishery.

(b) Migratory time distribution after the impact of a fishery.

headed for cold mainland streams and Seymour Canal in the north and for Ernest Sound and Behm Canal in the south (Fig. 3) were thus affected. Recent tagging studies in northern S.E. Alaska (Hoffman 1982) indicated that pink salmon destined for spawning grounds on the mainland and in Seymour Canal passed through Upper Chatham Strait from late June until mid-July, well within the boundaries of the fishing seasons of 1924-1944 (Table 1).

Distance from entry portal to spawning grounds was probably another very important factor. If the opening and closing dates of the seasons in the northern areas (Table 1) are examined, it can be seen that the inner areas, Frederick Sound and Stephen's Passage, opened and closed a little later than Icy and Chatham Strait. The early populations here would thus be exploited at all points of their migration through S.E. Alaska, the longest of all the S.E. Alaska populations, with high fishing mortality as the probable result. In contrast, early populations in the southern district passed through only one regulatory area and over shorter distances than the northern populations and were not subject to fishing for as long a time period. Thus, some early streams, in particular those in inner areas of northern S.E. Alaska may have been exploited to such a degree that recovery has been very slow.

(2) Middle-run Populations

These populations passed through the fishery from late July to late August and were not exploited equally on all segments (Fig. 9). As the seasons closed on similar dates for 20 years, this would have affected the middle-run populations consistently over this period, subject to the annual variations in timing.

Time of spawning can be considered an adaptation to average environmental conditions of the particular streams due to natural selection (Thompson 1962). The appearance of the populations on the spawning grounds follows a generally normal curve (Sheridan 1951, Merrell 1962), as they do on passage through the fishery (Hoffman 1982). This normal curve can be viewed as the distribution of the survival rates of the phenotypes in the population with respect to timing and is the response of the population to the environmental conditions. In other words, the peak abundance on the spawning grounds occurs at the average optimum time for subsequent survival of the progeny.

The fishery of 1924-1944 would effectively act as an artificial selective force upon these populations, in effect through directional or "truncation" selection as described by Hartl (1980). This would cause the time of peak abundance to occur later as shown in Figure 10. Such a shift would be detrimental to the population under the assumption that the peak of spawning abundance reflects the average optimum time of spawning for population survival in that particular stream. The new peak of abundance or mean (Fig. 10) would be "out-of-phase" with regards to environmental factors, as the majority of the population will spawn later than the original mean time, leaving it less viable, or less fit.

A population exposed to this type of fishing pressure which selects against some earlier quantile of the population and leaves spawners only from the upper tail-end would undergo a retardation in spawning time (Fig. 10). Once the fishing pressure, the artificial selective force, is removed, natural selection once again dominates. The new phenotype

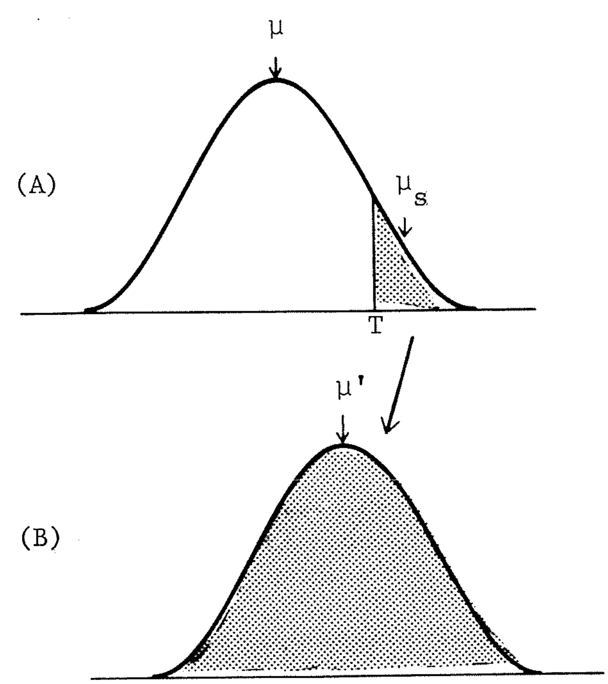

Figure 10. Diagram of truncation selection. (A) Distribution of phenotypes in parental population, mean μ. Those individuals with phenotypes above the truncation point (T) are saved for breeding the next generation. The selected parents are denoted by the hatching, and their mean phenotype by μ_s. (B) Distribution of phenotypes in offspring generation derived from the selected parents. The mean phenotype is denoted μ'. Note that μ' is greater than μ but less than μ_s. (From Hartl 1980).

distribution, as shown in Figure 10B, will then undergo truncation selection again, this time against the later arrivals, and the distribution will shift forward in time.

These trends in time of arrival onto the spawning grounds have been observed in a stream in northern S.E. Alaska, Sashin Creek on Baranof Island. The U.S. Fish and Wildlife Service and later the National Marine Fisheries Service operates a research station on Sashin Creek, where weir counts were taken from 1934 and seaward migrations of fry counted since 1940. Sashin Creek is located in Lower Chatham Strait, where a fishery operated from early July to mid-August from 1924 to 1945. A retardation in time of arrival into this creek has been reported by several authors (Skud 1958, McNeil 1969, Heard 1978). As seen in Figure 11a, the date of 50 percent migration shifted from mid-August in 1934 to mid-September in the 1940's. A similar shift occurred in the fishery during the years 1930-1942 in the western district (Fig. 8). The population in Sashin Creek seems to have been affected by truncation selection as described above. Following the change in regulation in 1945, when the seasons opened later, combined with a decrease in effort in the late 1940's and 1950's, caused the date of 50 percent arrival to move back to mid-August by 1956 and fluctuate around August 20 until 1967.

Concomitant with these trends, Skud (1958) and McNeil (1969) report a trend in fry survival, i.e., early arrival gave higher survival than late (Fig. 11b). All the late runs into Sashin Creek in the 1940's had very low fry survival, but it increased as the date of 50 percent arrival occurred earlier in the season. This was not related to abundance (Table 4), as large and small runs in the 1940's all gave low survival to fry migration.

Figure 11a. Date of 50 percent arrival of mature pink salmon in Sashin Creek, S.E. Alaska (from Heard 1978).

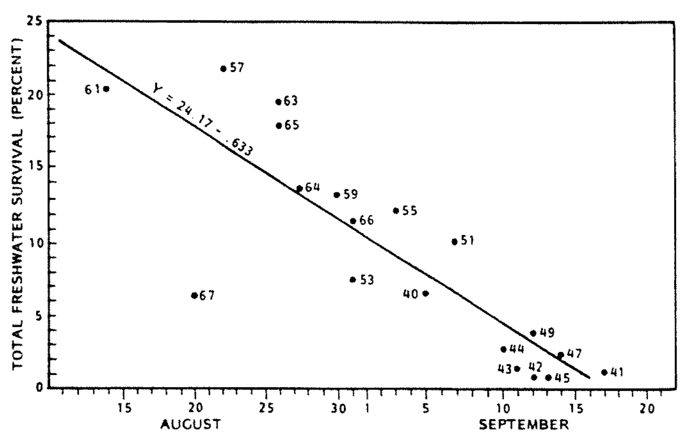

Figure 11b. Fry survival vs. time of 50 percent arrival of spawners in Sashin Creek, S.E. Alaska. (data from Heard 1978).

Table 4. Number of spawning adults and fry survival in Sashin Creek 1934-1968 (from Heard, 1978).

