Trends In Marine-Derived Nutrient Sources To South Coastal British Columbia Streams: Impending Implications To Salmonid Production

by

G.A. Larkin and P.A. Slaney

Watershed Restoration Management Report No. 3
1996

BRITISH
COLUMBIA

Funded by:

FOREST
RENEWAL BC

Watershed Restoration Program
Ministry of Environment, Lands and Parks
and Ministry of Forests

Trends In Marine-Derived Nutrient Sources To South Coastal British Columbia Streams: Impending Implications To Salmonid Production

by

G.A. Larkin[1] and P.A. Slaney[2]

[1] c/o Ministry of Environment, Lands and Parks, Watershed Restoration Program, 2204 Main Mall, University of British Columbia, Vancouver, B.C. V6T 1Z4

[2] Ministry of Environment, Lands and Parks, Watershed Restoration Program, 2204 Main Mall, University of British Columbia, Vancouver, B.C. V6T 1Z4

Watershed Restoration Management Report No. 3

1996

ABSTRACT

Larkin, G.A., and P.A. Slaney 1996. Trends in Marine-Derived Nutrient Sources to South Coastal British Columbia Streams: Impending Implications to Salmonid Production. Province of British Columbia, Ministry of Environment, Lands and Parks, and Ministry of Forests. Watershed Restoration Management Report No. 3:56p.

Marine nutrients and carbon transported from the sea by adult salmon migrants are significant and important to the productivity of the oligotrophic lakes and streams in which they spawn. Past land-use practices and salmon harvesting are well known to have reduced the availability of salmonid carcasses to some streams, resulting in a decline in marine-derived nutrient and carbon sources for stream-rearing salmonids, including coho and chinook salmon, steelhead and cutthroat trout and char. Forty-two years of escapement records for five species of Pacific salmon were examined for Georgia Strait, the west coast of Vancouver Island, and the mainland coast of British Columbia, to estimate the status of nutrient sources. Salmon stocks from enhanced streams frequently dominated escapements for entire regions, and as a result, the majority of the incoming marine nutrients are focused towards large stream systems already undergoing significant salmon enhancement, while nutrient influx to smaller, unenhanced streams has declined. In streams with smaller escapements, stocks already in decline are predicted to decrease further in a negative feedback loop because of lessened biological productivity and the size-dependent survival of stream rearing salmonid species. Recent declining trends in nutrient influxes to unenhanced streams in most regions are a cause for concern and more intensive examination. A recent cyclical depression in the survival of south coastal anadromous salmonids in the North Pacific Ocean is also an additive factor responsible for declining salmon escapements. Escapement targets used in wild salmon stock management need to include an allotment of spawners to provide the nutrient influx linked to the maintenance of stream productivity. As well as managing for greater salmon escapements, an external nutrient source to oligotrophic streams may be selectively needed in the interim to increase stream productivity until logging impacted watersheds are rehabilitated and the nutrient influx from carcasses of returning wild salmon spawners returns to historic levels.

ACKNOWLEDGMENTS

This study was conducted under the auspices of Forest Renewal BC for the Watershed Restoration Program. Escapement data from the SEDS database was provided by Greg Serbic from the Pacific Biological Station in Nanaimo. The manuscript was reviewed by Carl Walters, Jeff Cederholm and Ken Ashley, and their input is greatly appreciated.

INTRODUCTION

In spite of the oligotrophic nature of many watersheds that drain into the North Pacific Ocean, salmon production is high. Pacific salmon secure the link between the marine and freshwater environment by the annual return of adults from the sea to spawn and die. Almost their entire body weight is of marine origin, and is delivered to the freshwater system through excretion, gametes and carcass decomposition (Mathisen et al. 1988). The evolution of anadromous species in the northern hemisphere took advantage of the growth rate difference between marine and freshwater systems (Stearley 1992).

^{13}C and ^{15}N, at their natural abundance level, have been used as stable isotope tracers to determine trophic associations and nutrient dynamics in a variety of terrestrial and aquatic ecosystems (Peterson, and Fry 1987). Nitrogen and carbon in spawning salmon contain higher proportions of the heavier isotopic form of both elements than N and C imported to streams from other sources (Kline et al. 1990, 1994). Therefore, stable isotope analysis provides a means of tracing the N and C derived from spawning salmon through the trophic system of the streams they utilize (Bilby et al. 1996).

There is ample evidence that marine nutrients transported from the sea by salmon escapement are significant and important to the productivity of the oligotrophic lakes and streams in which they spawn. Pink and sockeye salmon, which typically spawn at high densities, have been well established as significant contributors of nutrients to the freshwater ecosystems they inhabit (Brickell, and Goering 1970, Richey et al. 1975). Recent descriptive studies, confirmed with carcass introduction experiments, have demonstrated that in a small coho stream, up to 40% of the N and C in the food chain is marine derived via coho salmon carcasses (Bilby et al. 1995). Salmon carcasses are an important source of nutrients for autotrophic production in streams (Richey et al. 1975), even when runs are relatively small (Schuldt, and Hershey 1995). Periphyton growth, as the base of the food chain of a chinook salmon and trout stream was stimulated by the nutrient influx from a relatively small number of chinook carcasses. Since low levels of primary and secondary productivity are characteristic of many headwater streams in the Pacific Northwest, even modest inputs of nutrients and carbon may be important in maintaining trophic productivity.

Past land-use practices and fish harvesting are well known to have reduced the availability of salmonid carcasses to streams (Slaney 1994). Decreased availability of carcass material can significantly reduce the nutrient influx to streams, diminishing productivity. The resulting decrease in fish size can reduce overwinter and marine survival, reducing the number of returning adults and further depressing stream productivity (Bilby et al. 1995). Since as little as a 10 mm increase in mean length of juvenile coho may double survival of pre-smolts through winter freshets to smolt stage (Scrivener, and Brown 1993), the abundance of spawners is potentially crucial to maintenance of fish populations that rear in streams. Runs of adult fish may continue to decline, returning less nutrients to already nutrient deficient streams, particularly if combined with overfishing of a now less productive stock (Slaney 1994). Thus a negative feed-back loop from nutrient-food chain impacts could be very significant to stream and lake rearing species of fish. Cyclical depressions or ‘regime shifts’ in the survival of the Pacific Northwest’s anadromous salmonids is another compounding factor which may further reduce the abundance of returning spawners (Beamish, and Neville 1996).

Experimental stream fertilization in oligotrophic streams has been conducted to examine potential benefits to the salmonid food chain, culminating in improved growth and abundance of fish. Algal chlorophyll *a*, fish growth, and standing crop of salmonids were all higher in fertilized stream sections when compared to control sections (Johnston et al. 1990, Slaney, and Ward 1993). Similarly, benthic insect communities have responded strongly to low level (2 - 4 ppb) increases in phosphorous and nitrate nitrogen

(Mundie et al. 1991, Quamme 1994, and Slaney et al. 1994). Results of fertilization research provide strong evidence that an external nutrient source to oligotrophic streams, equivalent to the nutrient influx from returning spawners, is needed to maintain stream productivity.

This study was, in part, prompted by the recent release of a review of the future of Pacific fisheries (Walters 1995) and the Strait of Georgia Fisheries Sustainability Review (Levy et al. 1996), but also by recent reported declines in returns of salmon and steelhead to Carnation Creek and the Keogh River as indicators of wild stocks in South Coastal B.C. (Tschaplinski et al. 1996, B.R. Ward, B.C. Fisheries Branch, *pers. comm. 1996*). Moreover, the recent papers by Schuldt , and Hershey (1995) and Bilby et al. (1996) which emphasize the role of carcass-derived nutrients in driving autotrophic and heterotrophic production, respectively, in salmon streams, supported the need for a broader coastal review of escapement levels. Escapements for salmon populations returning to the Georgia Basin, West Coast of Vancouver Island, and Mainland Coast, were examined to estimate the status of marine sources of nutrients to salmonid rearing habitats. Escapements are under many influences, including cyclical fluctuations in marine survival, fish harvesting, habitat changes, and salmonid enhancement programs. This report is intended as a preliminary investigation of escapement data to assess if marine nutrient influx has decreased in various regions.

METHODS

Salmon escapement data from the SEDS database (salmon escapement database and reporting system) was obtained for 5 species of salmon (sockeye, coho, pink, chum, chinook), for Fisheries and Oceans Pacific Region statistical areas 9 - 29E, for all available years (1953 to 1994). Statistical areas were combined into groups representing different regions of the study area as follows (Table 1, Fig. 1).

Table 1. Grouping of statistical areas into regions.

REGION	STATISTICAL AREAS
Mainland Coast (Rivers Inlet and Smith Inlet)	9 , and 10
Johnstone / Queen Charlotte Strait	11,12 , and 13
Georgia Strait	14 to 19
Lower Fraser River / Howe Sound	28A to 29E
West Coast of Vancouver Island, South	20, 21 , and 22
West Coast of Vancouver Island, Mid	23 , and 24
West Coast of Vancouver Island, North	25, 26 , and 27

To estimate the influx of nutrients from marine sources, escapements for each region were converted from numbers to weights. Escapements for each species were multiplied by an average weight for a spawning adult (Scott, and Crossman 1973) and approximate percent body composition (Leanne Haywood-Farmer, *pers. comm. 1996*; data on file, Ministry of Environment, Lands and Parks), to obtain the mass of nitrogen (N) and phosphorus (P) that the carcasses potentially contribute (Table 2). Steelhead trout are not included because only a portion die after spawning in the late winter-spring and historic abundances are not known for most streams.

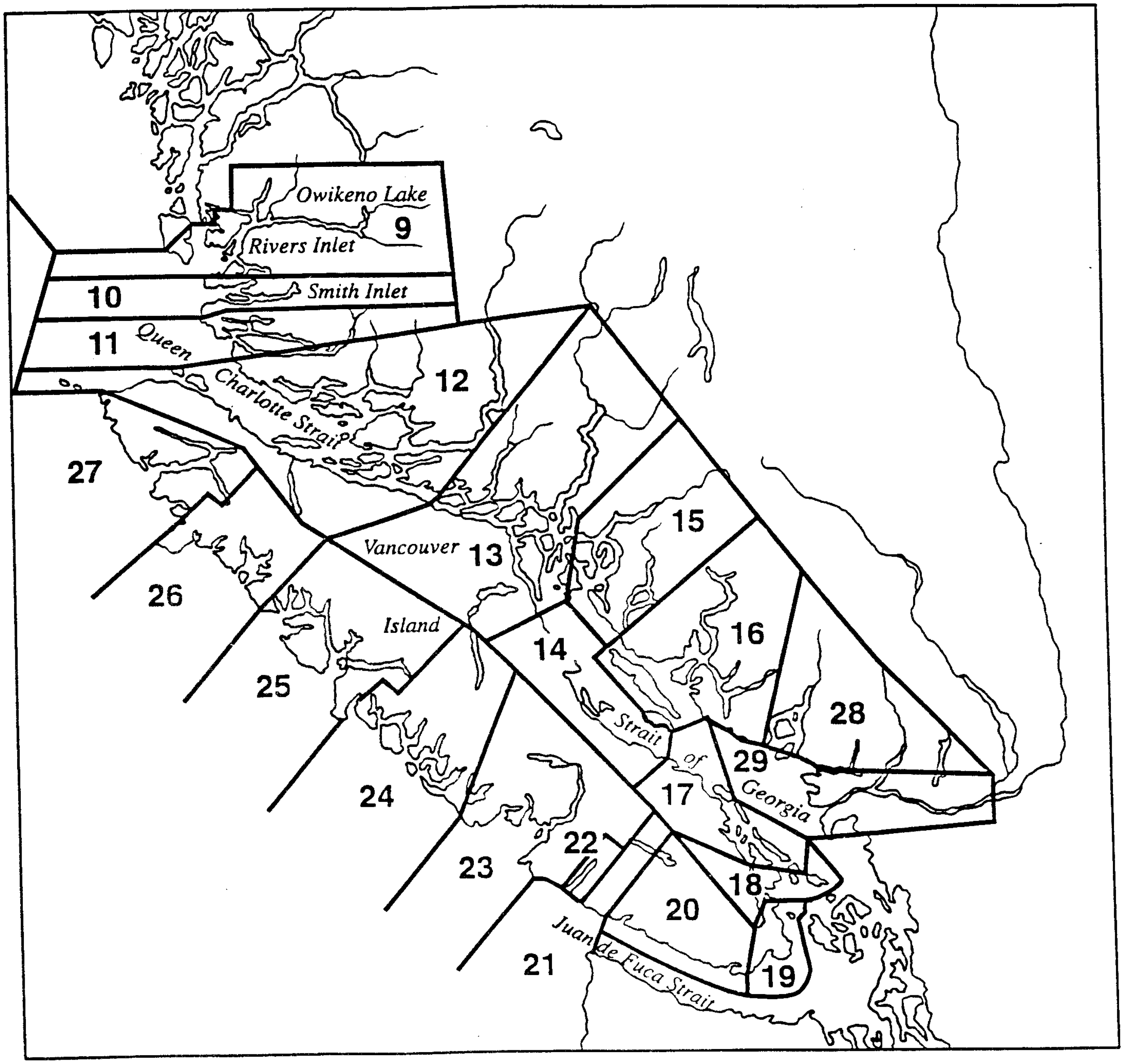


FIGURE 1 Boundaries of Fisheries and Oceans Pacific Region Statistical Areas

Table 2. Percent body composition and average weight for salmonids.

Information	Species	Value
Percent N in body weight	Average for all, adult	3.037
Percent P in body weight	Average for all, adult	0.359
Average adult weight	Sockeye	2.27 kg ≈ 5 lbs
	Coho	4.55 kg ≈ 10 lbs
	Pink	1.82 kg ≈ 4 lbs
	Chum	5.45 kg ≈ 12 lbs
	Chinook	15.91 kg ≈ 35 lbs

Nutrients (in kg) from each species within each of the regions were plotted for the last 42 years to obtain an influx trend. Trends based on the original SEDS data are referred to throughout this report as from the **'raw'** data.

The SEDS data is generated with the following disclaimer :
Note: Many non-environmental changes (e.g.- change in enumeration method) that can affect year to year changes in the reliabilities of spawning estimates have, historically, not been documented on the ***Annual Reports of Salmon Streams and Spawning Populations*** *from which these escapement data are derived. Comparison of annual escapements between, and within, streams must therefore proceed with caution. Users wishing to compare estimates are advised to research the accuracy and consistency of escapement measurement. In many instances, escapement estimates are useful only as indicators of growth or decline of salmon populations.*

The dependability of the data was thereby suspect in several instances, although useful to indicate broad trends. Many estimates from some of the earlier years may be 'dashboard surveys', in which fisheries officers took their best guess, often without leaving their vehicle or perhaps even their office, relying more on local reports (P.A. Larkin, *pers. comm. 1996*). Methods of enumeration are inconsistent from year to year, stream to stream, and species to species. Particular caution was urged with the coho data since in recent years, they are usually not counted directly; if any happen to be present during counts of other species, a guess is made as to the probable total number of spawners (R. Cook, and B. Adkins, DFO, *pers. comm. 1996*). Nevertheless, examination of long-term trends can still have merit, particularly if differences are large in magnitude (Levy et al. 1996).

Some problems were also encountered during the compilation of the data. Counts for all 5 species are not made for every stream, and as a result, the escapement record for each species can be comprised from a varying number of streams (coho and chum tend to have the largest number of streams in a region reporting escapements). As well, observations were not consistent for the entire 42 years. Streams that had recorded less that 4 yearly observations out of the 42 years for a given species (2 out of 21 for pinks which were split into odd and even year runs) were not included in the total escapement calculated for that species for the given region. These streams usually had low escapements and thus their omission had little impact (Mulholland, Lang Consulting Ltd. 1995). The total number of streams in the region, and the number of streams for each given species are provided in the discussion.

There are also discontinuities or gaps in the data. If no escapement data was available, a code in the SEDS database offers the following interpretations: (-1) none observed, (-2) unknown, (-3) stream not inspected for this species, (-4) species does not spawn in this stream, (-5) fry present, or (-6) adults present.

Some data gaps can greatly sway the nutrient influx trends determined. For example, in the West Coast of Vancouver Island, Mid-Region, the chinook data for the Somass River is complete except for 1986 and 1987 where the information is 'unknown'. Since the chinook run of the Somass River is dominant in this region, the missing data has a great influence on the escapement and therefore nutrient influx trend. In such obvious cases (as well as for streams with smaller, but still significant escapements) where a record is intact except for a couple of years, efforts were made to complete the database by filling in the gaps with average or regular step values from escapement data from either side. Note that only data gaps with information codes for (-1) unknown, (-2) stream not inspected for this species, and (-6) adults present, were interpolated. Some stream records were left untouched because they were so incomplete that filling the gaps by interpolation would have resulted in unreliable regional escapement estimates. The nutrient influx trends obtained from escapement data after omitting the low escapement streams and interpolating minor discontinuities are referred to throughout this report as from the **'adjusted'** data.

Many escapements within the study area are influenced by enhancement programs, particularly DFO's Salmonid Enhancement Program (SEP). Although the SEDS records are *not intended to* contain counts of hatchery fish, they inevitably do (B. Adkins, DFO, *pers. comm. 1996*). In order to eliminate the influence of enhancement on nutrient influx trends from wild salmon, streams that would contain enhanced stocks (from hatchery fish, sockeye lake fertilization, spawning channel creation, and other methods) had all of their escapement data removed from the adjusted data for the entire 42 years of their record (note: only for the species that were enhanced, SEP Annual Summary Reports, DFO). Unfortunately enhanced streams are often some of the few which have complete and reliable escapement records. Escapements for some species in some regions were often largely dominated by enhancement streams, to the extent that very few streams remained to be summed after removal of those affected. Although it is noted that escapements from some unenhanced streams may be influenced by strays from neighboring enhanced streams, their escapement records were not removed since effects were deemed minimal on regional escapement trends. The nutrient influx trends determined from the escapement data remaining after removal of enhanced streams are referred to throughout this report as from the data from '**unenhanced'** streams. Unenhanced stream escapement numbers should not be directly compared to the other data sets (raw and adjusted), but comparison of trends may provide valuable insight into the division of marine nutrient influx from wild stocks versus hatchery stocks.

Totals in kg for each species were also added together to acquire the trend of total N and P influx to each coastal stream region. Species of salmon share both spawning and rearing habitats, and therefore nutrient influx from one species may benefit another. Although the total nutrient influx to a region is dictated by species with larger escapements, examining trends over several decades can give insight into the nutrient status in streams of the region as a whole.

Lakes act as detention basins which moderate flows to downstream reaches. This can be of particular importance in areas of intense forest harvesting activity where more extreme flows (especially higher peak flows) result from changes in forest cover. Streams were determined to be lake-headed if a lake of significant size (visible on a 1:600,000 map (B.C. MoELP 1993)) existed (1) at the upstream end of the stream, or (2) downstream of the stream, but deemed to have significant influence on the flow regimes in areas of use for migrating adults and rearing juveniles. For example, small feeder streams to lakes were included in the lake-headed category since spawners would migrate via streams below the lake, and juveniles are likely to utilize the lake and surrounding area for rearing habitat. The unenhanced streams in each region were separated into lake-headed and non-lake-headed and their combined escapements plotted by species. As this analysis was auxiliary to the examination of nutrient status, the results are appended (Appendix A).

RESULTS AND DISCUSSION

Mainland Coast (Rivers Inlet and Smith Inlet) Region (Areas 9, and 10)

The Mainland Coast (Rivers Inlet and Smith Inlet) Region extends from approximately the south shore of Rivers Inlet to Cape Caution (just south of Smith Inlet). Forty-seven streams are included in this region (Table 3).

Table 3. Breakdown of streams, Mainland Coast (Rivers Inlet and Smith Inlet) region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
47	Sockeye	25	16	15
	Coho	37	27	27
	Odd Year Pink	30	26	25
	Even Year Pink	31	26	25
	Chum	28	21	20
	Chinook	15	12	11

The sockeye escapement record is nearly complete with 11 of the 16 streams in the adjusted data having counts for 42 years of the record. The trend determined from this data should reliably indicate nutrient influx (Fig. 2a). The early years of the record show a strong 5 year cycle that is typical of northern sockeye streams. The peaks and troughs in the trend in the last 20 years are found through the majority of the stock escapements. Marine nutrient influx has increased over the 42 years of the record, but there has been a substantial decline during the last 10 years.

There is no coho enhancement in this region, and wild coho escapements are small, with a maximum of approximately 20,000. The escapement record is ‘patchy’ with the number of streams reporting dropping off severely in the mid 80s, and then further declining after 1990. The nutrient influx trend after 1985 should be ignored completely with numbers pre-1985 viewed with great caution due to the poor record. The low levels of nutrients in the last 10 years are likely a reflection of poor data and not a reliable indicator of nutrient status (Fig. 2b).

Escapements from a handful of streams, including Johnston Creek, Kilbella River, Chuckwalla River, and the Nekite River, make up the majority of the nutrient influx from odd year pinks. Streams with smaller escapements have incomplete records, but this should not significantly affect the nutrient trend for the region since the major contributors have more complete data (Fig. 2c). Large escapements from Johnston Creek in the 1980s result in the nutrient influx peak in 1985, but there has since been a progressive decline.

Nutrient influx from even years pinks is primarily from significant runs from Johnston Creek, Milton River, Kilbella River, Chuckwalla River, Clyak River and the Nekite River which have good records for the entire 42 years. The Young River and Niel Creek have been important contributors in the past 10 years. The peak nutrient influx in 1972 is due to large escapement years in the Kilbella and Clyak Rivers (Fig. 2d). The trend is not significantly affected by the removal of the one stream with enhancement

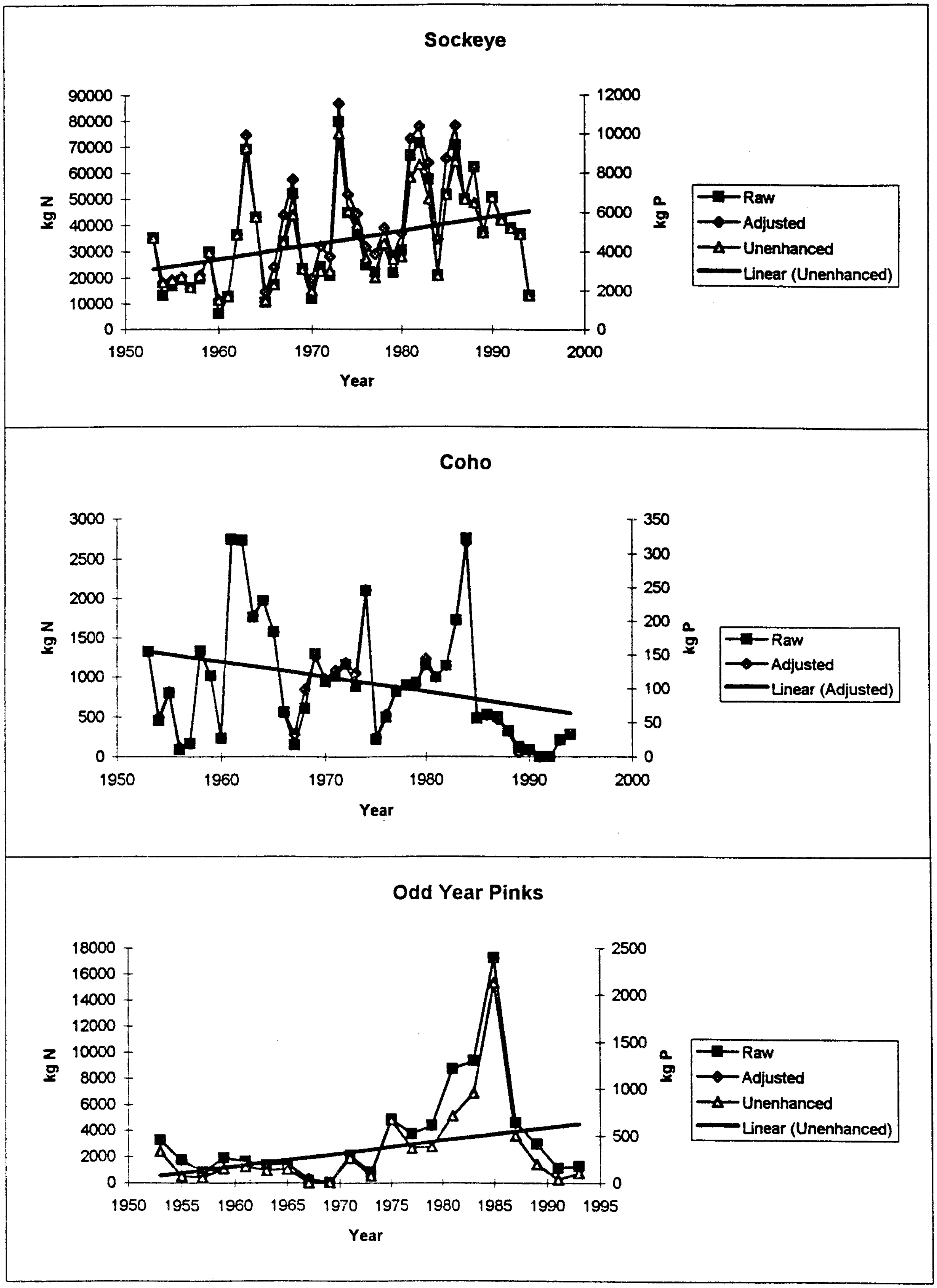


FIGURE 2a-2c Nutrient Influx to the Mainland Coast (Rivers Inlet and Smith Inlet) Region (a) Sockeye, (b) Coho, (c) Odd Year Pinks activity (Nekite River). There has been a significant increase in nutrient influx from even year pinks over the entire 42 years, but a decline in the most recent years.

Escapements from the Wannock, Chuckwalla, Clyak, Takush, Walkum and Nekite Rivers comprise the majority of the marine nutrient influx from chum and have good records for the entire 42 years. The Young, Niel and Draney Rivers have been important contributors in the past 10 years. The peak in 1982 was largely due to escapements from the Clyak and Wannock Rivers among others, and the peak in 1986 from the Nekite, Clyak and Young Rivers (Fig. 2e). Although the trendlines indicates relatively consistent escapements over the last 42 years, there were some increases through the late 70s and into the 80s, since which time there has been a rapid decline.

This region has low chinook escapements which peak at about 20,000 but are generally below 10,000. The Wannock River run dominates the nutrient influx but the Docee River run is also important. These two rivers have fairly complete records for the 42 years and thereby the trends should be reliable. The 1993 peak is a result of a strong Wannock River run. The raw and adjusted trends show an increase in nutrient influx from chinook to this region. However, removal of the dominant Wannock River run changes the trend to a slight decline (Fig. 2f).

The trend for all of the salmon species combined indicates an increase in the influx of marine derived nutrients to this region over the last 42 years (Fig. 2g). The trend from the unenhanced streams is not increasing as considerably, indicating that enhancement stocks augment the nutrient influx. There has been a striking decline in nutrient influx in the last 10 years, evident in many of the individual stocks (Figs. 2a , and 2e), and in the total nutrient influx trend.

Johnstone / Queen Charlotte Strait Region (Areas 11, 12, and 13)

The Johnstone / Queen Charlotte Strait Region stretches from Cape Caution south to Bute Inlet on the Mainland Coast, and from Cape Scott to Campbell River on the east side of Vancouver Island. One hundred and sixty-five streams are included in this region (Table 4).

Table 4. Breakdown of streams, Johnstone / Queen Charlotte Strait region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
165	Sockeye	37	20	17
	Coho	134	112	105
	Odd Year Pink	91	69	60
	Even Year Pink	105	81	72
	Chum	128	109	100
	Chinook	41	25	21

Nutrient influx from sockeye in this region is dominated by the Nimpkish River escapement, although runs from the Phillips River, Fulmore River, Quatse River and Mackenzie Sound Creek are also important in some years. Records for these streams are consistent over the 42 years. The peaks in the trend in 1988 and 1992 are due to the Nimpkish River run (Fig. 3a). The removal of the Nimpkish River

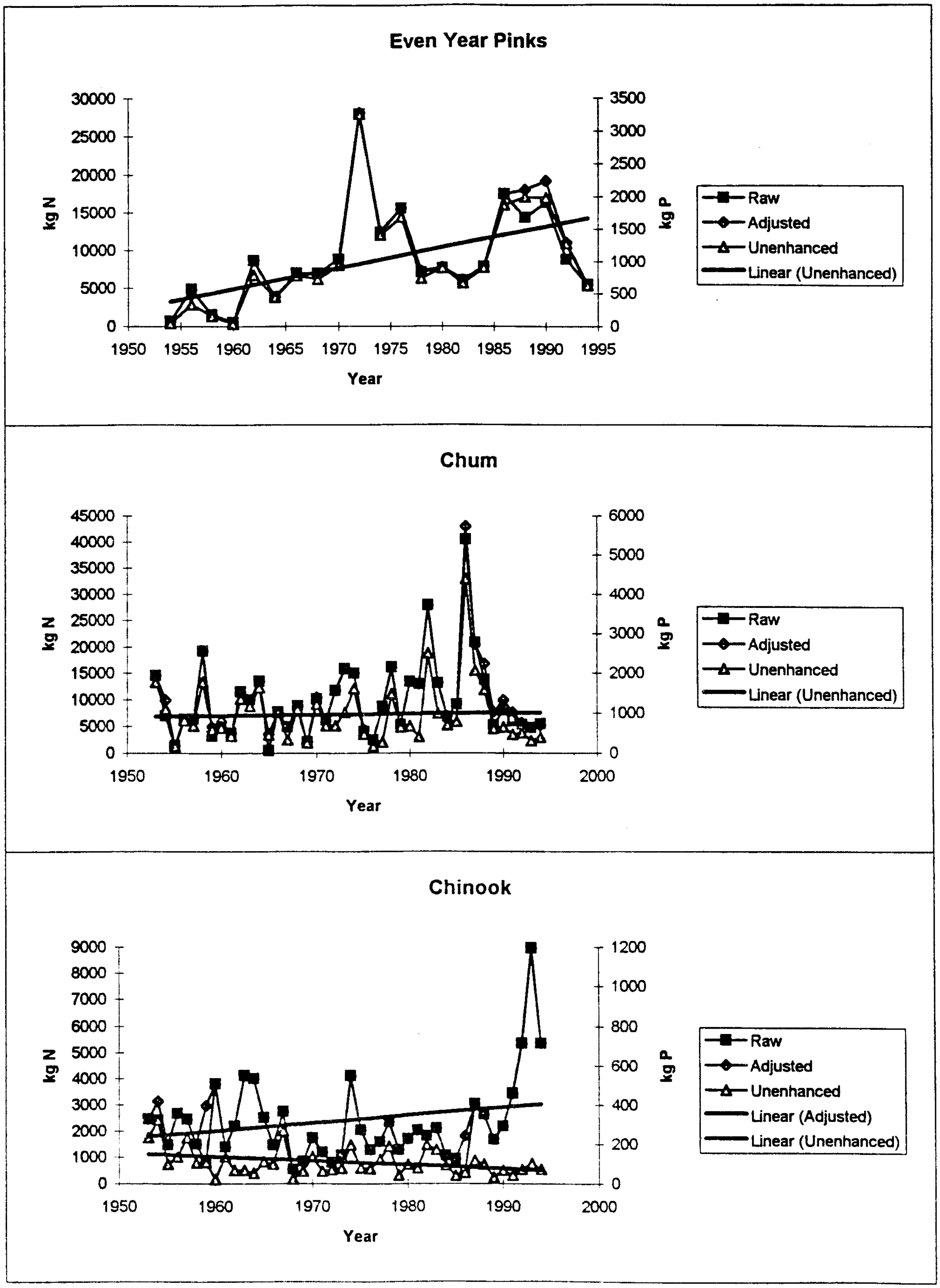


FIGURE 2d-2f Nutrient Influx to the Mainland Coast (Rivers Inlet and Smith Inlet) Region (d) Even Year Pinks, (e) Chum, (f) Chinook

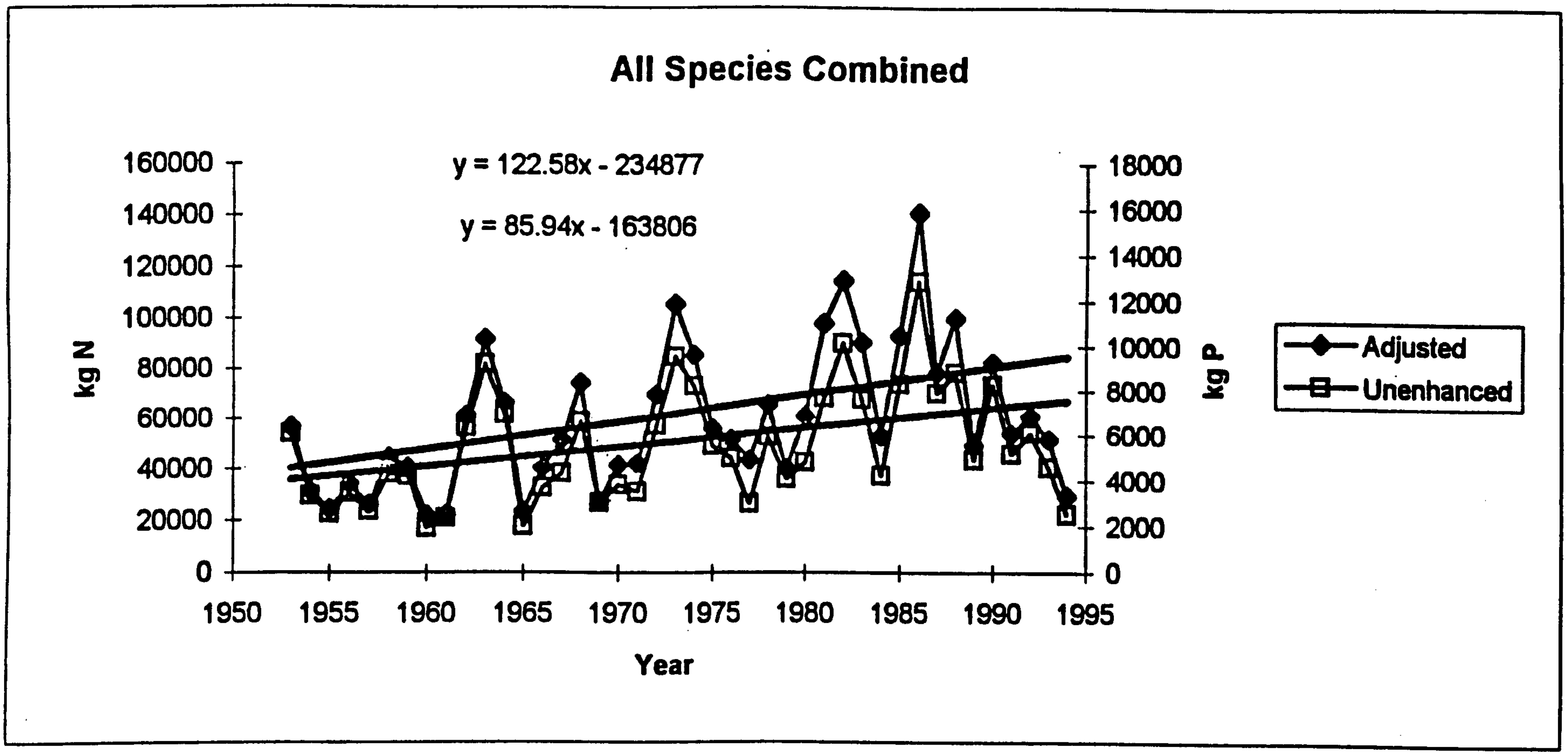


FIGURE 2g Nutrient Influx to the Mainland Coast (Rivers Inlet and Smith Inlet) Region
(g) All Species combined