Brood year	Number of adults	Percentage freshwater survival
1934	7.917	-
1935	6.323	-
1936	5.364	-
1937	9.085	-
1938	6.467	-
1939	16.830	-
1940	53.594	6.43
1941	84.303	1.16
1942	92.085	0.85
1943	14.883	1.52
1944	4.050	2.71
1945	5.465	0.85
1946	933	0.16
1947	1.486	2.07
1948	597	1.76
1949	4.902	3.67
1950	112	0.06
1951	4.366	10.15
1952[1]	45	-
1953	1.164	7.43
1954	21	5.48
1955	9.267	12.31
1956	933	0.50
1957	2.834	21.75
1958	217	6.13
1959	35.391	13.21
1960[1]	162	-
1961	28.759	20.19
1962[1]	8	1.20
1963	16.757	19.57
1964	2.193[2]	13.91[3]
1965	14.833	17.92[3]
1966	5.761	11.99[3]
1967	38.067	6.78

[1]An attempt was made to destroy the spawners or their progeny.

[2]Natural returning adults (327) were supplemented by the introduction of 1,866 adults taken from Bear Harbor, Kuiu Island.

[3]Fry weir not operated: figures are estimates of live alevins in the gravel just before start of emergence.

Thus the delayed time of arrival and spawning had a negative effect on progeny survival. The decrease in survival would ultimately retard the recovery of the population, even while escapement levels were allowed to increase by release of fishing pressure. This decrease in survival occurs between the time of adult entry to spawn and the time the fry migrate downstream. In Sashin Creek the difference between the date of 50 percent survival from 1940 to 1960 was about 3 weeks. If the mortality occurred in the egg stage, a possible cause would be cold temperatures as the migratory timing of pink salmon is known to be related to the temperature regime of their stream (Sheridan 1962). Bailey and Evans (1971) report that several workers have found that the initial stage of development before gastrulation is the most sensitive to low temperatures. Eggs deposited later than the "optimum" time run the risk of exposure to temperatures below their level of tolerance while still in the sensitive early stages, thus decreasing survival to hatching and emergence.

The population in Sashin Creek went from a late-spawning population to a middle-spawning population in about 5 generations. This could effectively retard recovery of the population in numbers by as many generations. In northern S.E. Alaska, streams in Chatham Strait, Frederick Sound, and Peril Strait are mid-late run streams and could possibly have been similarly affected to some degree.

(3) Late-run Populations

These stocks may be under- or unexploited in earlier years in some fishing districts, but after 1945 the seasons opened and closed later, lasting into September, and these stocks would then have become vulnerable. Individual stream survey records that are available should be examined in order to establish their response to the fishery and management regime.

In summary, the decline of the pink salmon fishery during the 1950's appears to have been due to a combination of factors, among them

1. Overexploitation, especially in years with poor returns,
2. A rigid regulatory system which opened and closed the fishing season with little or no regard for the complex nature of the runs.

This last factor caused a change in the migratory pattern of the pink salmon runs as evidenced in the shifting of the catch distribution in the fisheries. The migratory pattern of each run is the sum of population migratory patterns and would be changed according to the fate of the separate population components. These were affected depending on their temporal location in the fisheries (Fig. 9), where

1. Early-run populations with all segments equally exploited were depressed;
2. Middle-run populations, exploited only on an early segment (or lower quantile) would be subject to an artificial selective force which caused a shift backwards in time of spawning and consequently migration;
3. Late-run populations, arriving after season closure, would be unaffected.

Thus the migratory pattern of a run with all three population components present would appear shifted backwards. As the early-run populations were depressed, late-run populations dominated, and middle run populations were shifted in time.

The long-term result would be to retard the recovery of the runs due to (1) the depressed state of the earliest segments, and (2) the low survival of the middle-run populations which underwent artificial selection.

Management Implications

The results demonstrate that salmon management must consider the separate and different populations of which the pink salmon runs consist. Today's management is well aware of these problems in Alaskan salmon fisheries and S.E. Alaska presents an especially complex system, where management on population basis is all the more difficult. By necessity the various populations must be grouped for management purposes and a system based on biological characters, i.e., time of spawning as well as geographical location, is a natural one for consideration. Description of such stocks within an area makes possible the definition of their progression through any particular fishery. Natural separation will occur as some stocks will always arrive at different times. The early mainland stock and early Tenakee Inlet stock in northern S.E. Alaska would not be expected to occur together in a fishery in Chatham Strait, while Tenakee Inlet populations and the middle stocks from Chatham Strait would probably occur together in Upper Chatham Strait (Fig. 3). Hoffman (1982) noted such problems in tagging studies in northern S.E. Alaska in 1978-1980.

The results also illustrate that each of these areas of S.E. Alaska have runs with characteristic migratory entry patterns which depend on the timing of the contributing stocks. For instance, in Cordova Bay, the populations spawning in September predominate, the runs are of short duration, and the entire district can be classified as having one stock (Appendix 1e), and use of migratory time density for in-season management purposes would be a relatively straightforward problem. In contrast, the run in Icy Strait lasts from June through September (Appendix 1a), and the migratory time density must be viewed as a series of partially superimposed densities, as each stock passes through the area. The character of the run depends then, in part, on the annual variation in the relative abundance of the stocks, e.g., the failure of many early populations will result in an apparently late overall run. Thus separation of these stocks becomes crucial. Some can be separated in time and space as discussed above; others may need to be separated by analytical methods as they will occur together in a fishery. Such studies should be given a high priority in future research.

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APPENDIX 1

Cumulative catches, expressed as fractions of total seasonal catch for 7 areas in S.E. Alaska.