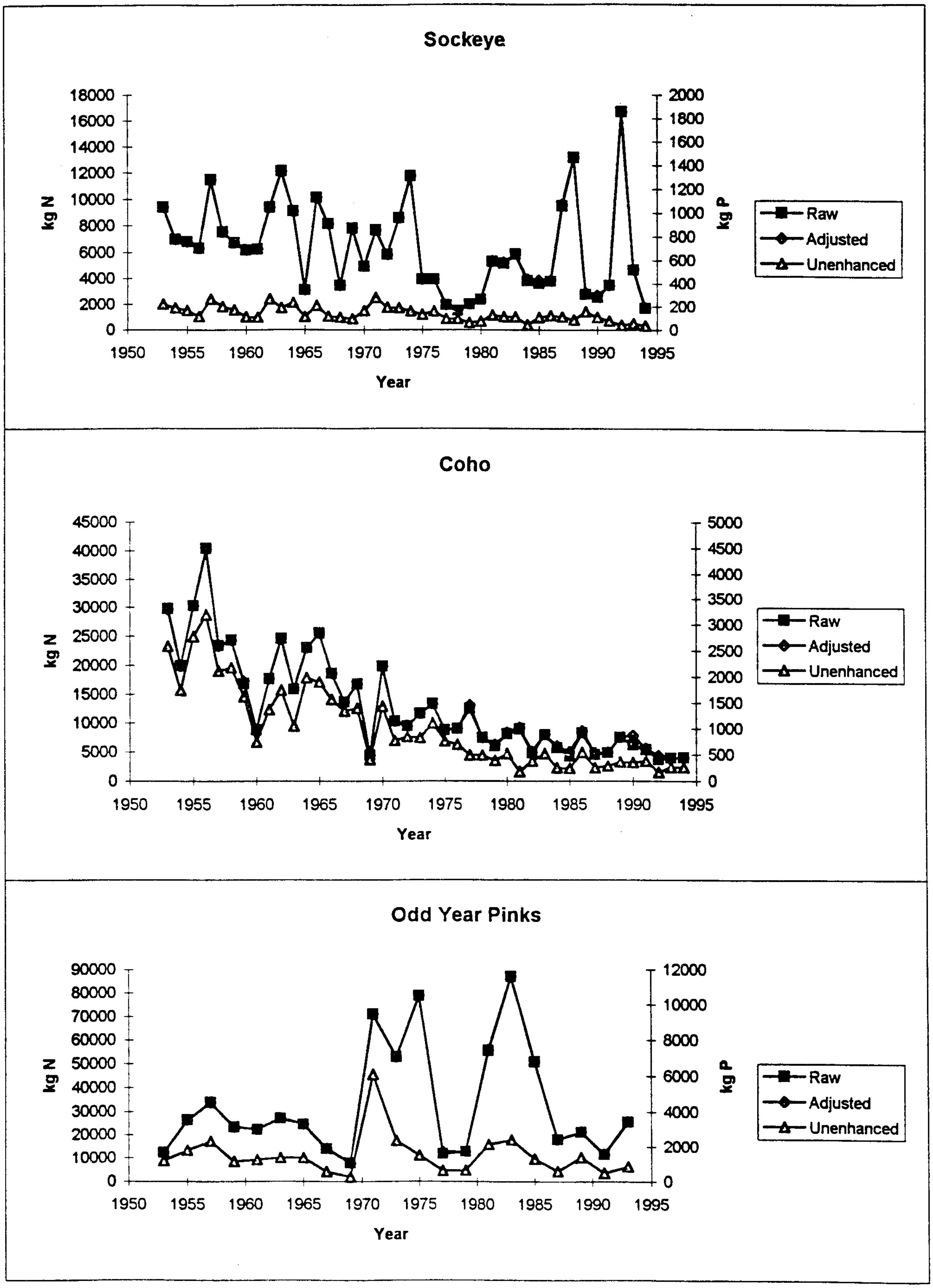


FIGURE 3a-3c Nutrient Influx to the Johnstone / Queen Charlotte Strait Region
(a) Sockeye, (b) Coho, (c) Odd Year Pinks

as one of the 2 enhanced streams illustrates its dominance of the raw and adjusted nutrient influx trends. The remaining streams show a small, but progressive decline in nutrient influx.

The nutrient influx from coho is derived in large part from several streams reporting small escapements, with 10 or 12 larger escapement streams having more complete records. The Quinsam River has been dominant in the past 10 years because of a large hatchery operation. The number of streams reporting dropped off in the 1970s and then again in the early 1980s. Most streams no longer monitored had low escapements for the years previous or had stocks that appeared to have crashed. Removal of enhancement streams does not significantly change the distinct downward trend in nutrient influx from coho over the last 40 years (Fig. 3b).

Nutrient influx from odd year pink escapements is evenly distributed among 10 to 15 strong runs with good records. The 1971 to 1975 peaks in the trend are well spread throughout these large escapement streams, but the 1981 peak was primarily due to the Kakweiken River (Fig 3c). Recent lower nutrient influx is due to smaller than normal returns to the major escapements and decreasing spawner counts and reporting in smaller escapement streams. The removal of escapements from enhanced streams produces a somewhat more consistent trend over the last 42 years. The peak in 1971 is still evident since it is well spread throughout many individual escapements.

Even year pink escapement in this region is largely made up from escapements from 15 or more large run streams with good records. Peaks and troughs in the nutrient influx trend are found in a majority of stream records. All three trends show an increase in marine nutrient influx (Fig. 3d).

Nutrient influx from chum is dominated by large runs from the Nimpkish River, Ahnuhati River, Hydon Creek, and notably the Orford and Southgate Rivers. The record for chum is quite complete for streams with both large and mid-size runs and should produce a reliable trend. A pattern on a four year cycle can be seen from the late 70s to late 80s. The removal of enhanced streams has little impact on the trends, likely due to the large number of reporting streams. Over the last 42 years there has been a very modest increase in nutrient influx (Fig. 3e).

The Campbell, Salmon, Phillips, Homathco, Kingcome, Wakeman, Nimpkish and Kliniklini Rivers have large chinook escapements and good records, and therefore dictate the nutrient influx trend (Fig. 3f). The peaks and troughs in the trend are found in records from small and large escapement streams alike. Both the adjusted and unenhanced nutrient influx trends show a clear decline over the last 40 years. Note the small number of streams that report chinook escapements (Table 4).

When all species are combined, the nutrient influx trend from unenhanced stocks is one of gradual decline (Fig. 3g). Enhancement stocks are contributing nutrients to such an extent that when they are included (adjusted data), nutrient influx to the region appears to be on the increase. The large even year pink escapements are responsible for the undulations in the total nutrient influx record for the last 10 years.

Georgia Strait Region (Areas 14, 15, 16, 17, 18, and 19)

The Georgia Strait Region extends from approximately Campbell River to Victoria on Vancouver Island, and from Bute Inlet to Sechelt Inlet on the Mainland Coast. One hundred and forty-nine streams are included in this region (Table 5).

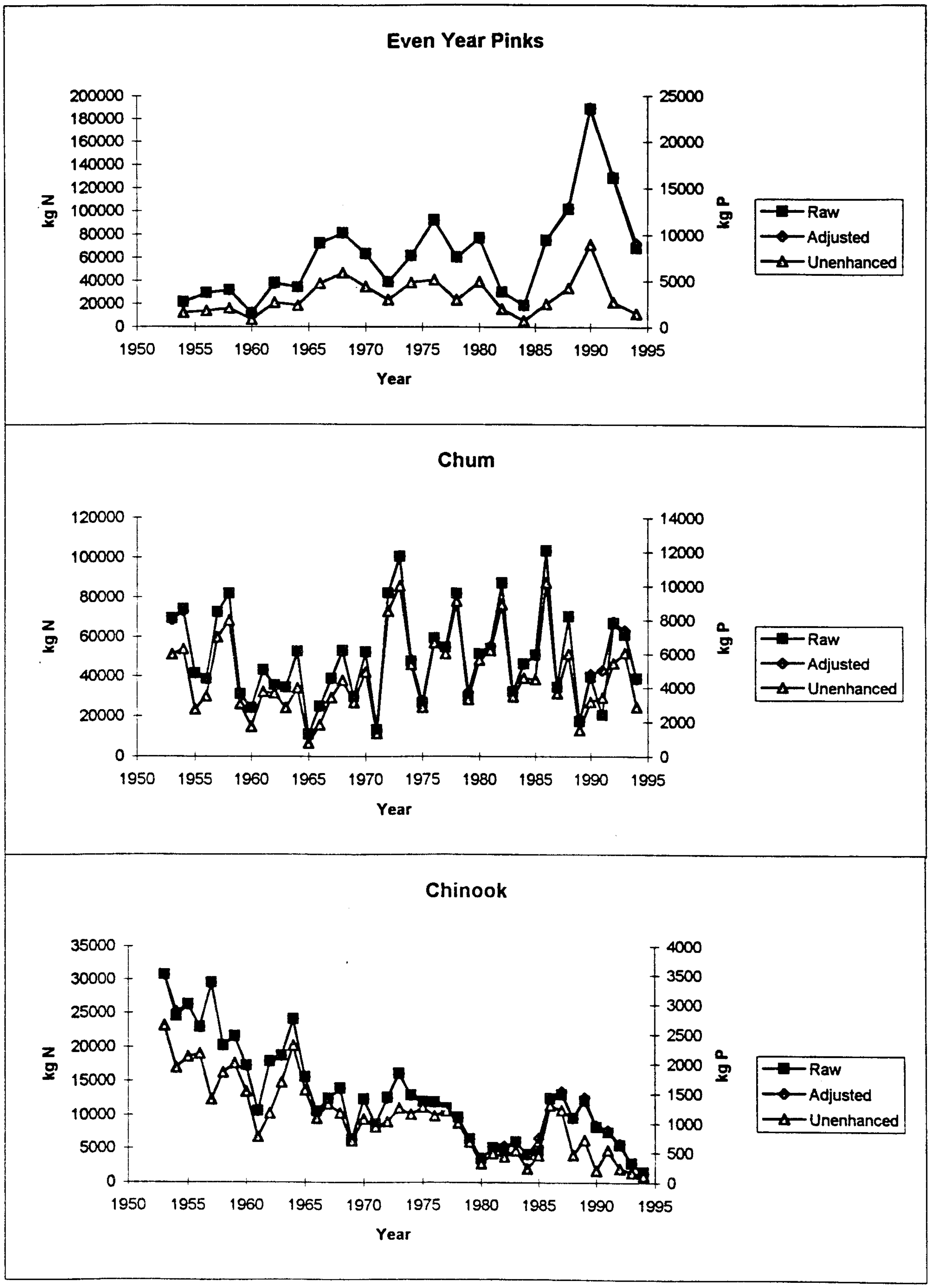


FIGURE 3d-3f Nutrient Influx to the Johnstone / Queen Charlotte Strait Region
(d) Even Year Pinks, (e) Chum, (f) Chinook

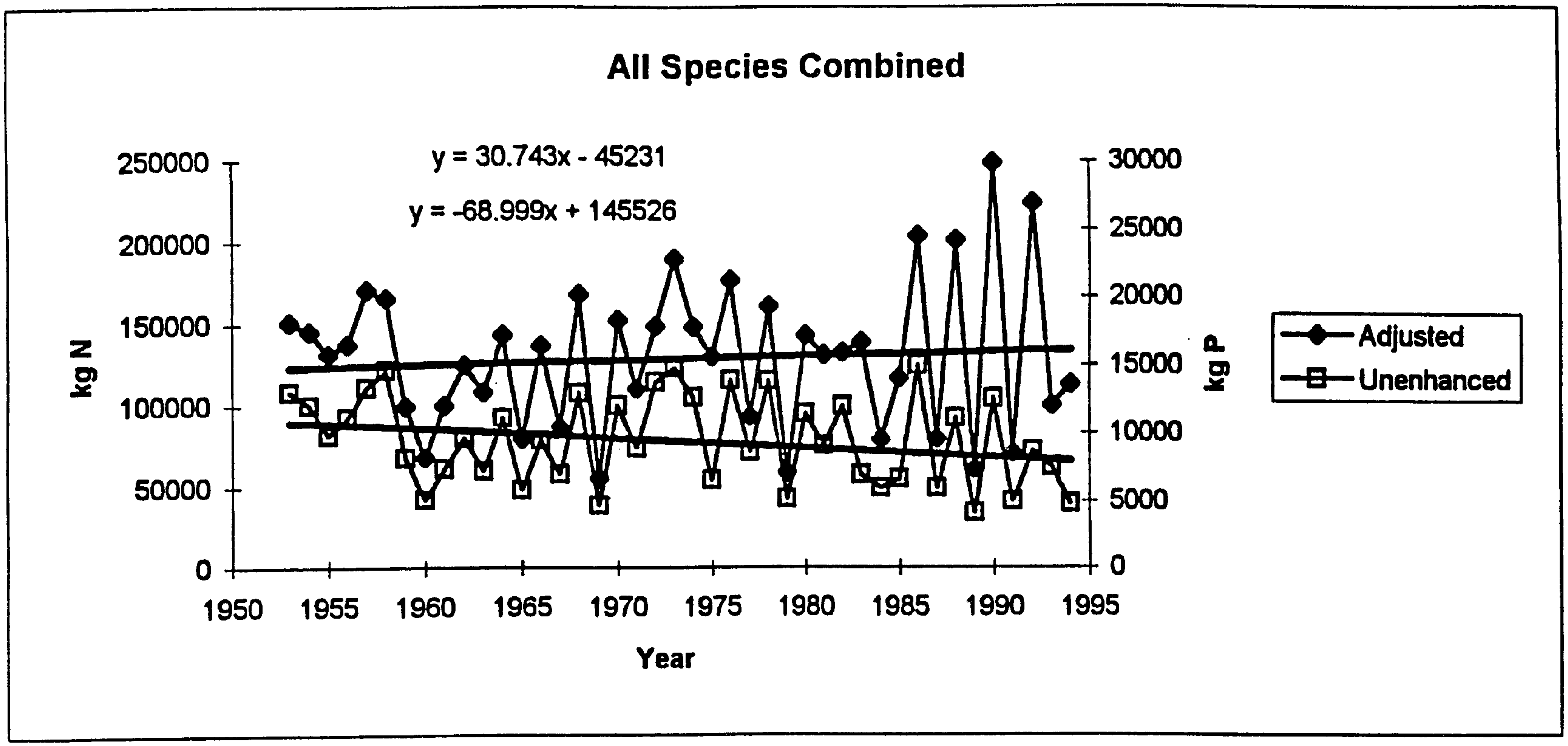


FIGURE 3g Nutrient Influx to the Johnstone / Queen Charlotte Strait Region
(g) All Species combined

Table 5. Breakdown of streams, Georgia Strait region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
149	Sockeye	17	8	8
	Coho	125	105	84
	Odd Year Pink	91	34	26
	Even Year Pink	105	21	13
	Chum	120	104	85
	Chinook	31	16	8

The nutrient influx from sockeye in this region is extremely dominated by escapements from Sakinaw Lake. The Tzoonie River run was also important until its record ends in 1969. Note that only 17 streams reported sockeye escapements, 8 of which make up the adjusted data (Fig. 4a). A four year cyclic trend can be seen through most of the 42 years. There are no enhancement programs for sockeye stocks in this region. A decline in nutrient influx is evident.

The coho record is complete until the most recent few years. There are several large runs, the largest being the Cowichan, that make up the majority of the total escapement for the region and formulate the nutrient influx trend. These large escapement streams have good data records and should produce a reliable trend. There has been a substantial decline in nutrient influx, particularly in the last 20 years, evident in the adjusted data, as well as in the streams with no enhancement (Fig. 4b).

Several streams, including the Puntledge, Oyster, Tsable, Vancouver and Skwawka Rivers, have large runs which could influence the odd year pink nutrient influx. The Toba and Klite River runs were also important until the mid 80s when their records end. The high influx in the earlier years is due to the Skwawka River; its escapements level off and remain more constant since 1965 (Fig. 4c). Recent fluctuations in the raw and adjusted trends are due to the enhancement efforts on the Puntledge River. Even neglecting the early dominance of the Skwawka River, there has been a decline in nutrient influx over the last 40 years.

The Oyster, Puntledge and Tsolum River runs equally dominate the even year pink nutrient influx, and have quite complete records. The high influx in the 1950s as well as the 1990 peak (enhancement activity) are due to the Oyster River run (Fig. 4d). The even year pink escapement in this region is so dominated by streams with enhancement activity that the nutrient influx drops to near zero when they are removed.

Over 100 streams make up the adjusted data for chum stocks in this region. The Puntledge, Qualicum, Little Qualicum, Nanaimo and Cowichan Rivers have large runs, and there are several streams with mid-size runs. Although observations on small run streams decline in the late 1980s, the large run streams and the majority of the mid-size run streams have good records and as a result the nutrient influx trend should be quite reliable (Fig. 4e). There appears to be a consistent increase in chum spawners over the past 30 years from the adjusted data. However, after removing enhancement influence, the remaining streams show a modest decline in marine nutrient influx.

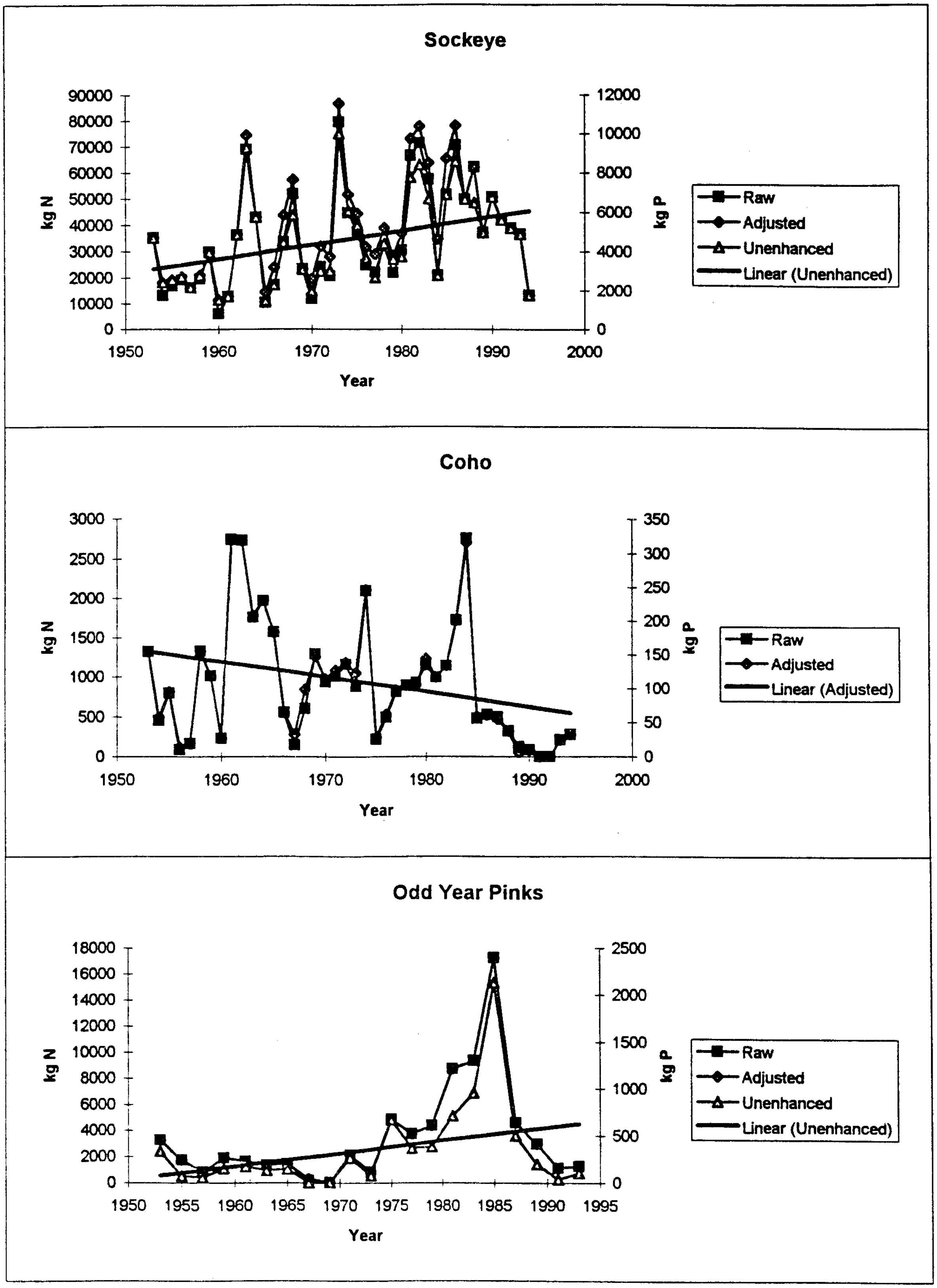


FIGURE 4a-4c Nutrient Influx to the Georgia Strait Region
(a) Sockeye, (b) Coho, (c) Odd Year Pinks

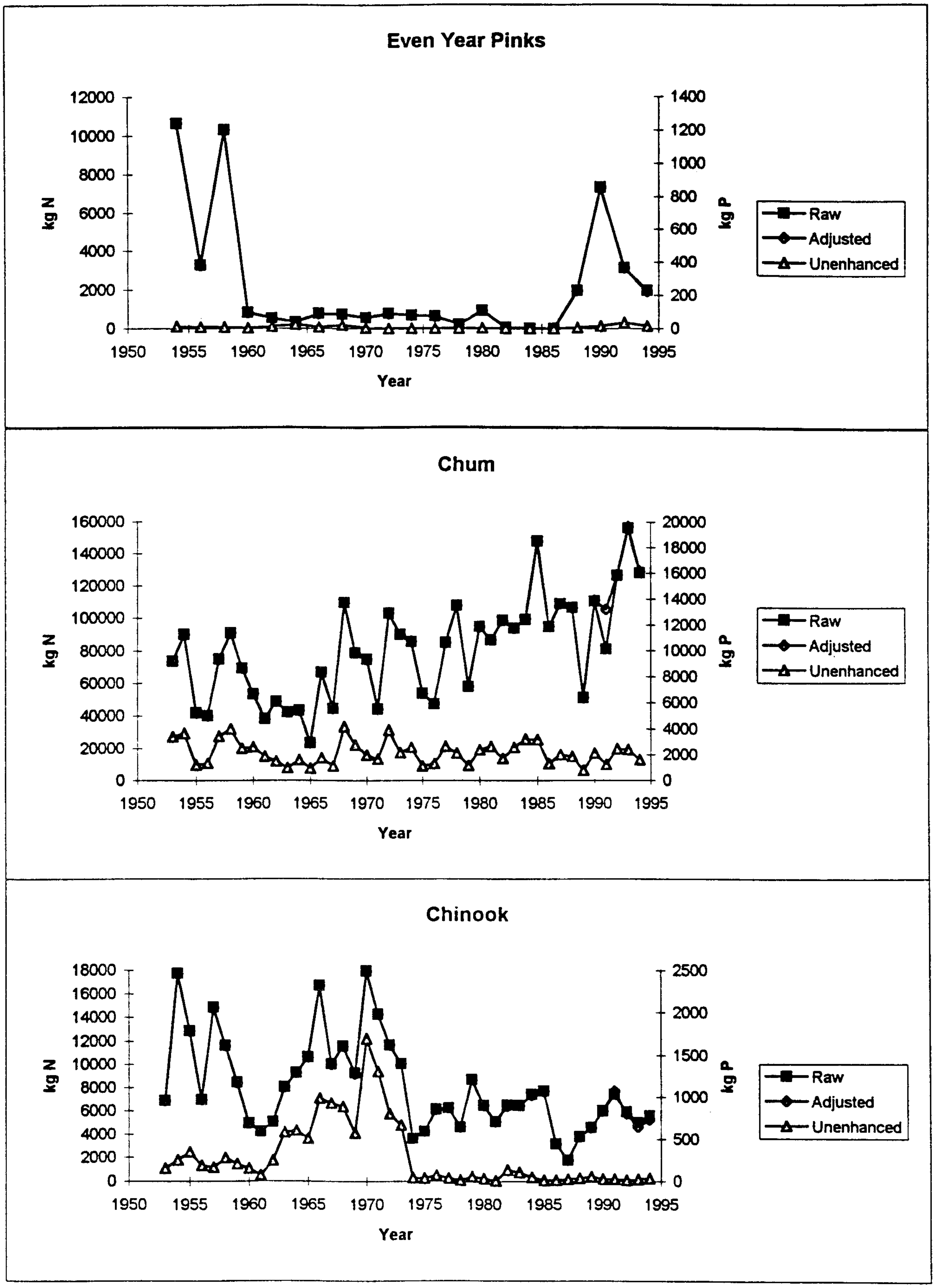


FIGURE 4d-4f Nutrient Influx to the Georgia Strait Region
(d) Even Year Pinks, (e) Chum, (f) Chinook

Nutrient influx from chinook is dominated by the Cowichan River run which has the largest and most consistent escapement in the region. Runs from the Puntledge, Qualicum, Little Qualicum, and Koksilah Rivers are also significant in some years. These runs have fairly complete records while those for other streams in the region are extremely 'patchy'. Several mid sized runs were no longer regularly observed after 1974, a drop that can be seen in the nutrient influx trend (particularly for the unenhanced streams data which drops to near zero) (Fig. 4f). The decline in nutrient influx since the mid 70s is likely at least in part due to fewer streams reporting. Note that only 31 streams reported chinook escapements, 16 of which make up the adjusted data. This accuracy of this nutrient influx trend is in question due to the inconsistent reporting of escapements.

When all species are combined, the nutrient influx trend from the adjusted data shows a considerable increase in nutrient influx over the last 42 years (Fig. 4g). However, nutrient influx to unenhanced streams has been in decline. Enhanced stocks have been responsible for so much of the nutrient influx that the trendlines significantly diverge. Total nutrient influx to the region is dominated by huge chum escapements overwhelming the contributions of other species.

Lower Fraser River / Howe Sound Region (Areas 28A, B, 29B, C, D, and E)

The Lower Fraser River / Howe Sound Region includes Howe Sound, Burrard Inlet and tributaries of the Fraser River that join the mainstem west of Hell's Gate. Two hundred and forty-nine streams are included in this region (Table 6). Note that there was no reporting for any species in this region for 1994, so all 1994 escapements are based on data from previous years.

Table 6. Breakdown of streams, Lower Fraser River / Howe Sound region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
249	Sockeye	75	28	23
	Coho	225	171	136
	Odd Year Pink	104	57	47
	Even Year Pink	14	2	2
	Chum	174	113	84
	Chinook	53	29	21

The Birkenhead River run dominates the sockeye escapement and thereby nutrient influx to this region, with runs from Pitt River, Harrison River, Sweltzer River and Weaver Creek also significant. Weaver Creek (spawning channel) was largely responsible for the peaks in 1982 and 1986. The records for all of these major contributors are relatively complete and the trend of gradual increase in nutrient influx from the adjusted data is likely accurate. Nutrient influx drops to near zero after removal of the enhanced streams (Fig. 5a).

The Seymour, Birkenhead, Cheakamus, Campbell, Pitt, Norrish, Chehalis and Chilliwack Rivers all have significant runs which contribute to the nutrient influx from coho to this region. The Squamish River run was also significant until 1990 when observations stopped. Most peaks in the nutrient influx

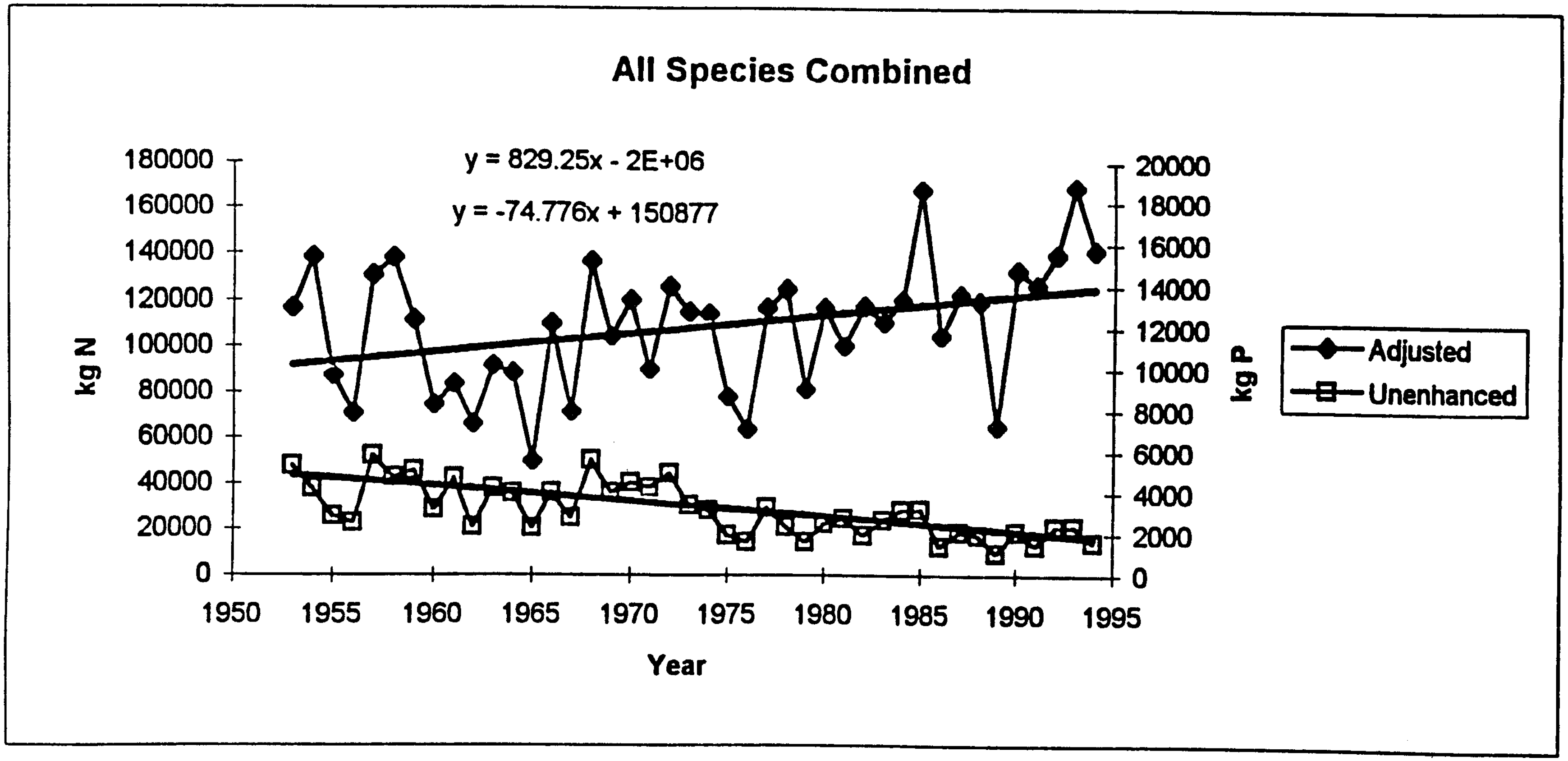


FIGURE 4g Nutrient Influx to the Georgia Strait Region
(g) All Species Combined

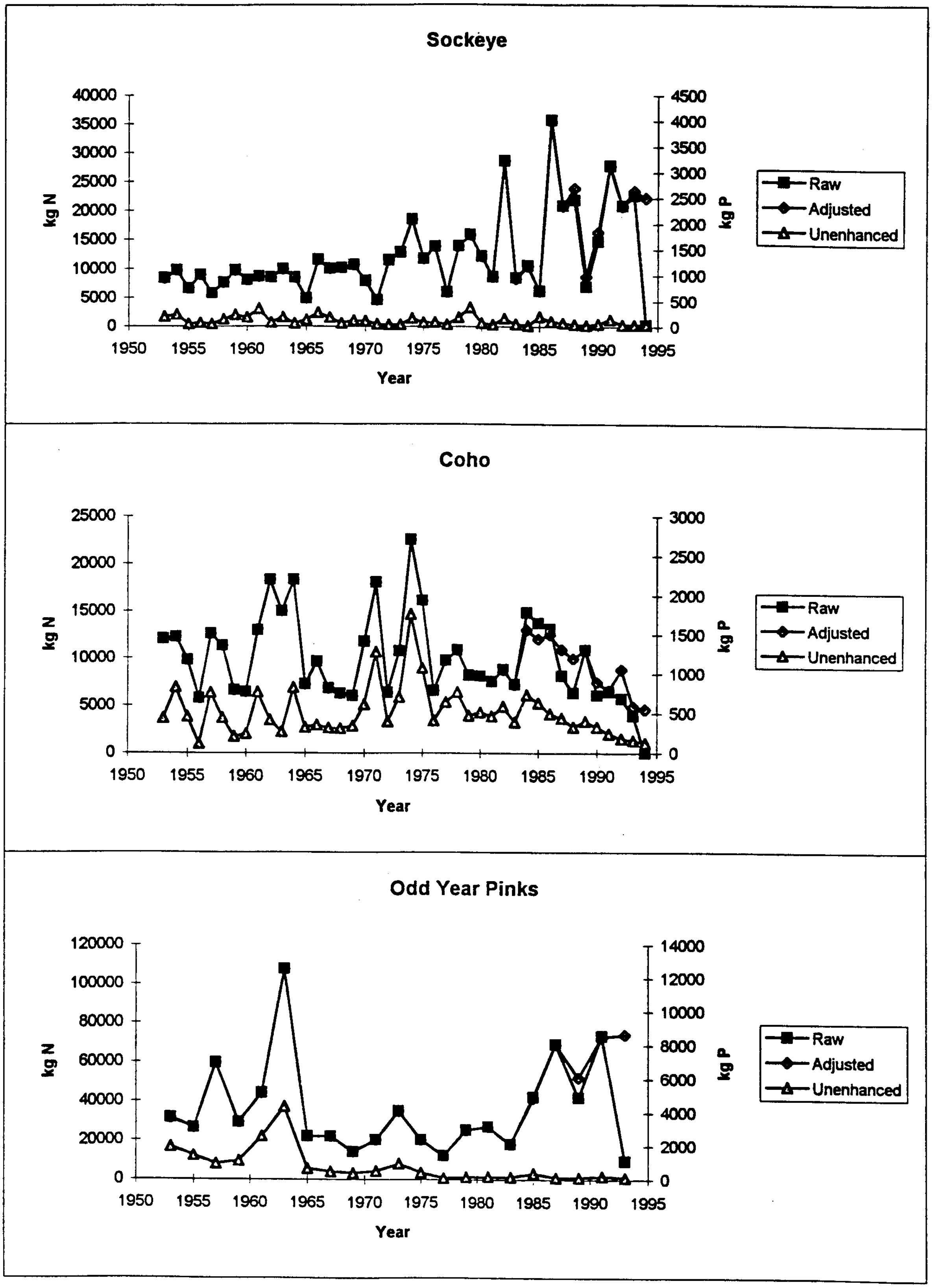


FIGURE 5a-5c Nutrient Influx to the Lower Fraser River / Howe Sound Region
(a) Sockeye, (b) Coho, (c) Odd Year Pinks

trend seem to be well spread throughout the many contributing streams. The adjusted and unenhanced nutrient influx trends are of moderate decline, particularly in the last 10 years (Fig. 5b).

Nutrient influx from odd year pinks is dominated by the Harrison River run. Runs from the Indian, Mamquam, Chilliwack, Sweltzer and Coquihalla River are also significant, as was the Cheakamus River until the mid 60s when escapement plummeted. The record for these large contributors is quite complete and should produce a fairly reliable trend. The nutrient influx trend produced from the raw and adjusted data varies significantly from year to year. This variation is likely due to the intensity of enhancement activity since the trend produced from unenhanced stream data is much more consistent. Nutrient influx in the unenhanced streams has been declining over the last 30 years of the record (Fig. 5c). Even year pinks are not considered for this region due to low escapement numbers and few observations (only 2 streams).

The Stave, Harrison and Chilliwack Rivers have the largest chum runs and dictate the nutrient influx trend. Other important runs are from the Indian, Squamish, Cheakamus, Mamquam, Alouette, Chehalis and Squawkum Rivers, and Inch Creek. The Lillooet River also had a significant run since 1982, but its record does not cover the years prior. The 1985 peak is well spread through the majority of the escapements. The record is relatively complete for all of these large run streams and the resulting upward trend (from adjusted and unenhanced stream data) should be an accurate reflection of nutrient status (Fig. 5d).