Period (1) to 1924

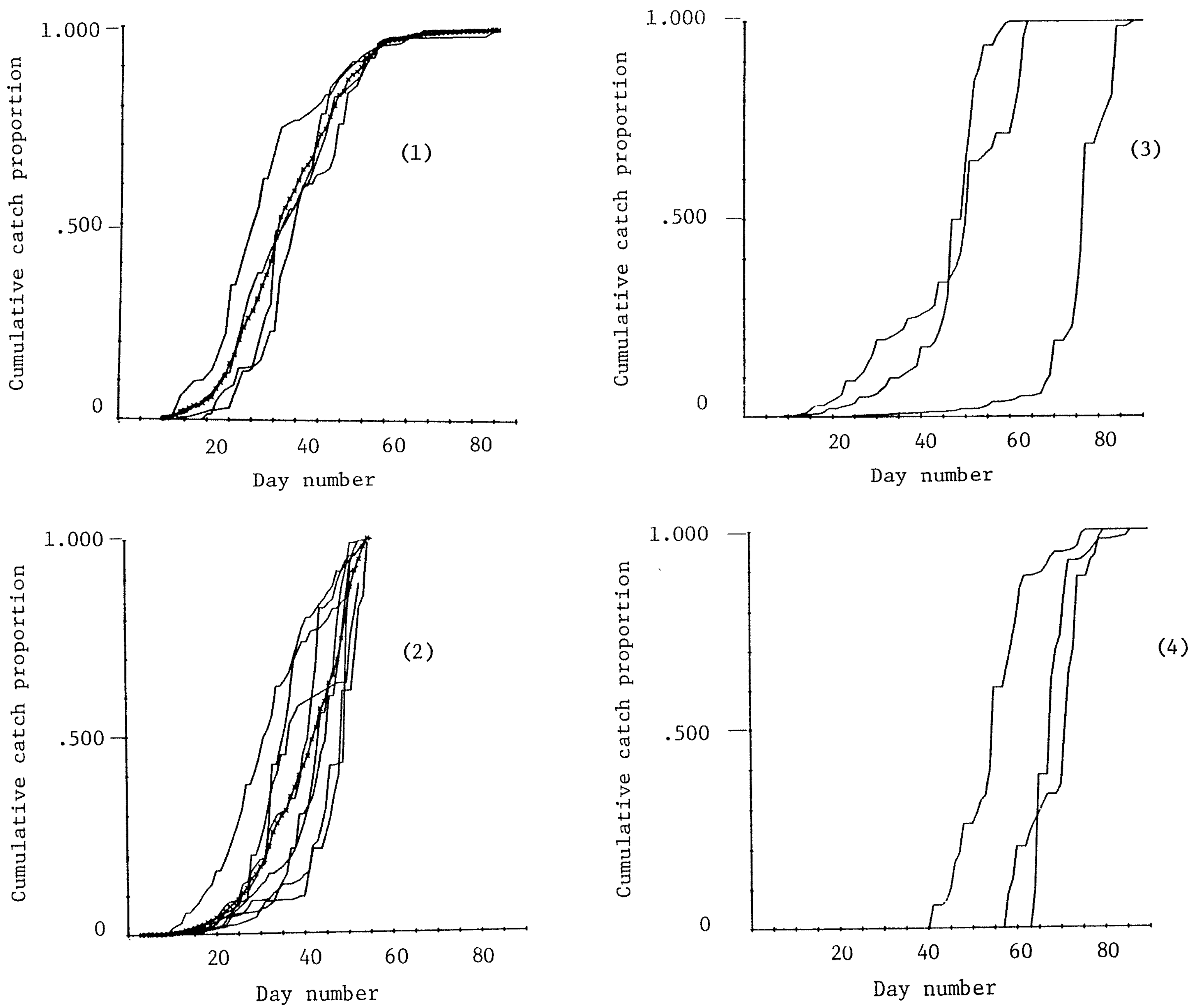
Period (2) 1925 - 1940

Period (3) 1941 - 1944

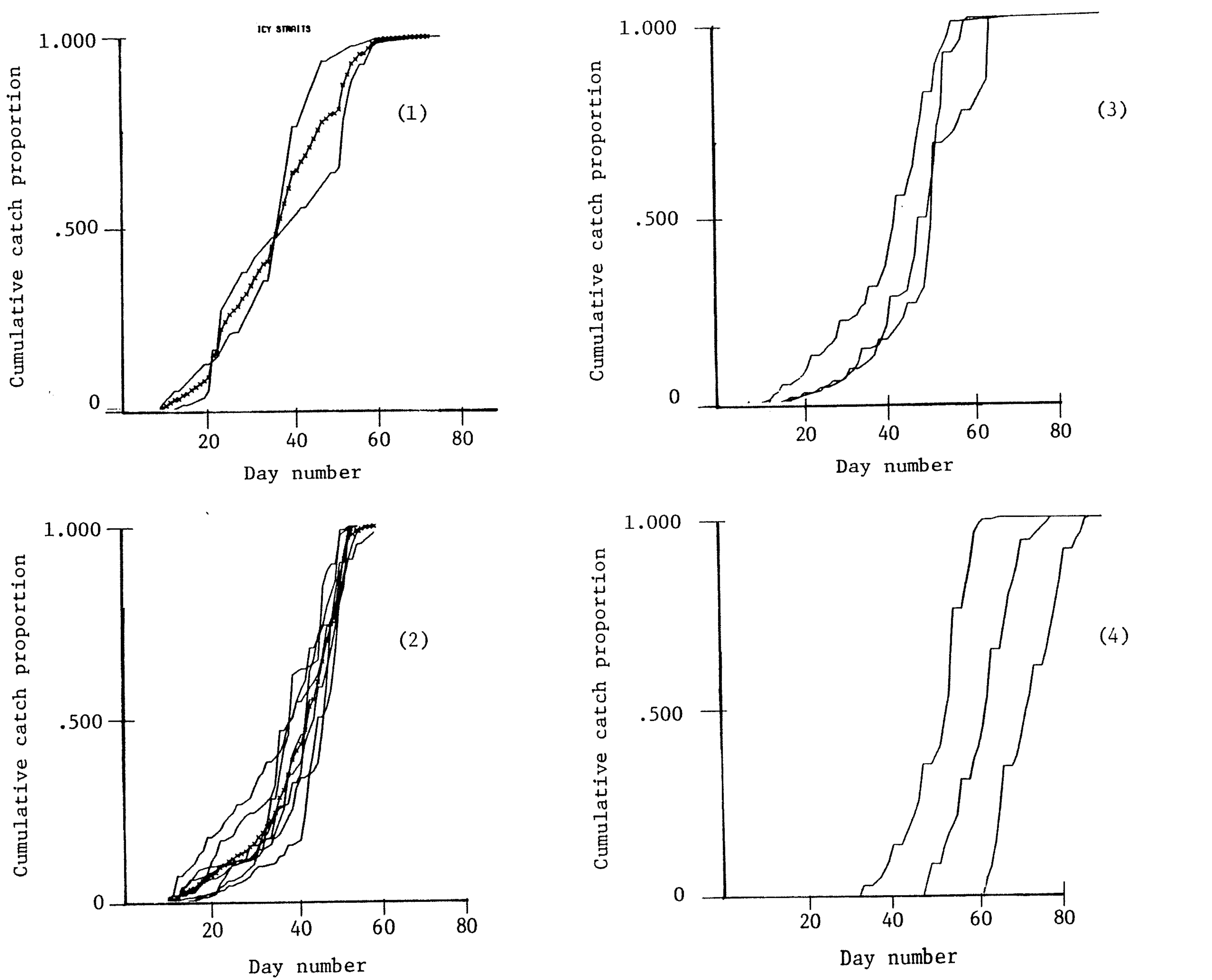
Period (4) after 1945

Mean catch distribution is indicated by -x-x-x-x-x- .

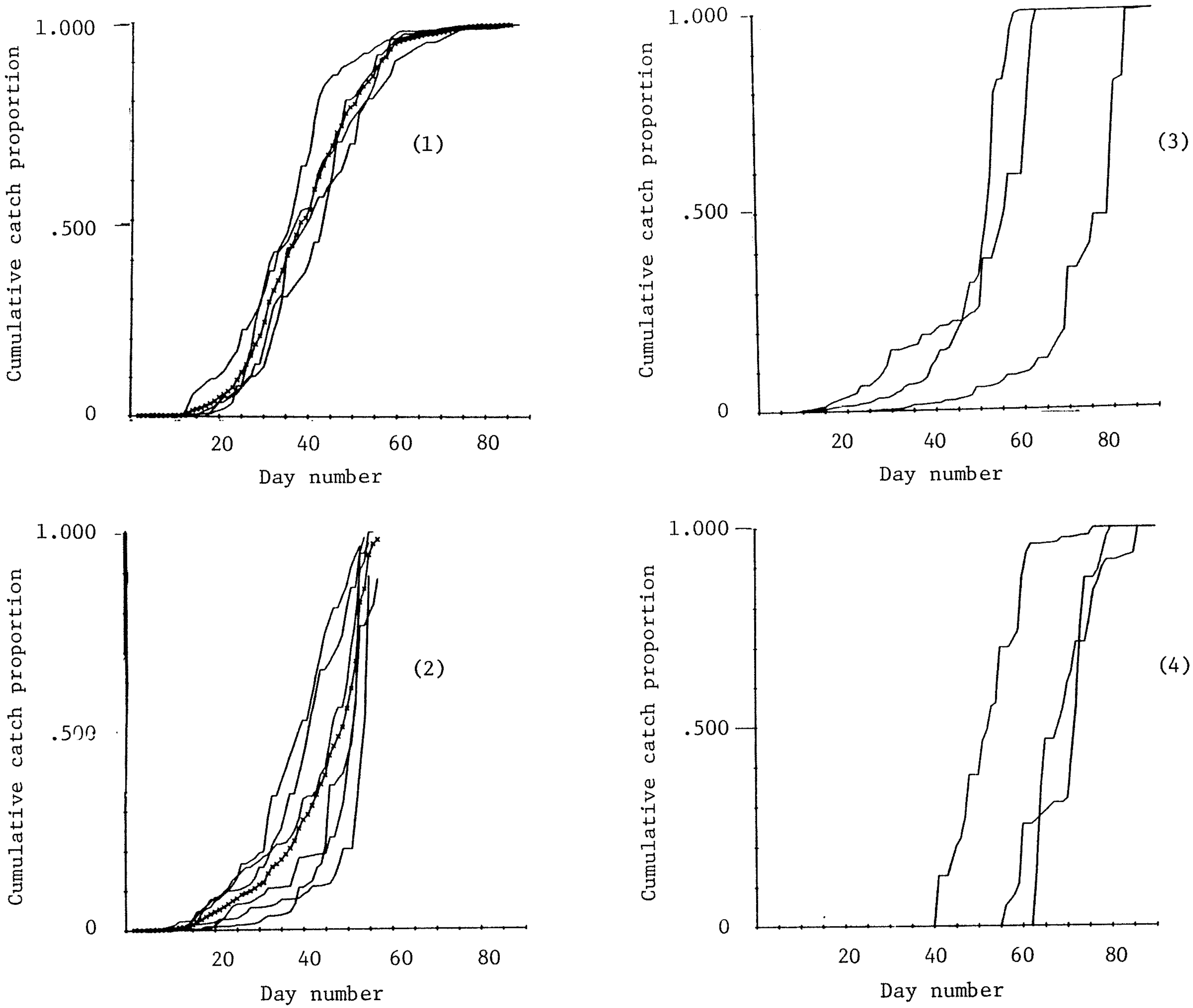
Day 1 = June 15.



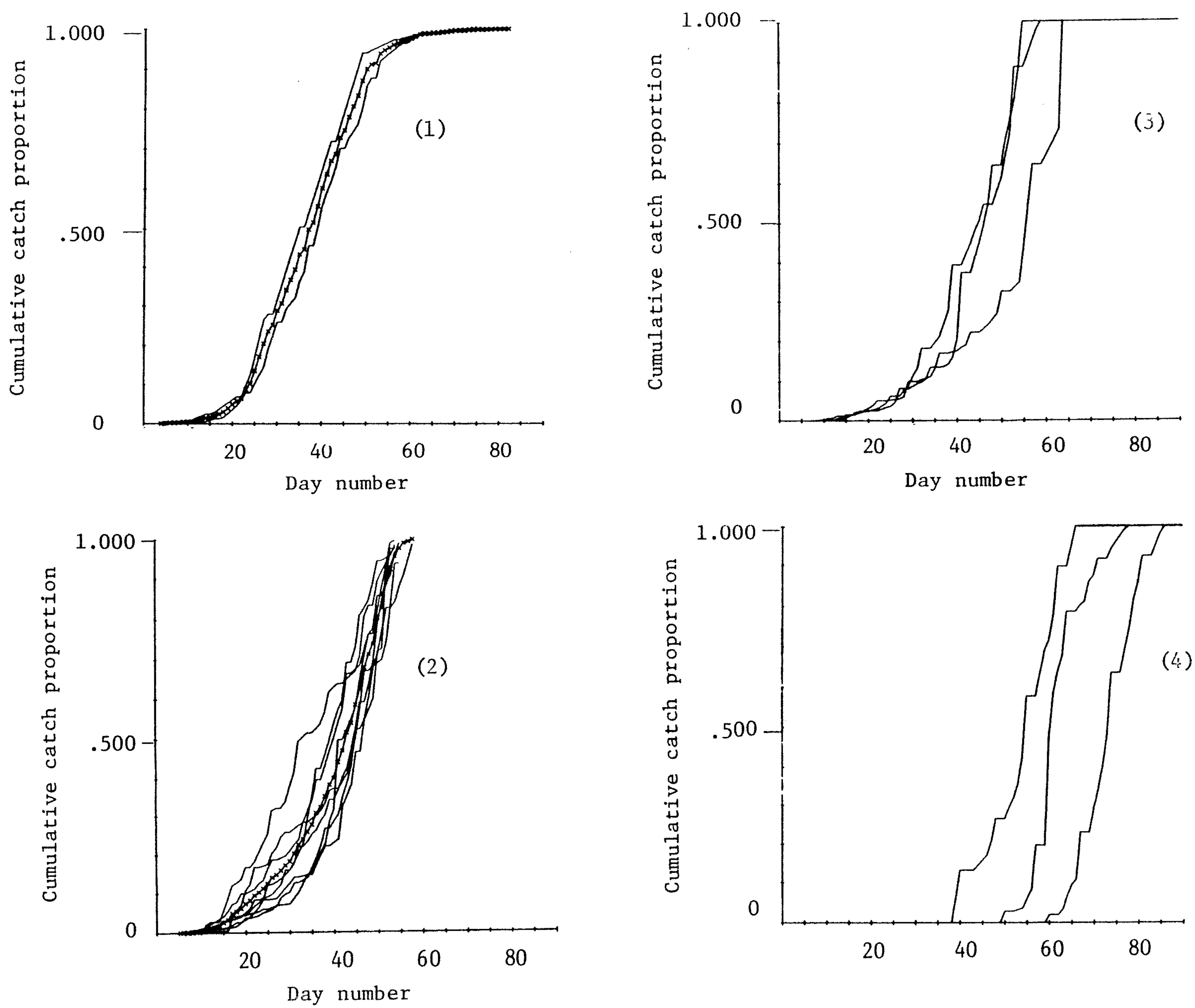
Appendix Figure 1A. Cumulative catch proportions for even years in Outer Icy Strait, periods 1-4.