The Squamish River was a major influence in nutrient influx from chinook from the 1950s to 1970s, but counts have severely dropped off in the last 15 years. The Harrison River was also an important contributor until 1986 when its record ends. The Chilliwack River run picks up when the Harrison River data ends, so no sharp drop is seen in the nutrient influx trend (Fig. 5e). The 1985 peak is caused by the Harrison River. The accuracy of the trend (decline in both the adjusted and unenhanced stream data) is questionable because many of the important runs have incomplete records.

The nutrient influx trend from the adjusted data for all species combined shows a considerable increase in nutrient influx over the last 42 years (Fig. 5f). However, nutrient influx to unenhanced streams has been relatively constant, which implies that all of the increase in nutrient influx is due to enhancement activity and concentrated to enhanced streams. Total nutrient influx to the region is dominated by huge chum escapements overwhelming the contributions of other species.

West Coast of Vancouver Island, South Region (Areas 20, 21, and 22)

The West Coast of Vancouver Island, South Region, extends from approximately Nitinat Lake south to Victoria. Thirty-four streams are included in this region (Table 7).

Table 7. Breakdown of streams, West Coast of Vancouver Island, South region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
34	Sockeye	8	5	3
	Coho	29	21	18
	Odd Year Pink	3	2	1
	Even Year Pink	4	4	3
	Chum	23	19	16
	Chinook	12	6	4

Even Year Pinks are not considered for this region

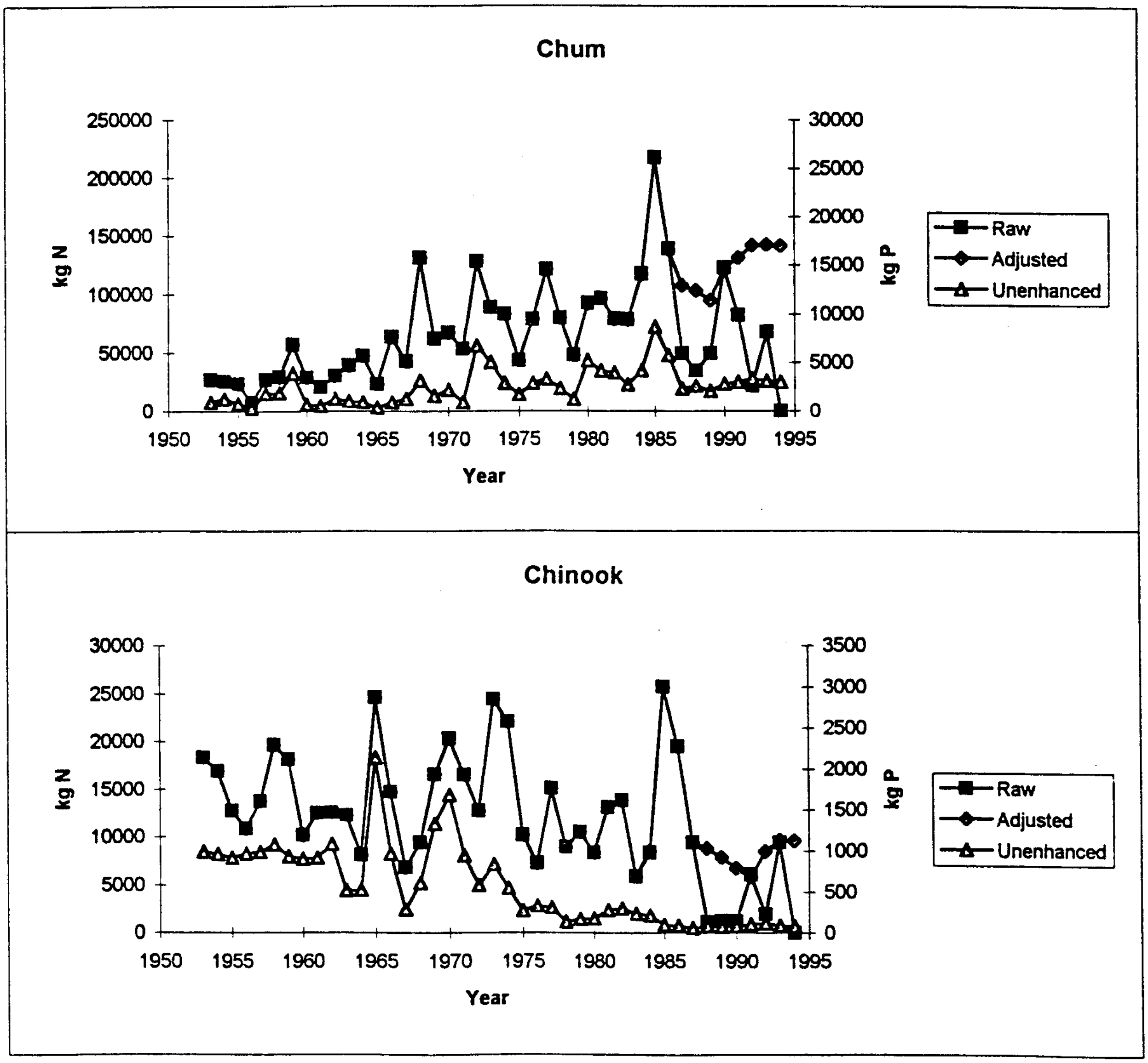


FIGURE 5d-5e Nutrient Influx to the Lower Fraser River / Howe Sound Region
(d) Chum, (e) Chinook

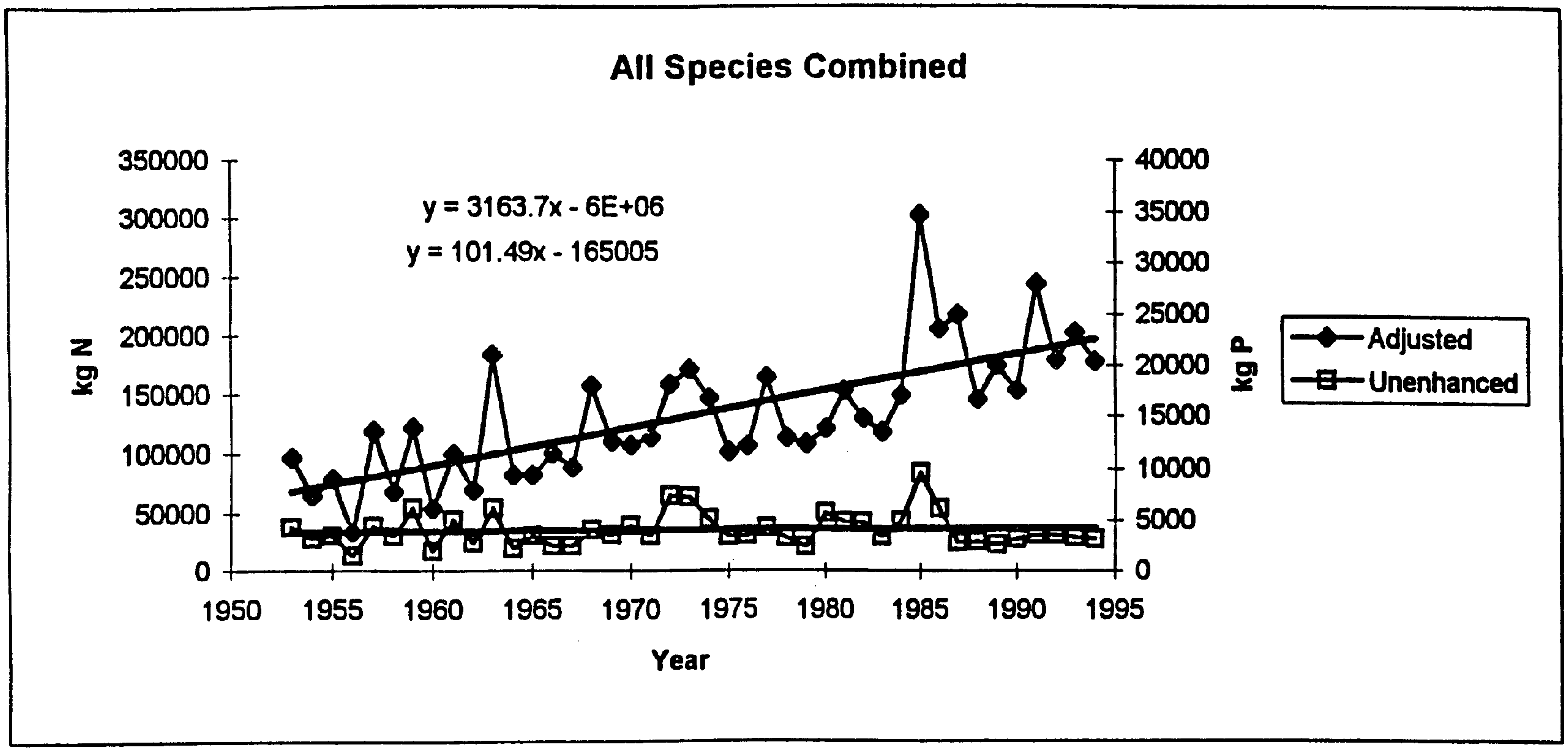


FIGURE 5f Nutrient Influx to the Lower Fraser River / Howe Sound Region
(f) All species combined

Hobiton Lake dominates the sockeye escapement and therefore nutrient influx to this region, but the Cheewhat River run is also important in some years. Both have good records so the trend should be an accurate indicator of nutrient status. The 1982 peak in the trend is due to the Hobiton Lake escapement (Fig. 6a). Without escapements from the enhanced streams (Hobiton Lake, San Juan River), the nutrient influx drops to near zero.

The San Juan River run dominates the nutrient influx from coho, but the run from the Nitinat River is also significant. Peaks in 1964 and 1970 are due to the San Juan River (Fig. 6b). The trough in 1985 is due to a depressed year for the San Juan River and many other streams reporting ‘none observed’. The trend of the adjusted data is a gradual decline, and without the escapements from enhanced, nutrient influx drops to near zero.

Odd year pinks are not considered for this region due to very low escapement numbers and few observations (4 streams total). Similarly, even year pinks are not considered for this region due to an extremely patchy escapement record (especially since 1966) and few observations (4 streams total).

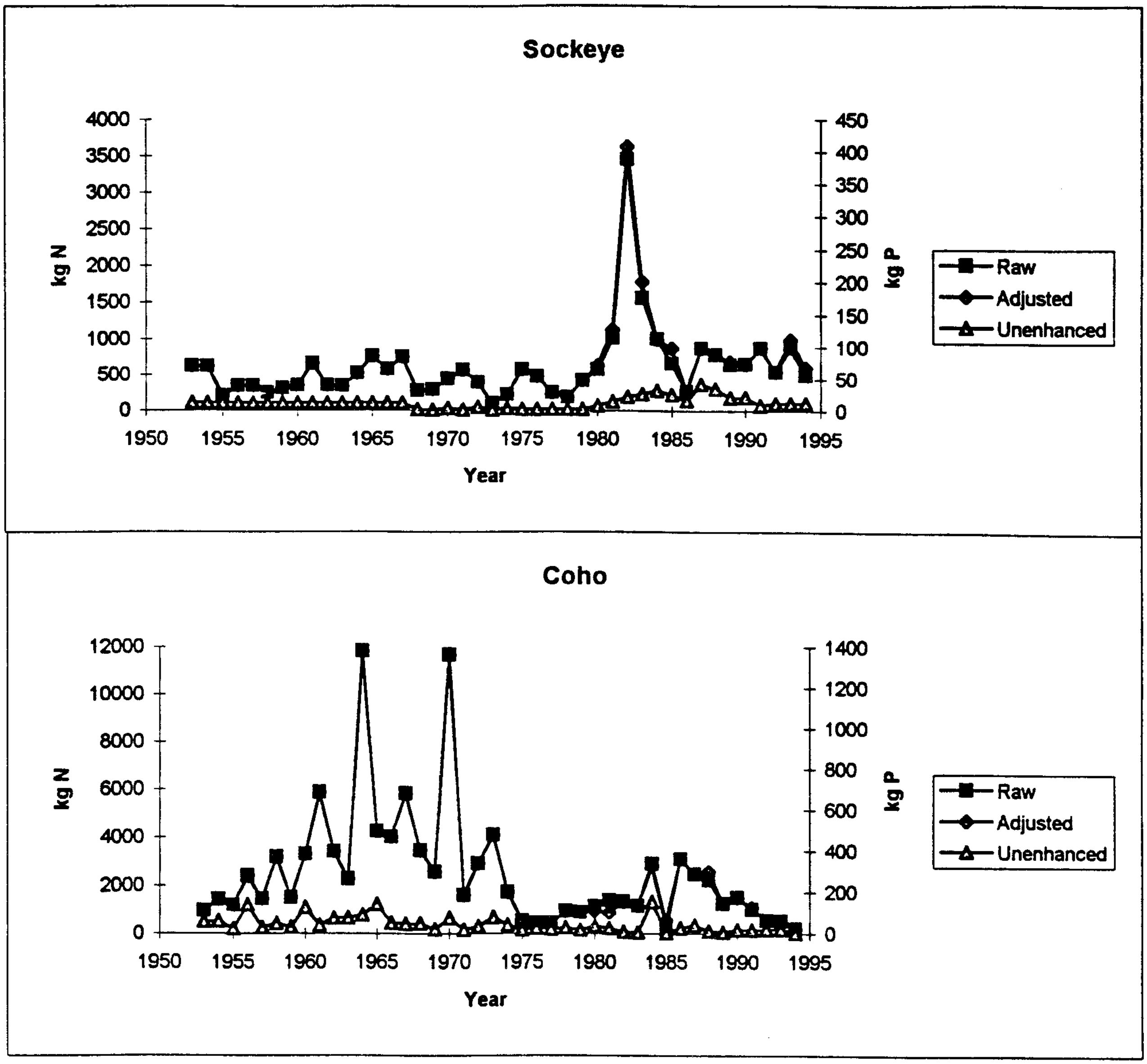
Nutrient influx to this region from chum is dominated by the Nitinat River escapement. Runs from the Sooke River, De Mamiel Creek and Hobiton Lake are also significant. Escapement records are fairly complete, even for smaller run streams, and should be produce an accurate nutrient influx trend (Fig. 6c). Peaks in 1972, 1988 and 1991 are due to the influence of the Nitinat and Sooke Rivers. Low influx in the late 70s is due to low run years in the Nitinat River. The trough in 1990 in the raw data trend is due to no observation (unknown) in the Nitinat River and several of the smaller run streams. The overall trend from the adjusted data is of significant increase in nutrient influx. The removal of the two enhanced streams (Nitinat and San Juan Rivers) reduces influx dramatically.

The Nitinat, San Juan, Gordon and Sooke Rivers have the largest chinook runs; the Nitinat has been dominant for the last 20 years. Escapement numbers are low (generally below 15,000 until recent years). Recent fluctuations in the raw and adjusted data nutrient influx trends are due to enhancement activity on the Nitinat River. The adjusted data shows a trend of increasing influx, but after removal of the Nitinat and San Juan Rivers (enhanced), escapements and nutrient influx are low (Fig. 6d).

The nutrient influx trend from the adjusted data for all species combined shows a considerable increase in nutrient influx over the last 42 years (Fig. 6e). Nutrient influx to unenhanced streams has been much more constant and in mild decline, implicating that all of the increase in nutrient influx is due to enhancement activity. Total nutrient influx to the region is dominated by huge chum escapements overwhelming the contributions of other species.

West Coast of Vancouver Island, Mid-Region (Areas 23, and 24)

The West Coast of Vancouver Island, Mid-Region, extends from Estevan Point (south end of Nootka Sound) south to Nitinat Lake. One hundred and four streams are included in this region (Table 8).



Odd Year Pinks are not considered for this region

FIGURE 6a-6b Nutrient Influx to the West Coast of Vancouver Island, South Region
(a) Sockeye, (b) Coho

Even Year Pinks are not considered for this region

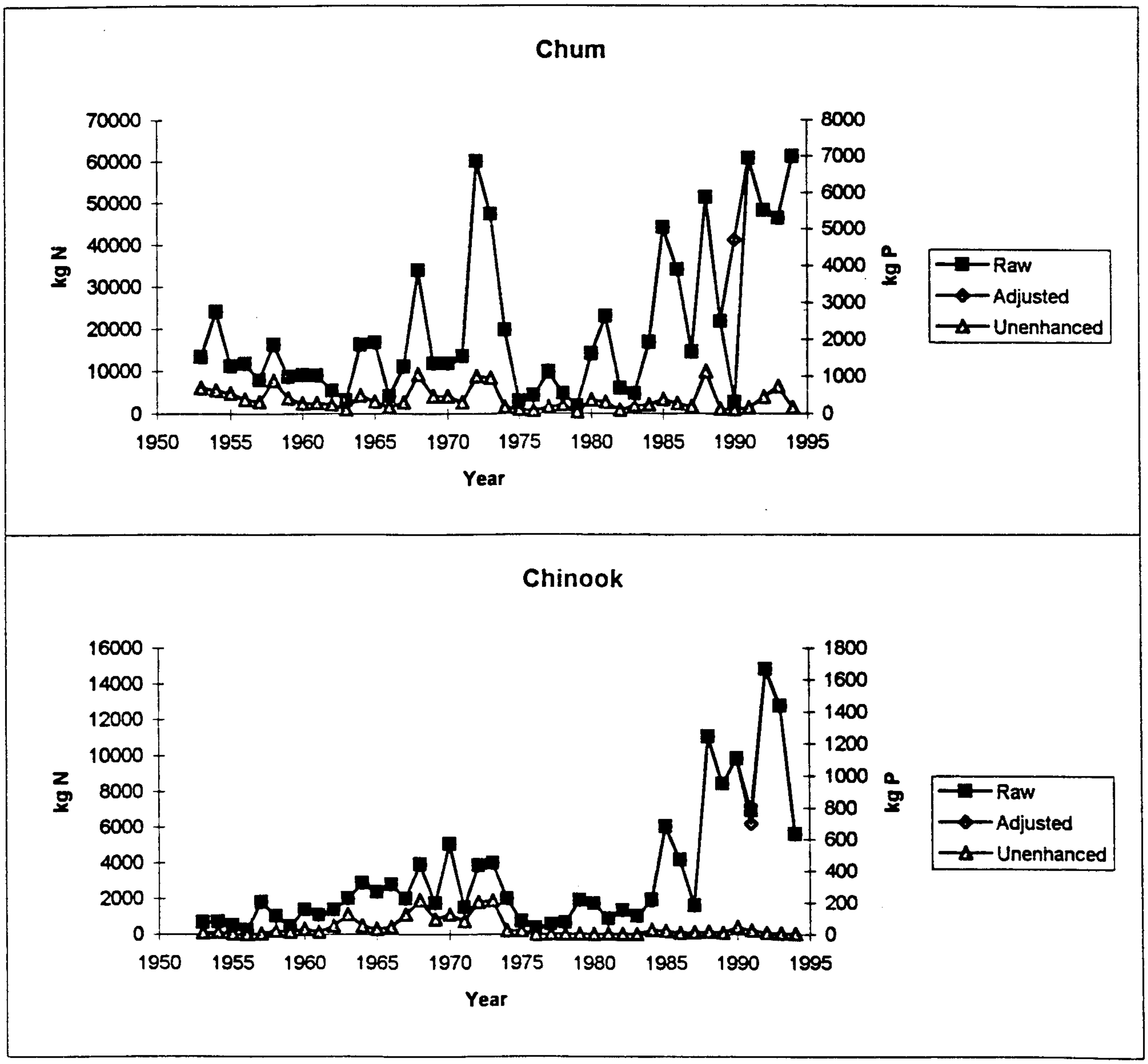


FIGURE 6c-6d Nutrient Influx to the West Coast of Vancouver Island, South Region
(c) Chum, (d) Chinook