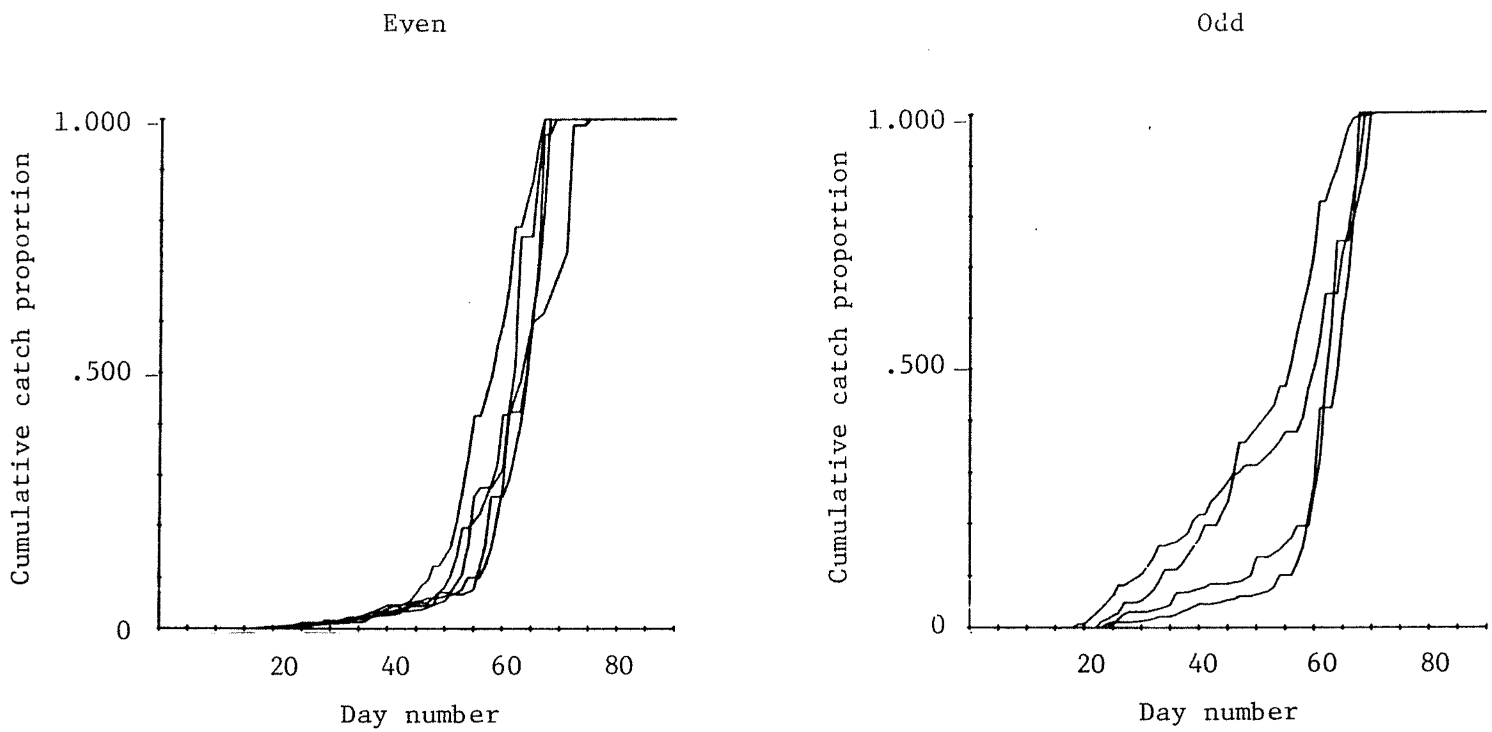
Appendix Figure 1B. Cumulative catch proportions for odd years in Outer Icy Strait, periods 1-4.



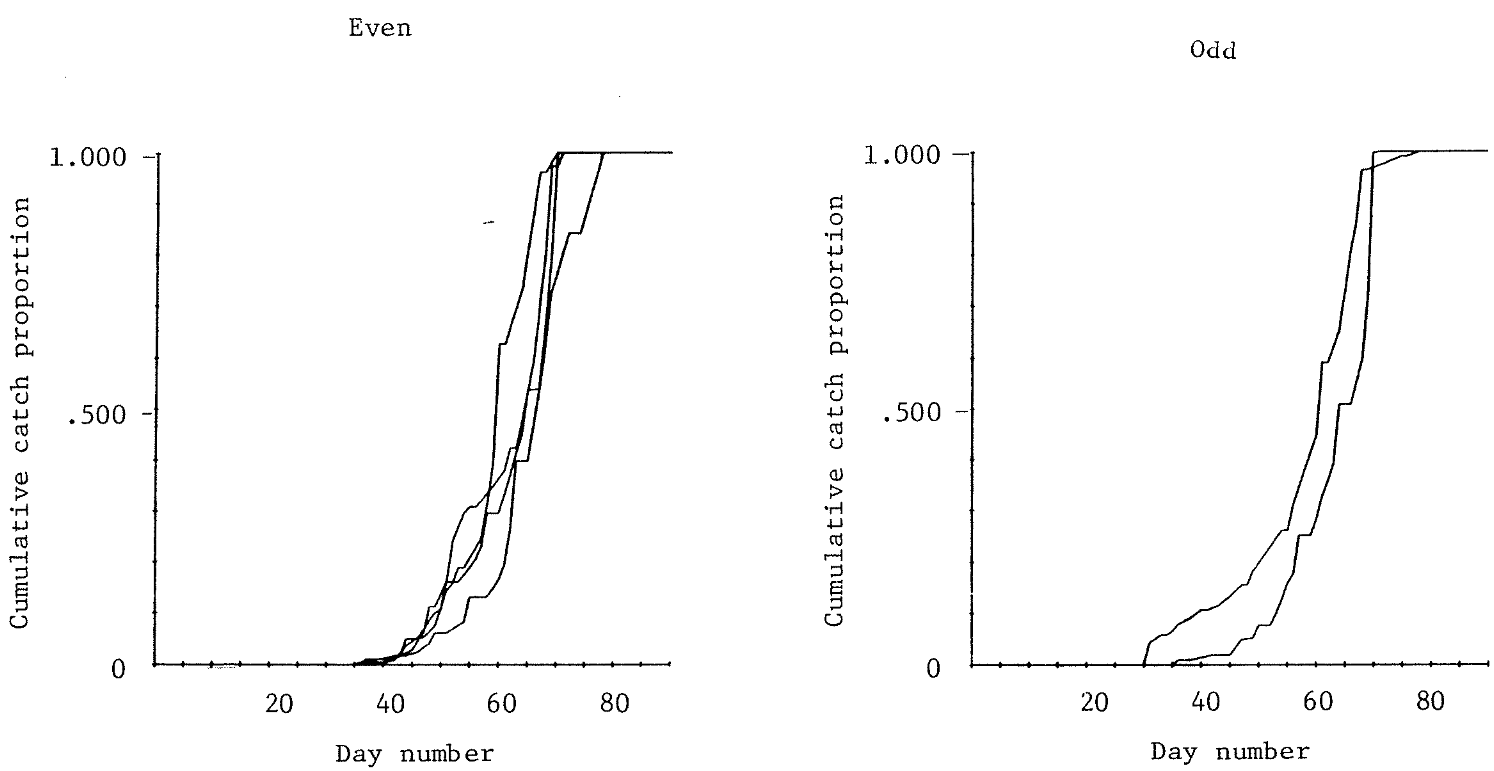
Appendix Figure 1C. Cumulative catch proportions for even years in inner Icy Strait, periods 1–4.