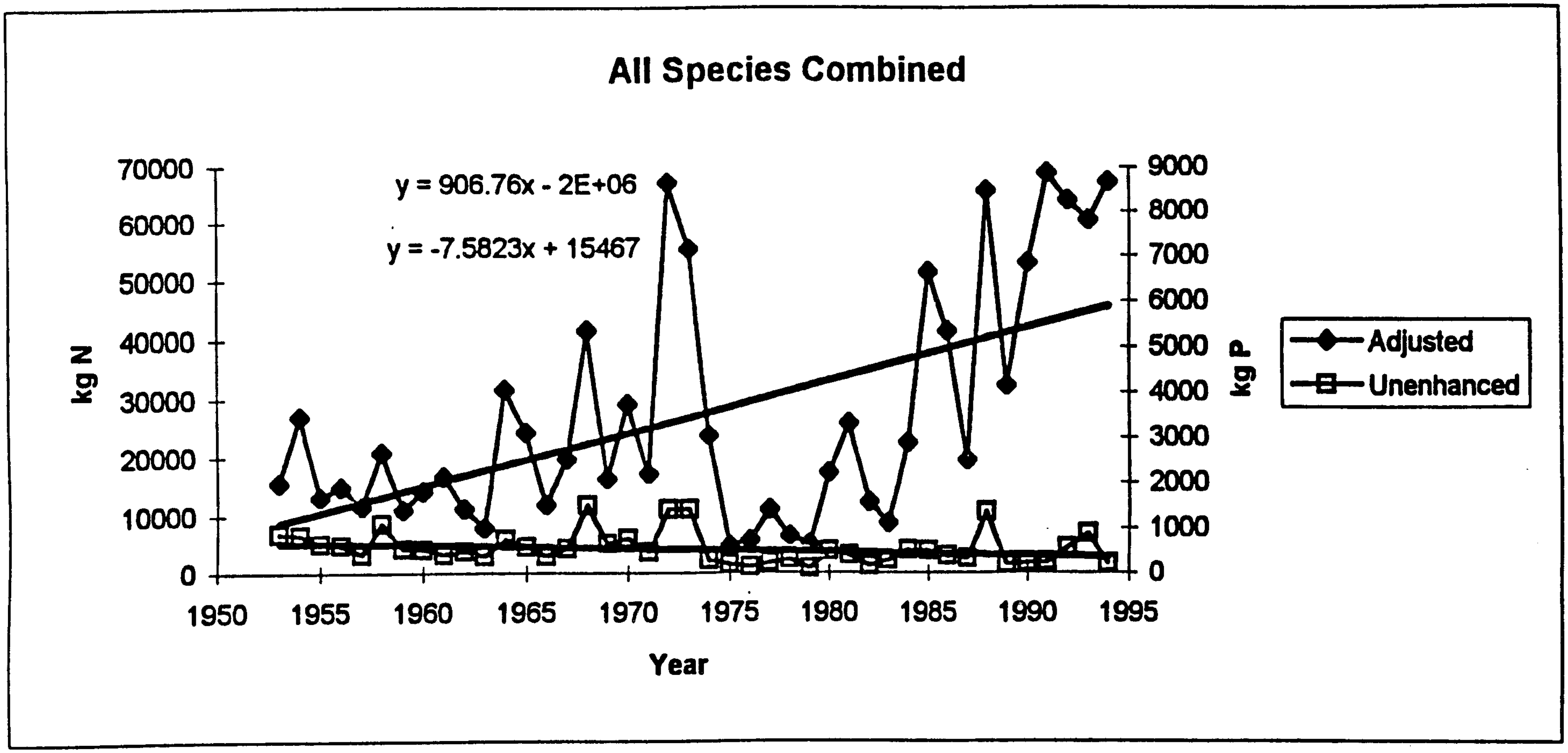


FIGURE 6e Nutrient Influx to the West Coast of Vancouver Island, South Region
(e) All species combined

Table 8. Breakdown of streams, West Coast of Vancouver Island, Mid-region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
104	Sockeye	43	21	15
	Coho	79	64	60
	Odd Year Pink	17	5	5
	Even Year Pink	22	14	14
	Chum	81	72	71
	Chinook	42	23	21

Nutrient influx from sockeye in this region is dominated by the Somass River run. Runs from Henderson Lake, Kennedy Lake, Kennedy River and Clayoquat Arm Beaches are also significant; records are good for these larger run streams. Fluctuations in the adjusted data nutrient trend over the last 15 or so years are related to the influence of the Somass River run, but overall, there has been a continuing increase in nutrient influx (Fig. 7a). The removal of the lakes and their systems that have been part of the SEP lake fertilization program reduces nutrient influx to near zero.

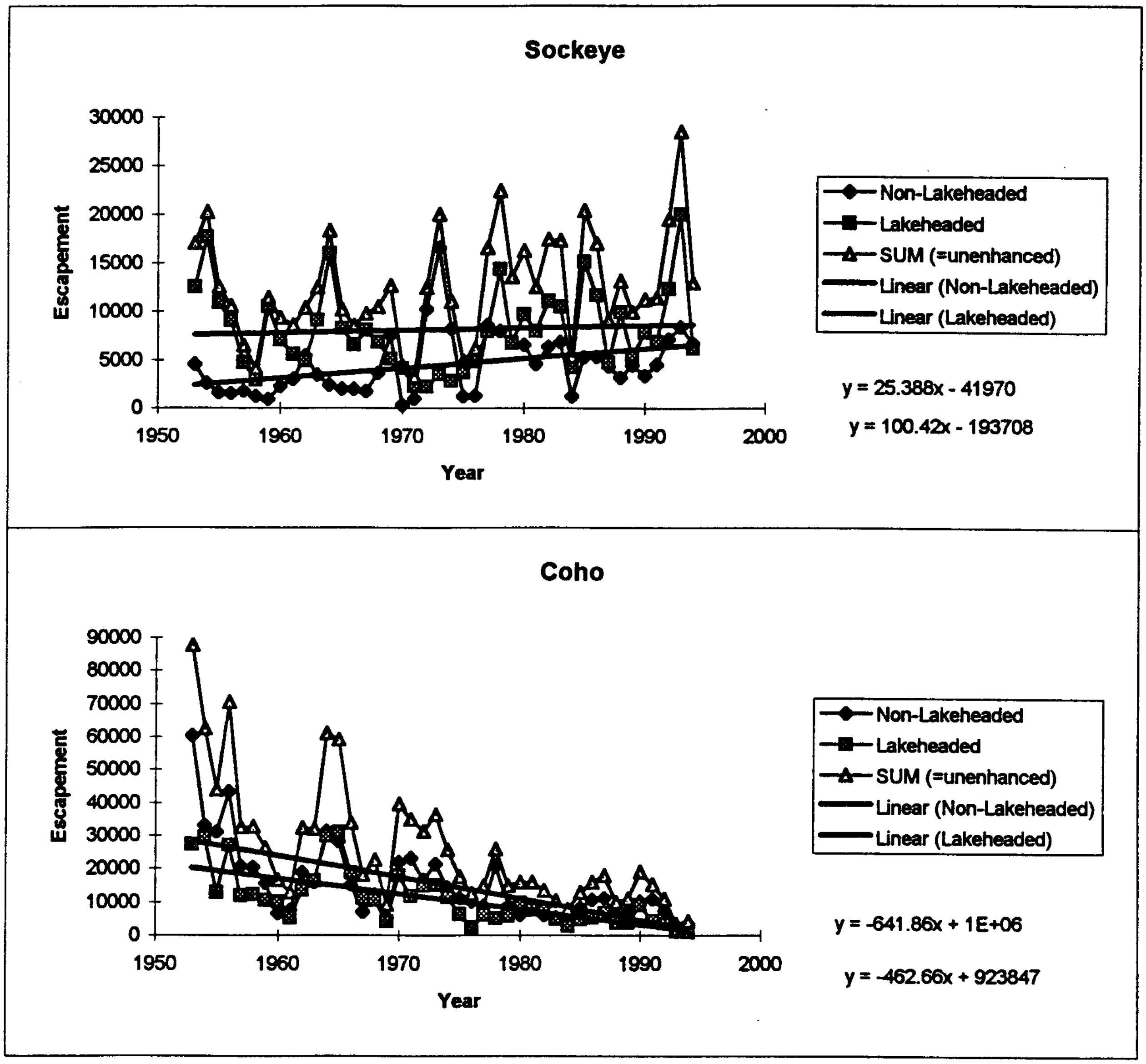
The coho escapement record for this entire region is extremely inconsistent, even for the dominant Somass River run (missing 1980 - 1990). The trends from the adjusted and unenhanced stream data show almost parallel declines in nutrient influx. However, it is uncertain if these trends are an accurate reflection of the nutrient status due to the poor data record (Fig. 7b).

Odd year pinks are not considered for this region due to very low escapement numbers and few observations (only 5 streams considered for odd year adjusted data). Likewise, even year pinks not considered due to an incomplete record (ends in 1980) and a small number of reporting streams (14).

The Sarita and Nahmint Rivers have the dominant chum runs in this region, but more than a dozen other streams also have significant runs. Streams with smaller escapements have less complete records, particularly though the 80s, but this should not significantly affect the nutrient influx trends since the major contributors have quite complete data (Fig. 7c). Enhanced stream escapements are negligible contributors to the total. The chum nutrient influx trend should be fairly reliable, and shows a gradual decline.

The Somass River run dominates chinook escapement for this region and is solely responsible for the fluctuations in nutrient influx during the last 10 years. Stocks in many of the smaller run streams have been in constant decline - many have not been monitored since their stocks appear to have crashed in the mid 1980s. Removal of the enhanced streams produces a nutrient influx trend of gradual decline over the last 42 years (Fig. 7d). The adjusted data trend also shows a decline, except for the last 10 years because of the enhancement activity on the Somass River.

When all species are combined, the nutrient influx trend from the adjusted data shows a considerable increase in nutrient influx over the last 42 years (Fig. 7e). However, nutrient influx to unenhanced streams has been in decline. Enhancement stocks have been responsible for so much of the nutrient influx that the trendlines significantly diverge. Total nutrient influx to the region is not dominated by any species, but much of the influx in recent years is due to the enhanced chinook runs from the Somass River.



Odd Year Pinks are not considered for this region

FIGURE 7a-7b Nutrient Influx to the West Coast of Vancouver Island, Mid-Region
(a) Sockeye, (b) Coho

Even Year Pinks are not considered for this region

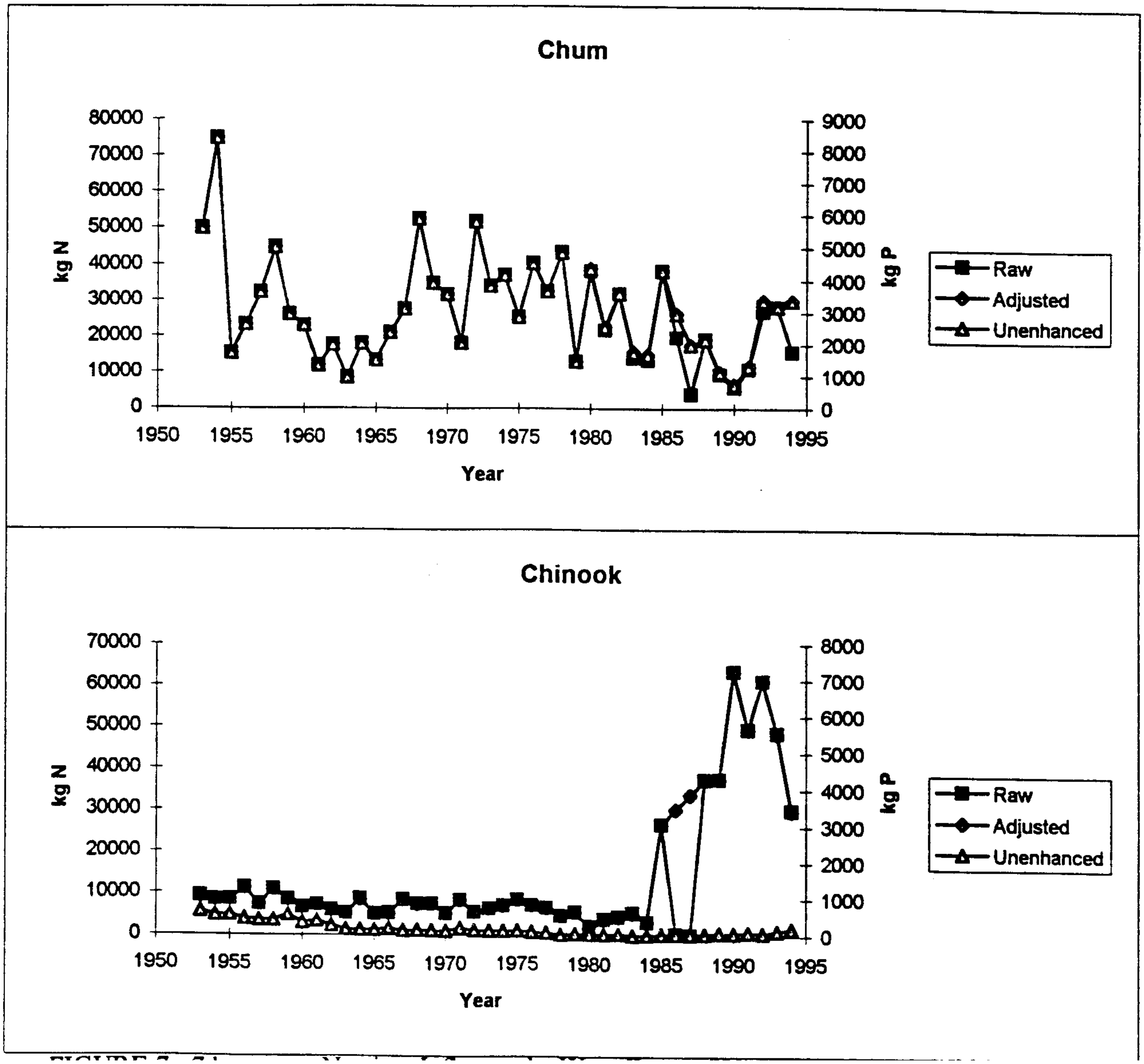


FIGURE 7c-7d Nutrient Influx to the West Coast of Vancouver Island, Mid-Region (c) Chum, (d) Chinook

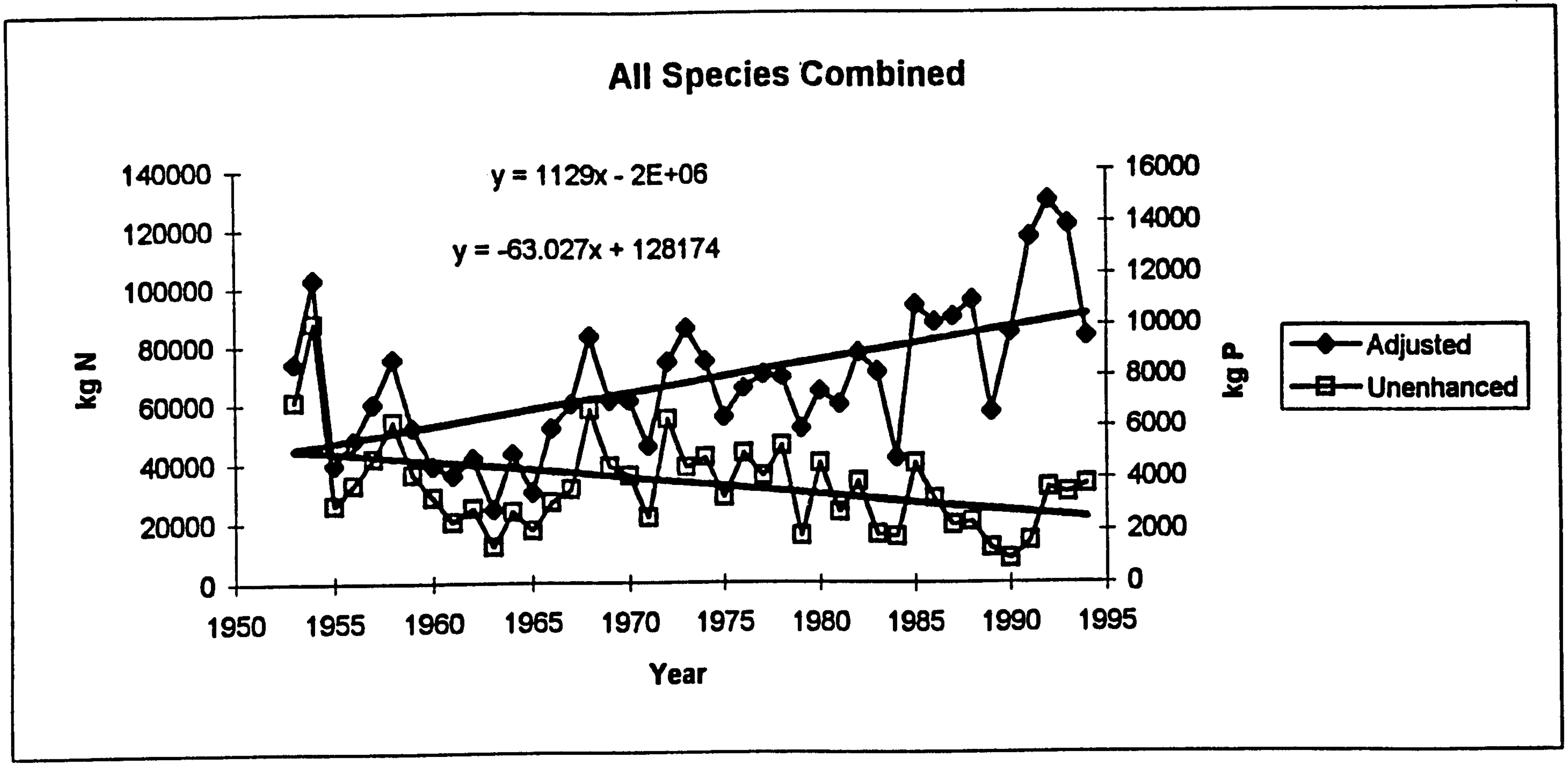


FIGURE 7e Nutrient Influx to the West Coast of Vancouver Island, Mid-Region
(e) All species combined

West Coast of Vancouver Island, North Region (Areas 25, 26, and 27)

The West Coast of Vancouver Island, North Region, extends from Cape Scott south to Estevan Point. One hundred and forty-four streams are included in this region (Table 9).