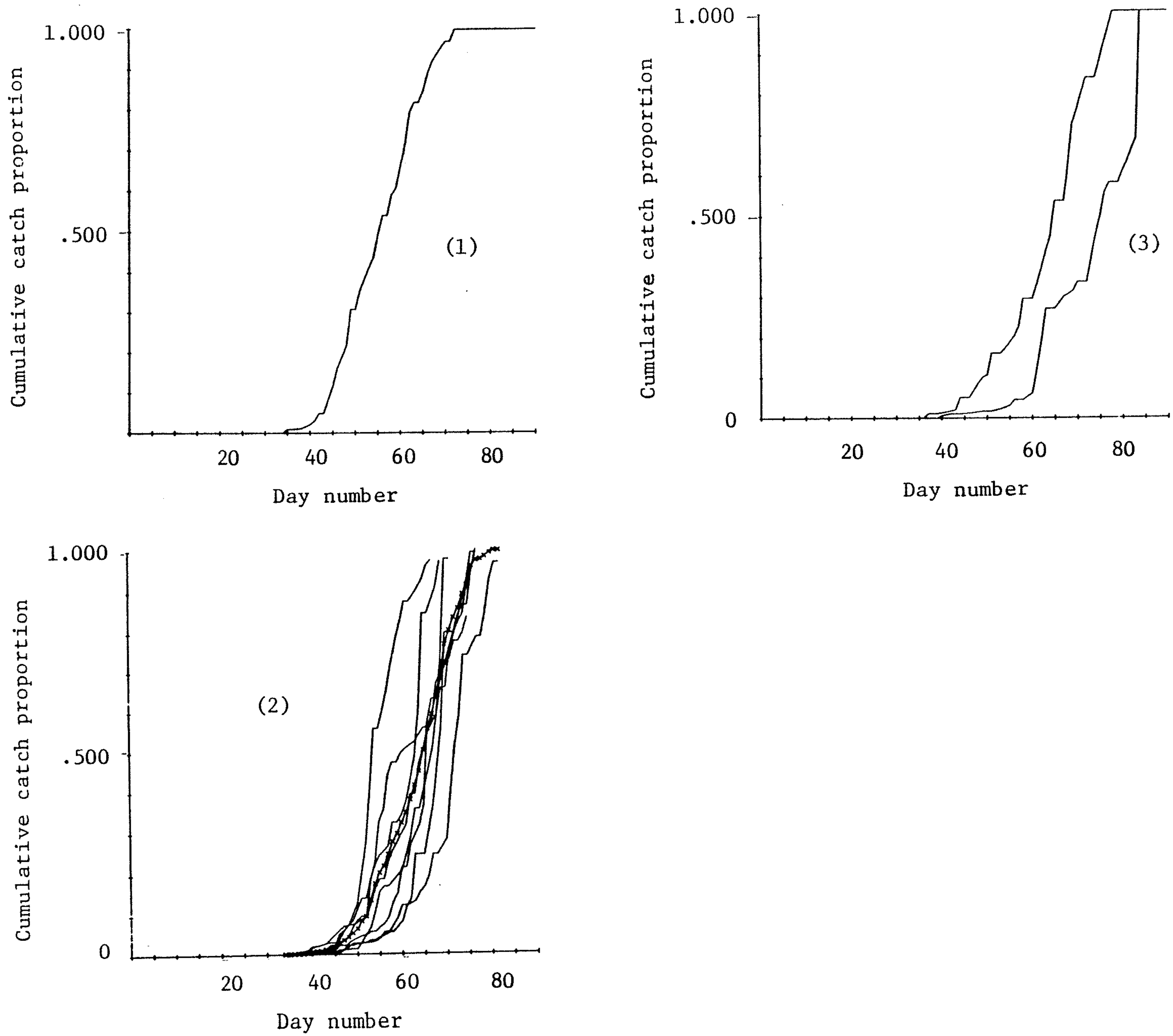
Appendix Figure 1D. Cumulative catch proportions for odd years in Inner Icy Strait, periods 1-4.



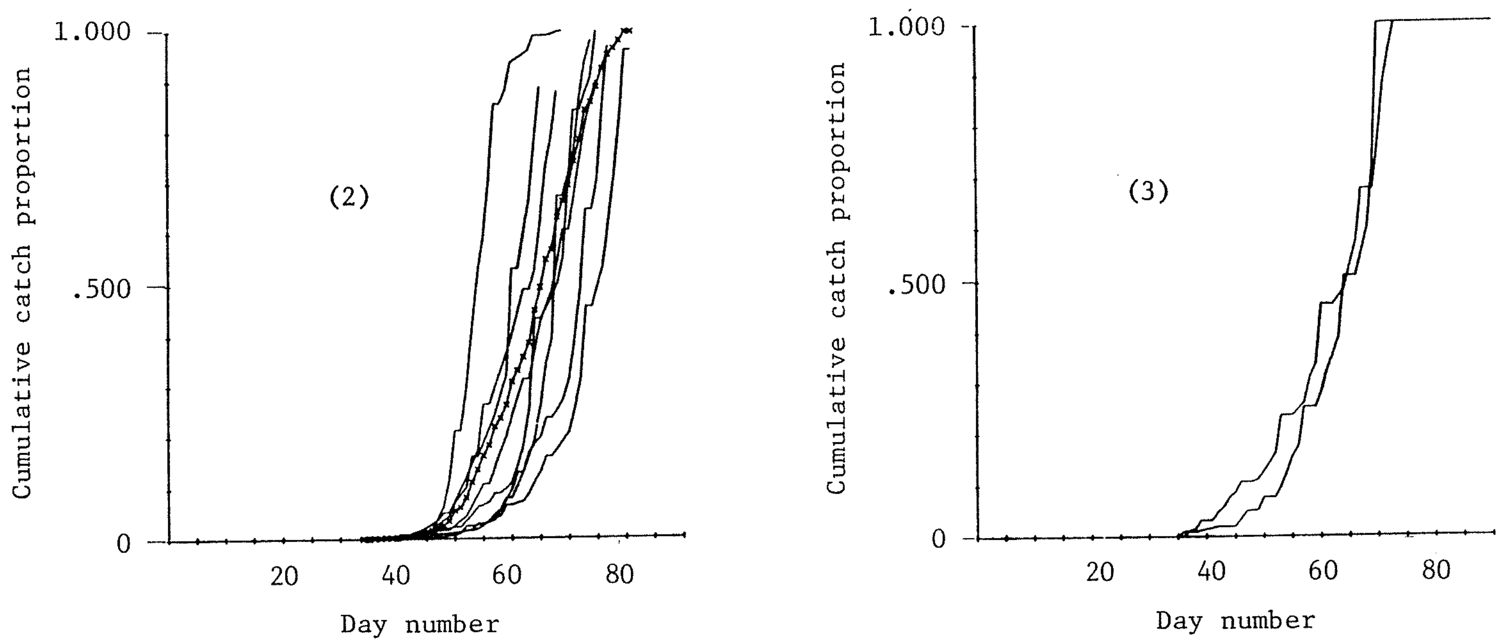
Appendix Figure 1E. Cumulative catch proportions for even and odd years in Chatham Strait, periods 2 and 3 combined.



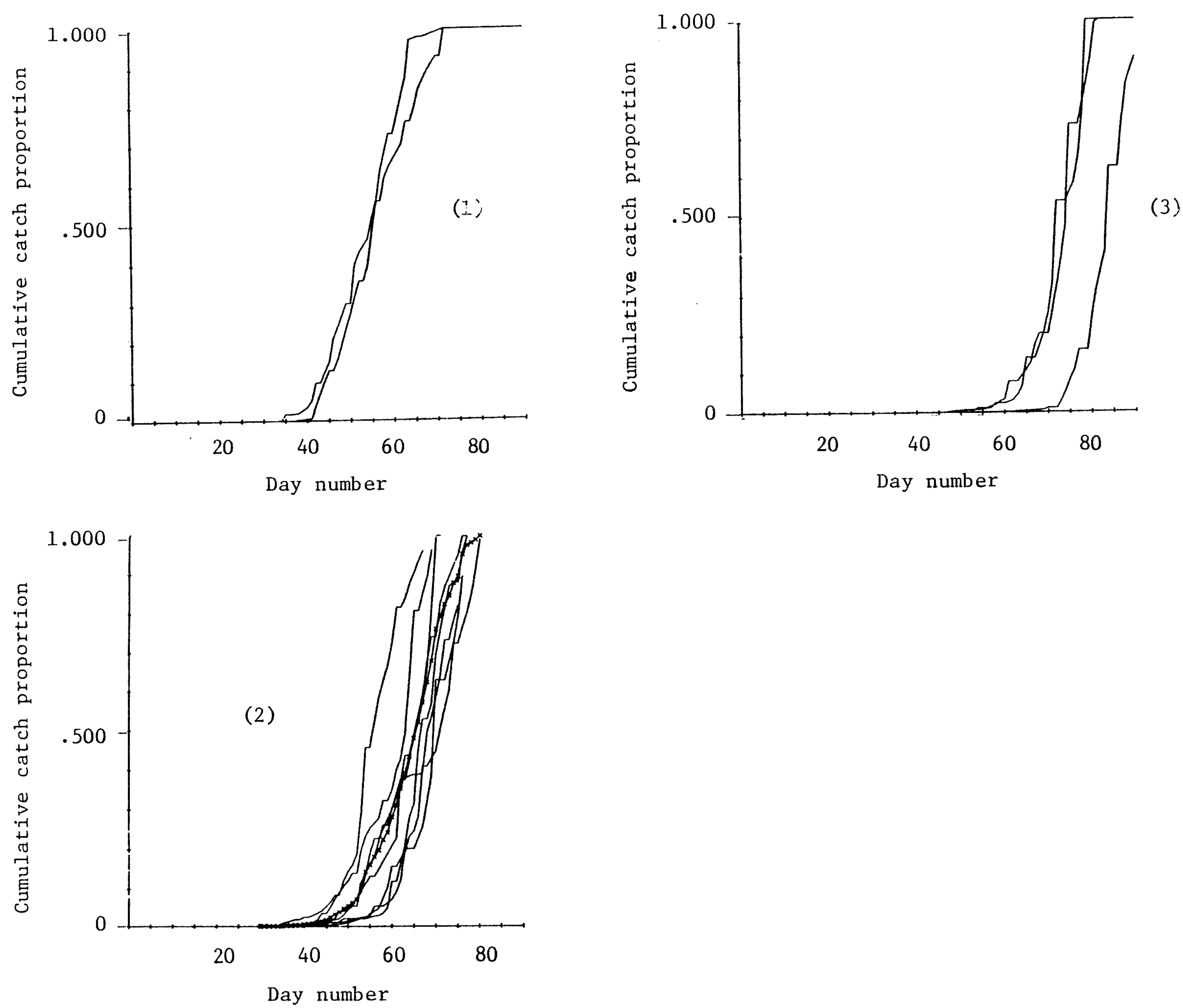
Appendix Figure 1F. Cumulative catch proportions for even and odd years in Sumner Strait, periods 2 and 3 combined.



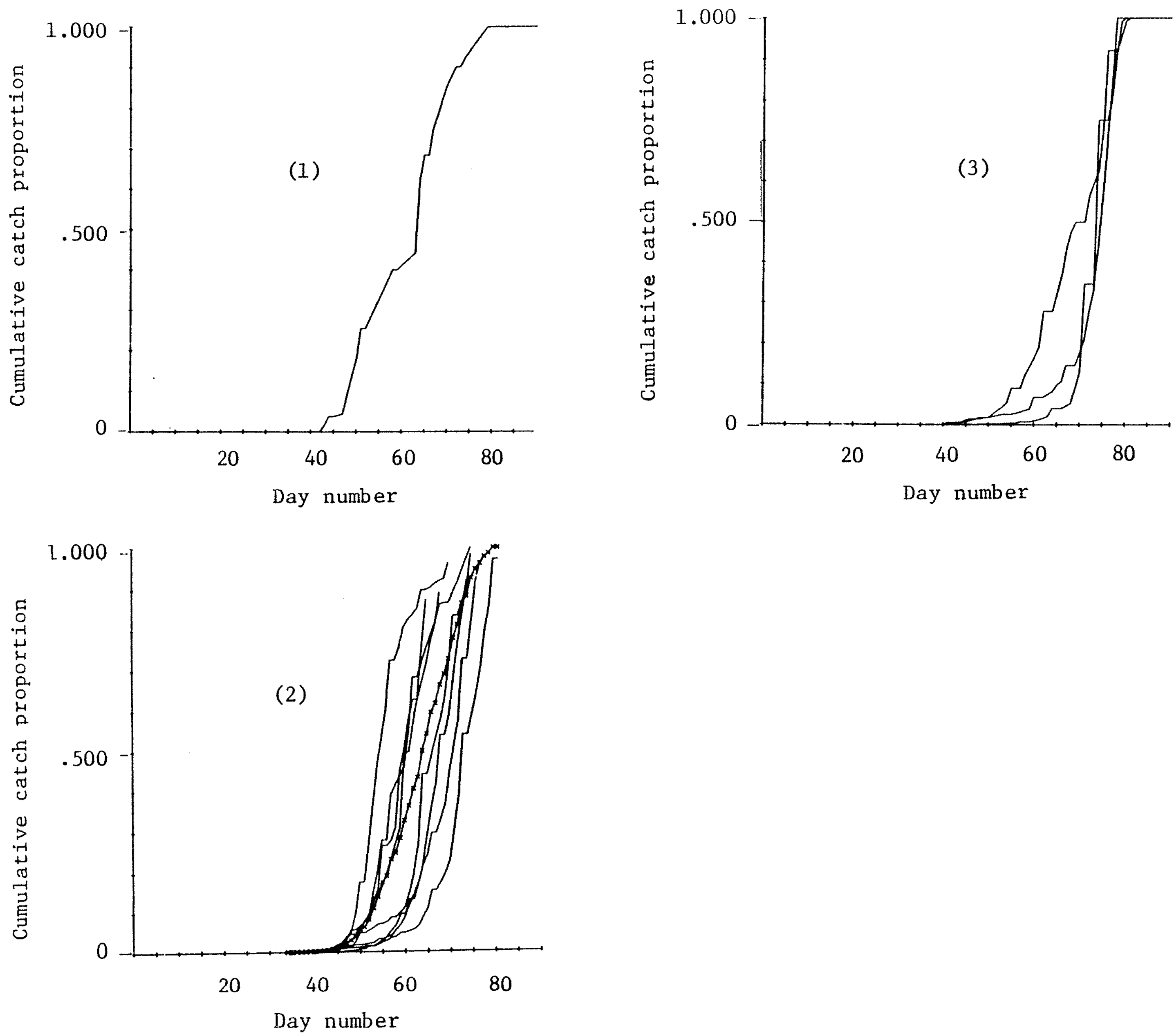
Appendix Figure 1G. Cumulative catch proportions for even years in Gulf of Esquibel (Noyes Island), periods 1-3.