Table 9. Breakdown of streams, West Coast of Vancouver Island, North region.

Streams in Region	Species	Streams reporting any escapement for species	# of streams used in *adjusted data*	# of streams remaining after enhanced streams removed *(unenhanced data)*
144	Sockeye	61	32	32
	Coho	132	101	96
	Odd Year Pink	45	22	22
	Even Year Pink	88	63	63
	Chum	134	118	113
	Chinook	69	44	41

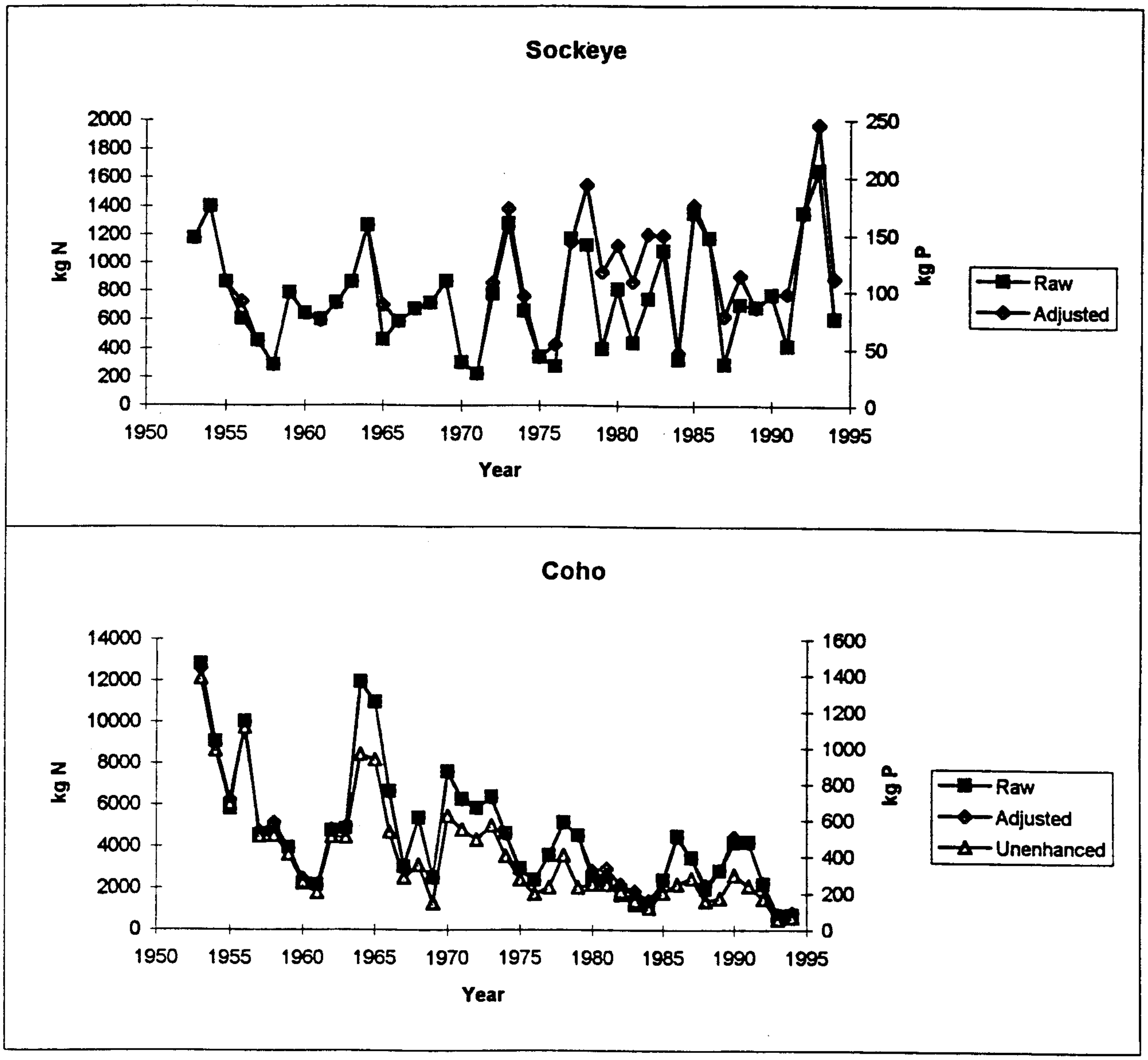
The Gold River has the largest run and therefore the most influence on the nutrient influx trend for sockeye for this region. However, the record for its run and for many other streams are sufficiently inconsistent that the accuracy of the trend is questionable (Fig. 8a). There has been a gradual increase in nutrient influx, despite the gaps in the record.

The nutrient influx from coho to this region is not dominated by the escapement from any one stream, but is made up of many mid- to small-size runs with inconsistent records. There is an noticeable decline seen in nutrient influx from coho, but this may be partially attributable to the inconsistent data (Fig. 8b). The great swings in the number of streams reporting from year to year makes the trend altogether unreliable.

Odd year pinks are not considered for this region due to low escapement numbers and extremely inconsistent observations in any of the 22 streams reporting. The Burman River run dominates the even year pink record until its stocks appear to crash in 1982; the record for many streams ends in the early 80s. Owing to the number of streams reporting dropping off in the 1980s, it is difficult to determine if the drop in nutrient influx is due to lack of observations or stocks declining (Fig. 8c).

The chum record for this region is reasonably complete, with perhaps the exception of some smaller run streams from area 27 (northernmost end of Vancouver Island). There are no dominant streams as the escapement record is made up of a large number of mid-sized runs. This data is probably very reliable and depicts a small increase in nutrient influx over the last 40 years (Fig. 8d). Escapements from enhanced streams only make up a small amount of the total influx.

The nutrient influx from chinook in this region is largely made up from runs from the Marble, Kaouk, Artlish, Tahsis, Burman and Gold Rivers, all of which have good records. The Conuma River has been dominant for the last 5-7 years due to enhancement activity. Owing to the complete records of the major contributing streams, the slight downward trend seen from 1953 to 1987 was likely accurate; the recent uptrend is due to the Conuma River enhancement (Fig. 8e). Although the adjusted data shows a



Odd Year Pinks are not considered for this region

FIGURE 8a-8b Nutrient Influx to the West Coast of Vancouver Island, North Region
(a)Sockeye, (b) Coho

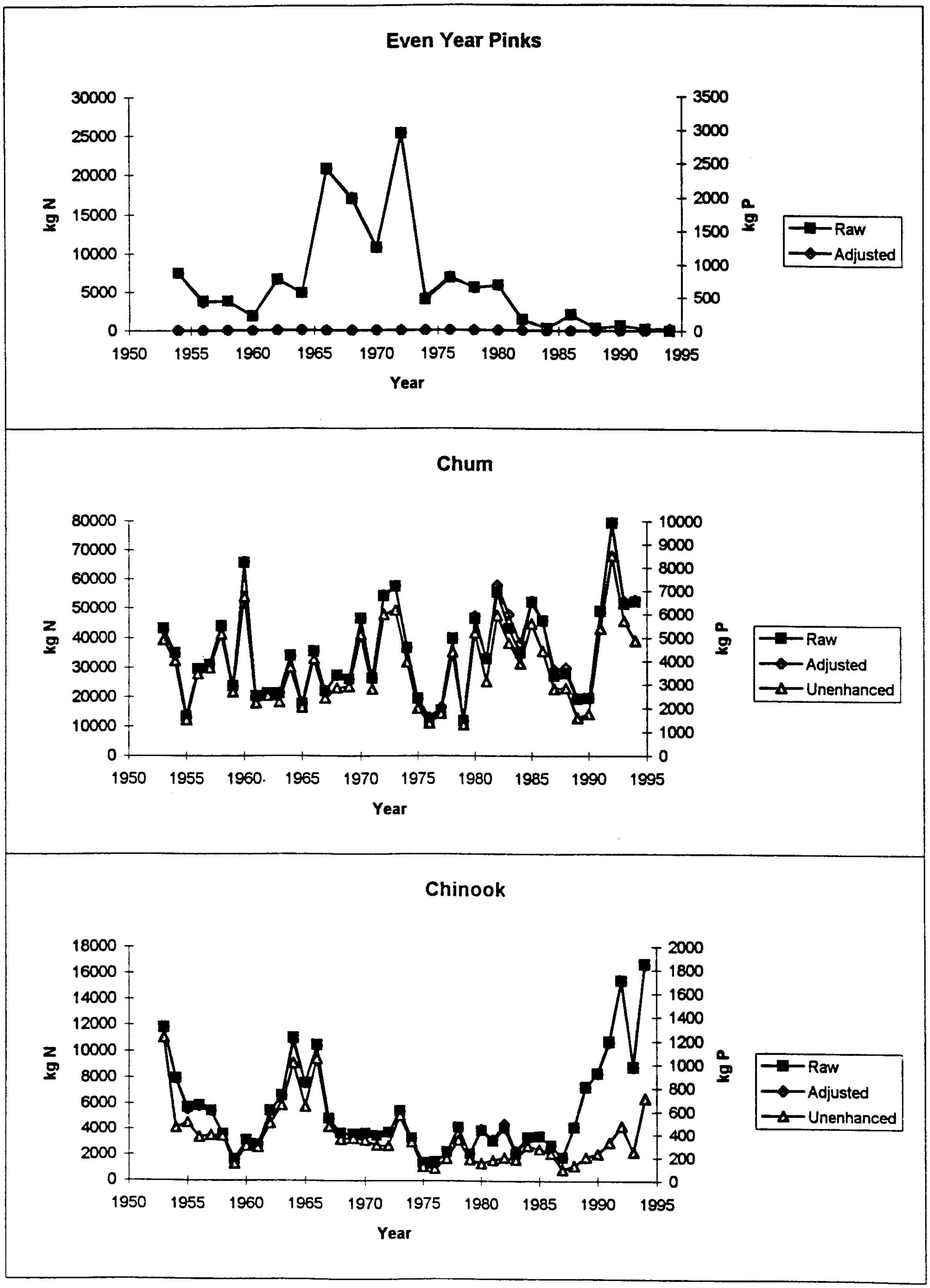


FIGURE 8c-8e Nutrient Influx to the West Coast of Vancouver Island, North Region (c) Even Year Pinks, (d) Chum, (e) Chinook slight increase in nutrient influx from chinook, there has been a gradual decline in streams without enhancement.

Trends from all species combined show relatively constant levels of nutrient influx to the region (Fig. 8f). The adjusted and unenhanced values are very similar and only in recent years are the escapements appreciably different. Enhancement escapements do not have the same impact on marine nutrient influx as in other regions. Total nutrient influx to the region is dominated by chum escapements, with little influence from the unreliable records for some of the other species in the region.

MANAGEMENT IMPLICATIONS

Among B.C.'s south coastal streams, the dominance of escapements from enhanced streams is evident in both species and regional nutrient influx trends. With respect to individual species, nutrient influx often declined considerably, even to near zero, when only stocks from unenhanced streams were considered. Stocks from enhanced streams often completely dominated escapements for entire regions. Although regional trends from adjusted data suggested that nutrient influx to most regions is increasing, trendlines from wild salmon escapements (unenhanced streams) do not depict the same degree of increase, and, in fact, strongly indicate a substantial decrease in marine nutrient influx in some regions. The dominance of the enhanced streams results in the majority of the marine nutrient influx focusing towards larger stream systems that are already undergoing significant enhancement. (Such large escapements would not be self-supporting even with large influxes of nutrients because most streams do not have adequate capacity to overcome other obstacles to survival such as limited or degraded habitat.) In contrast, nutrient influx to smaller, unenhanced wild salmon streams appears to be declining.

The importance of marine-derived nutrients to the productivity of the oligotrophic lakes and streams was recently quantified by Bilby et al. (1996). Nitrogen (N) and carbon (C) from salmon carcasses were quickly absorbed by the trophic system and all aquatic organisms exhibited significant enrichment of ^{15}N and ^{13}C (Table 10).

Table 10. Proportion of salmon derived N and C in the biota of anadromous streams in Washington (adapted from Bilby et al. 1996).

	Grizzly Creek				East Fork Creek	
	Average values		Peak values			
	% marine N	% marine C	% marine N	% marine C	% marine N	% marine C
Riparian foliage	17.5	0	-	-		
Epilithic organic matter	20.7	25.2	30.4	26.6		
Grazers	24.8	29.2	36.4	33.9	32.6	15.6
Shredders	23.8	0	-	-		
Collectors-gatherers	14.43	29.4	20.8	33.1		
Invertebrate predators	10.9	27.5	18.0	31.8	19.2	24.6
Age -0 cutthroat trout	18.5	23.4	38.2	36.8		
Age -1 and -2 cutthroat trout	25.6	24.8	44.8	36.2		
Cutthroat trout					45.8	47.4
Age -0 coho salmon	30.6	39.5			30.0	15.7
Age -1 steelhead					31.7	60.5

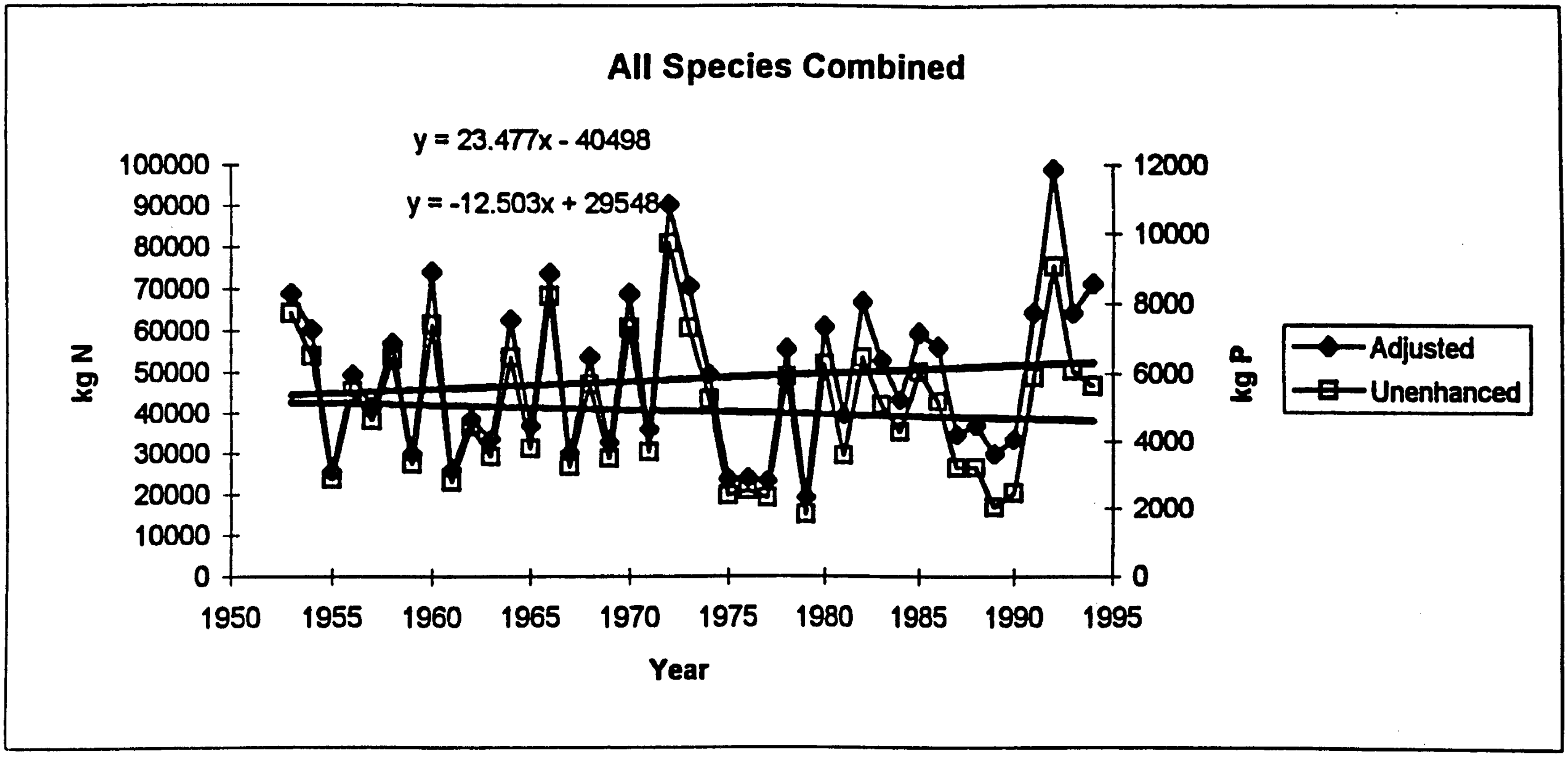


FIGURE 8f Nutrient Influx to the West Coast of Vancouver Island, North Region
(f) All species combined

Schuldt, and Hershey (1995) also emphasize the impact of externally derived nutrients to streams flowing into Lake Superior. Even if only small amounts of N and P are added, the contribution may be significant to driving primary production, especially in a system that is nutrient limited (Table 11).