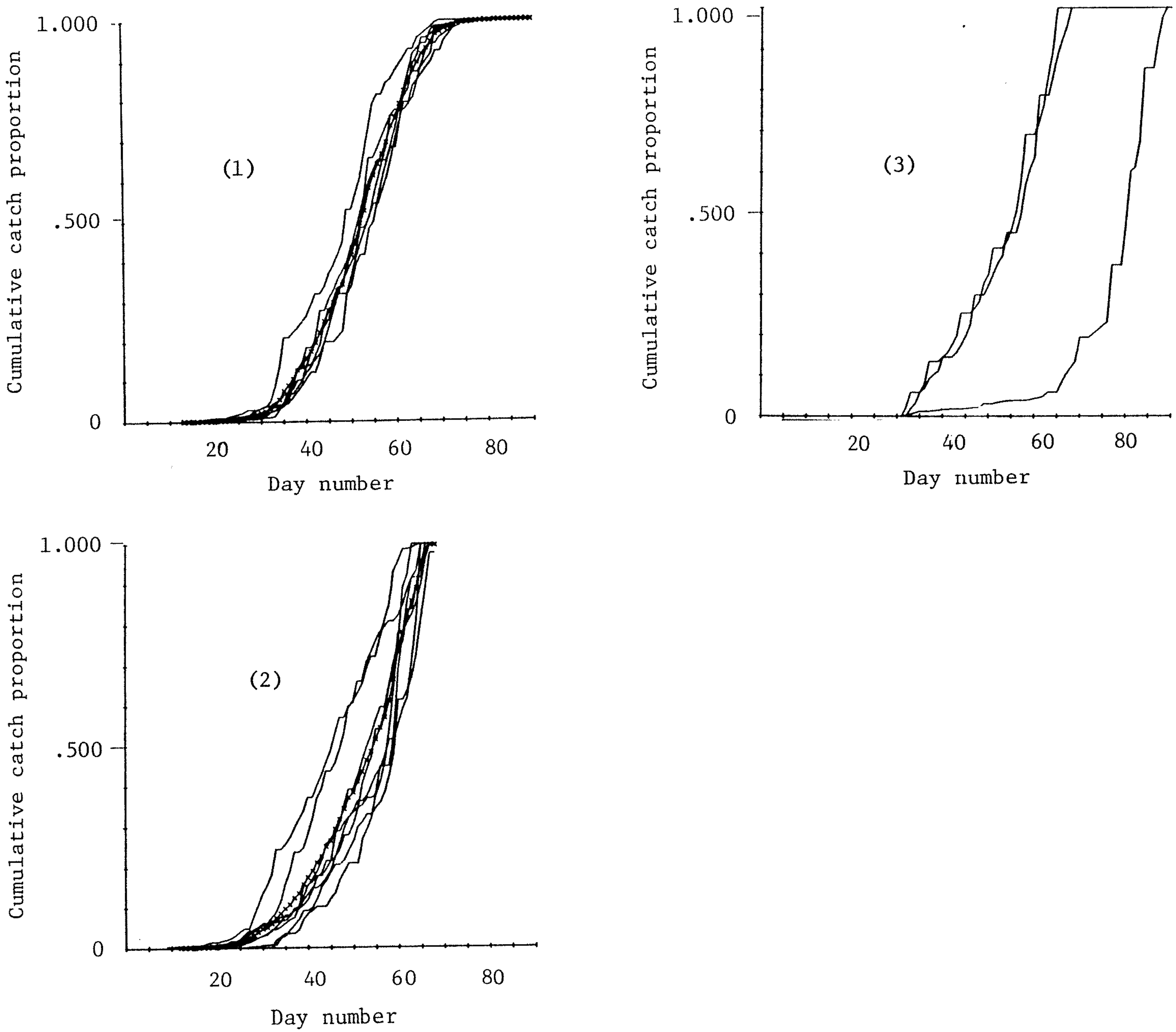
Appendix Figure 1H. Cumulative catch proportions for odd years in Gulf of Esquibel (Noyes Island), periods 2 and 3.



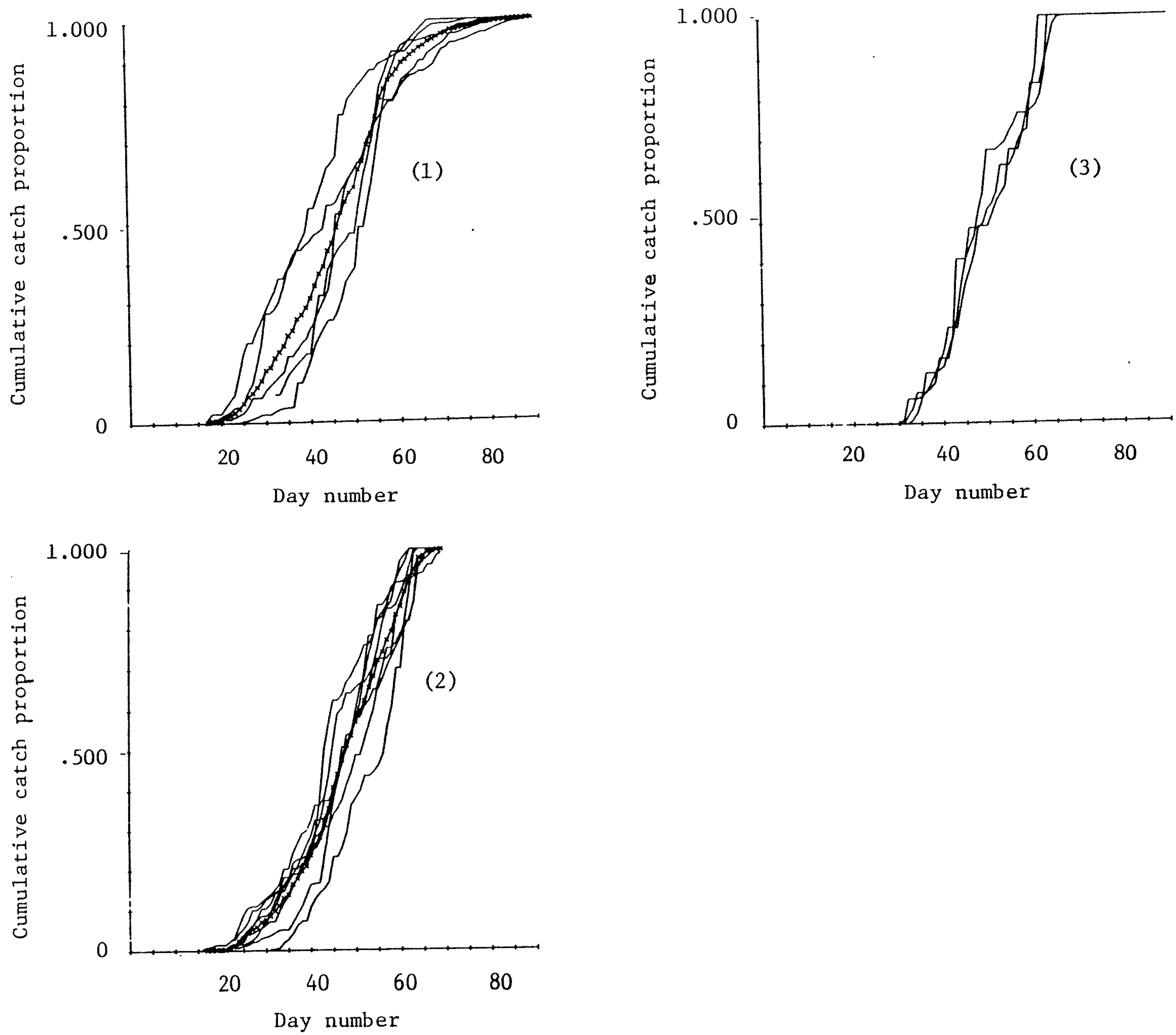
Appendix Figure 1I. Cumulative catch proportions for even years in Cordova Bay, periods 1-3.



Appendix Figure 1J. Cumulative catch proportions for odd years in Cordova Bay, periods 1-3.



Appendix Figure 1K. Cumulative catch proportions for even years in Revillagigedo Channel, periods 1-3.



Appendix Figure 1L. Cumulative catch proportions for odd eyars in Revillagigedo Channel, periods 1-3.