Table 11. Calculated contributions of phosphorous and nitrogen to the Baptism River and McCarthy Creek (Lake Superior) as a result of carcass decomposition (adapted from Schuldt, and Hershey 1995).

	Time (d)	Salmon Contribution (μg/L)	Ambient Concentration mean (μg/L)	% Increase
Phosphorus				
Baptism River	15	4.55	5.7	80
	30	2.86	5.7	50
McCarthy Creek	15	1.44	8.8	16
	30	0.72	8.8	8
Nitrogen				
Baptism River	15	60.78	518	12
	30	38.28	518	7
McCarthy Creek	15	19.27	281	7
	30	9.64	281	3

In streams with small salmon escapements, stocks already in decline are likely to decrease further due to lessened biological productivity and the size-survival dependence of rearing species of salmonids. It is inferred that a ‘trough’ in marine conditions, in combination with continuing fishing pressure and habitat impacts, is resulting in declining trends in escapements of some coastal salmon stocks, thereby depressing potential sources of marine-derived nutrients and carbon from salmon carcasses in many wild salmon streams.

These observations reveal the significance of enhancement activity in maintaining species escapements and marine nutrient influx in some areas of south coastal B.C.. Trusting the total escapement for any species to a few dominant streams is risky since the stock is more vulnerable to collapse (P.A. Larkin, *pers. comm. 1996*). Many arguments have also condemned large-scale enhancement for overfishing of weaker stocks, and for introgressing wild stocks with hatchery fish, thereby decreasing genetic diversity (Hilborn 1991). Restoration efforts should concentrate on improving the abundance of wild stocks of each species where declines in historical escapements are evident or even suggested by trends in existing escapement data. Escapement targets used in salmon stock management need to include an allotment of spawners to provide the nutrient influx essential to the maintenance of stream productivity, which is a fundamental change from the conventional stock-recruitment method of catch allocation which ignores implications of overharvesting of many nursery lakes and streams. Harvest management, especially of weak stocks, needs to be reconsidered in light of the significant risk of nutrient-food chain impacts on stock productivity.

Further experimental work is needed to demonstrate that the nutrients derived from salmon carcasses directly result in increased fish production (such as by controlled carcass introduction and depletion experiments). Isotope signatures only reveal the movement of nutrients through the food chain and do not establish that nutrients from any source drive production. However, enough information has been gathered from isotope studies and fertilization experiments to conclude that wild stocks may be at risk and therefore argue for an immediate management response. Allowing for larger numbers of returning spawners would at least "buy some time" to further determine the magnitude of the role of carcass-derived nutrients and carbon supplies in salmonid production. Decreases in allowable catch could be a small price compared to the consequences of no action, whereby weak stocks decline further into a negative feedback loop, with the opportunity to reverse the process being lost.

As well as managing for greater salmon escapements, external organic and inorganic nutrient sources to oligotrophic streams with depressed salmon runs are selectively needed to increase biological productivity until the nutrient influx from returning spawners is returned to historic levels. Transport of excess salmon carcasses from hatcheries and spawning channels is an option supported by the results of Schuldt, and Hershey (1995), but caution would be needed so that there is no movement outside local drainages to prevent disease transfer. Once-annual inputs of slow release nutrient briquettes is another option that has been successfully tested (Mouldey, and Ashley 1996) and has application until salmon escapements recover.

In logging-impacted watersheds, any form of acceleration of watershed recovery, including hillslope stabilization (erosion control by re-establishing natural drainages and revegetation of disturbed soils), streambank stabilization, replacement of overwintering instream cover or providing spawning areas for non-rearing species, will improve stock productivity by increasing salmon survivals, thus restoring nutrients to the system as increased numbers of returning spawners. Nutrient loss rates, however, may be high without habitat restoration because of the continuing loss of large instream wood and the lack of its recruitment from logged riparian zones, which would otherwise require a century to recover naturally (Slaney 1996). The frequency of large woody debris (LWD) in streams has been demonstrated to greatly affect the retention of salmon carcasses, particularly in high gradient coastal streams (Cederholm et al. 1989, Cederholm, and Peterson 1985). Thus, the capacity of many streams to retain carcasses may be greatly reduced by past logging practices which simultaneously alters stream hydrographs and reduces instream LWD.

Without a broadly-based integrated strategy of 'renewal' by intensifying research on nutrient-salmon interdependence, habitat protection efforts, extensive hillslope and fish habitat restoration and mitigation, and risk-adverse fisheries exploitation, we are confronted with the unsustainability of the weaker stocks of coastal wild anadromous salmonids.

REFERENCES

Anonymous. 1993. British Columbia Recreational Atlas. Province of British Columbia, Ministry of Environment, Lands and Parks.

Beamish, R., and C. Neville. 1996. Sustaining salmon fisheries in a changing environment. *In* Towards sustainable fisheries: Balancing conservation and use of salmon and steelhead in the Pacific northwest. Conference Program and Abstracts, April 26-30, 1996, Victoria, BC.

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53:164-173.

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1995. Role of salmon carcasses in maintaining stream productivity: ecological significance and management considerations. *In* Abstracts from the annual meeting of the North Pacific International Chapter of the American Fisheries Society, Vancouver, BC.

Brickell, D.C., and J.J. Goering. 1970. Chemical effects of salmon decomposition on aquatic ecosystems. Pages 125-138 *in* R.S. Murphy [ed.] First international symposium on water pollution control in cold climates. U.S. Government Printing Office, Washington, D.C.

Cederholm, C.J., D.B. Houston, D.L. Cole, and W.J. Scarlett. 1989. Fate of coho salmon *(Oncorhynchus kisutch)* carcasses in spawning streams. Canadian Journal of Fisheries and Aquatic Sciences 46:1347-1355.

Cederholm, C.J., and N.P. Peterson. 1985. Retention of coho salmon *(Oncorhynchus kisutch)* carcasses by organic debris in small streams. Canadian Journal of Fisheries and Aquatic Sciences 42:1222-1225.

Government of Canada, Department of Fisheries and Oceans, Salmonid Enhancement Program:
- 1979/80 Annual Summary Report
- 1980/81 Annual Summary Report
- 1981/82 Annual Summary Report
- 1983/84 Annual Summary Report
- 1986/87 Update
- 1987/88 Update
- 1988/89 Update
- 1989/90 Update
- 1990/91 Update

Hilborn, R. 1991. Hatcheries and the future of salmon and steelhead in the northwest *in* The Osprey. A newsletter published by the Steelhead Committee, Federation of Flyfishers, Issue No. 11.

Johnston, N.T., C.P. Perrin, P.A. Slaney, and B.R. Ward 1990. Increased juvenile growth by whole-river fertilization. Canadian Journal of Fisheries and Aquatic Sciences 47:862-872.

Kline, T.C. Jr., J.J. Goering, O.A. Mathisen, P.H. Poe, P.L. Parker, and R.S. Scanlan. 1993. Recycling of elements transported upstream by runs of Pacific salmon: II. $\delta^{15}N$ and $\delta^{13}C$ evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50:2350-2365.

Kline, T.C. Jr., J.J. Goering, O.A. Mathisen, P.H. Poe, P.L. Parker, and R.S. Scanlan. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}N$ and $\delta^{13}C$ evidence in Sashin Creek, southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 47:136-144.

Levy, D.A., L.U. Young, and L.W. Dwernychuk [eds.]. 1996. Strait of Georgia fisheries sustainability review. Hatfield Consultants Ltd., West Vancouver, BC, January 1996.

Mathisen, O.A., P.L. Parker, J.J. Goering, T.C. Kline, P.H. Poe, and R.S. Scalan. 1988. Recycling of marine elements transported into freshwater systems by anadromous salmon. Verhandlungen Der Internationalen Vereinigung Fur Theoretische und Angewandte Limnologie 23:2249-2258.

Mouldey, S., and K.I. Ashley. 1996. Development and testing of slow release fertilizer for restoring salmonid habitat. Province of British Columbia, Ministry of Environment, Lands and Parks, Fisheries Research and Development Section. Project Report No. RD54.

Mulholland, Land Consulting Ltd. 1995. Strait of Georgia salmonid escapement analysis. Prepared for Hatfield Consultants Ltd., West Vancouver, BC, February 1995.

Mundie, J.H., K.S. Simpson, and C.J. Perrin.. 1991. Responses of stream periphyton and benthic insects to increases in dissolved inorganic phosphorus in a mesocosm. Canadian Journal of Fisheries and Aquatic Sciences 48:2061-2072.

Peterson, B.J., and B. Fry 1987. Stable isotopes in ecosystem studies. Annual Review of Ecology and Systematics 18:293-320.

Quamme, D.L. 1994. Phosphorus limited community dynamics of stream benthic algae and insects. Master's thesis, Department of Zoology, University of British Columbia, Vancouver, BC.

Richey, J.E., M.A. Perkins, and C.R. Goldman. 1975. Effects of kokanee salmon (*Oncorhynchus nerka*) decomposition on the ecology of a subalpine stream. Journal of Fisheries Research Board of Canada 32(6):817-820.

Schuldt, J.A., and A.E. Hershey. 1995. Effect of salmon carcass decomposition on Lake Superior tributary streams. Journal of the North American Benthological Society 14(2):259-268.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada.. Fisheries Research Board of Canada Bulletin 184, Ottawa, ON.

Scrivener, J.C., and T.G. Brown. 1993. Impact and complexity from forest practices on streams and their salmonid fishes in British Columbia. Pages 41-49 *in* G. Schooner et S. Asselin [éds.] Le développement du Saumon atlantique au Québec: connaître les règles du jeu pour réussir. Colloque international de la Fédération québécoise pour le saumon atlantique. Québec, décembre 1992. Collection *Salmo salar* nº1: 201 p.

Slaney, P.A. 1996. Long-term indicators of the declining productivity of anadromous salmonid habitats in south coastal British Columbia. *In* Towards sustainable fisheries: Balancing conservation and use of salmon and steelhead in the Pacific northwest, Conference Program and Abstracts, April 26-30, 1996, Victoria, BC.

Slaney, P.A. 1994. The Watershed Restoration Program of British Columbia: an opportunity and a challenge. Pages 117-133 *in* W.T. Dushenko, H.E. Poll, and K. Johnston [eds.] Environmental impact assessment and remediation: towards 2000. Canadian Society of Environmental Biologists, Toronto, ON.

Slaney, P., K. Ashley, C. Wightman, R. Ptolemy, and D. Zaldokas. 1994. Low-level fertilization as a habitat management option for nutrient deficient trout stream in British Columbia. *In* Proceedings of the 9th International Trout Stream Habitat Improvement Workshop, September 6-9, 1994. Calgary, AB. Trout Unlimited Canada. 23p.

Slaney, P.A, and B.R. Ward 1993. Experimental fertilization of nutrient deficient streams in British Columbia. Pages 128-141 *in* G. Schooner et S. Asselin [éds.] Le développement du Saumon atlantique au Québec: connaître les règles du jeu pour réussir. Colloque international de la Fédération québécoise pour le saumon atlantique. Québec, décembre 1992. Collection *Salmo salar* nº1: 201 p.

Stearley, R.F. 1992. Historical ecology of Salmoninae, with special reference to *Oncorhynchus*. Pages 622-658 *in* Chapter 23 R.L. Mayden [ed.] Systematics, historical ecology, and North American freshwater fishes. Stanford University Press, Stanford, CA.

Tschaplinski, P.J., J.C. Scrivener, and L.B. Holtby. 1996. The dynamics of salmon populations in Carnation Creek and the effects of logging, climate variation, and fishing on adult coho and chum returns, 1970-1993. *In* S. Chapman, D.L. Hogan, and P.J. Tschaplinski [eds.] Carnation Creek and Queen Charlotte Islands fishery forestry workshop: applying 20 years of coastal research to management solutions. British Columbia Ministry of Forests Research Branch, Victoria, BC *In press*.

Walters, C.J. 1995. Fish on the line: the future of Pacific fisheries. A report to the David Suzuki Foundation. 82p.

APPENDIX A

Lakeheaded streams were separated from non-lakeheaded streams in each region to determine if the escapement trends for the two were different for any given species (Figs. A1-A7). There were only 3 instances when the escapement trends opposed each other (i.e., one increasing, one declining) (Figs. A2e, A3e, A7b).

Many of the total escapements were divided roughly 50/50 between lakeheaded and non-lakeheaded streams, even though there were generally fewer of the lake-headed streams (Table A1). This suggests that lakeheaded streams tend to carry a large percentage of the total escapement. The only consistent trend within stocks was the dominance of lakeheaded streams in sockeye escapements, which is not unexpected. The flow moderating effect of lakes does not influence the habitat quality to such an extent that it is conclusively reflected in the escapements.

Table A1. Number of enhanced, lakeheaded and non-lakeheaded streams in each region for each species.

SPECIES	CATEGORY	9-10	11-13	14-19	20-22	23-24	25-27	28-29
Sockeye	Enhanced	15	17	8	3	15	32	23
	Lakeheaded	4	16	5	3	12	13	13
	Non-lakeheaded	11	1	3	0	3	19	10
Coho	Enhanced	27	105	84	18	60	96	136
	Lakeheaded	6	34	7	5	21	17	28
	Non-lakeheaded	21	71	77	13	39	79	108
Even Year Pinks	Enhanced	25	60	26	1	5	22	47
	Lakeheaded	3	29	7	0	4	8	13
	Non-lakeheaded	22	31	19	1	1	14	34
Odd Year Pinks	Enhanced	25	72	13	3	14	63	2
	Lakeheaded	3	33	5	2	9	15	1
	Non-lakeheaded	22	39	8	1	5	48	1
Chum	Enhanced	20	100	85	16	71	113	84
	Lakeheaded	3	34	10	4	21	18	15
	Non-lakeheaded	17	99	75	12	50	95	69
Chinook	Enhanced	11	21	8	4	21	41	21
	Lakeheaded	2	15	3	2	12	10	7
	Non-lakeheaded	9	6	5	2	9	31	14

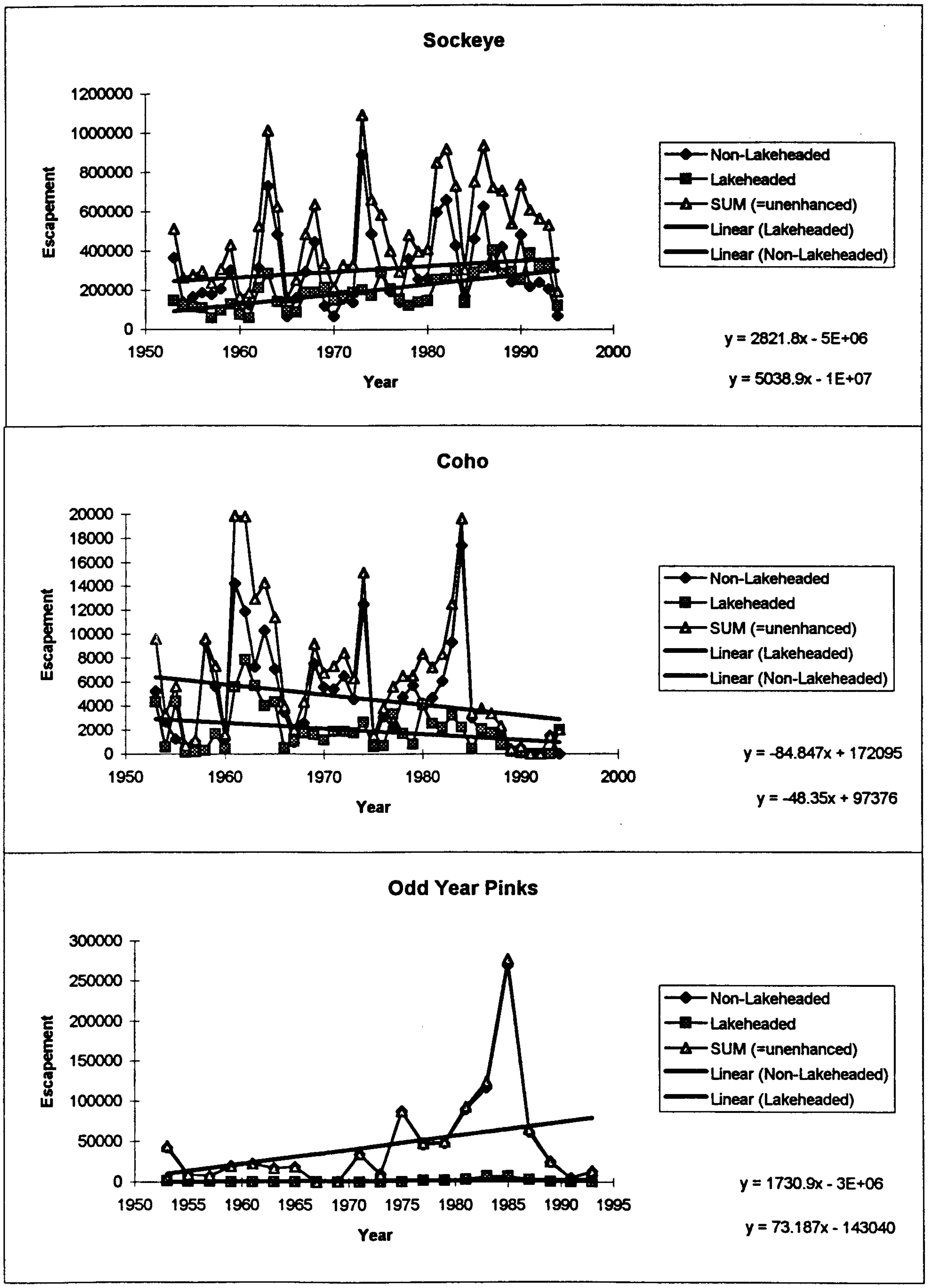


FIGURE A1a-A1c Escapement trends of Lakeheaded and Non-lakeheaded Streams in the Manland Coast (Rivers and Smith Inlets) Region (a) Sockeye, (b) Coho, (c) Odd Year Pinks

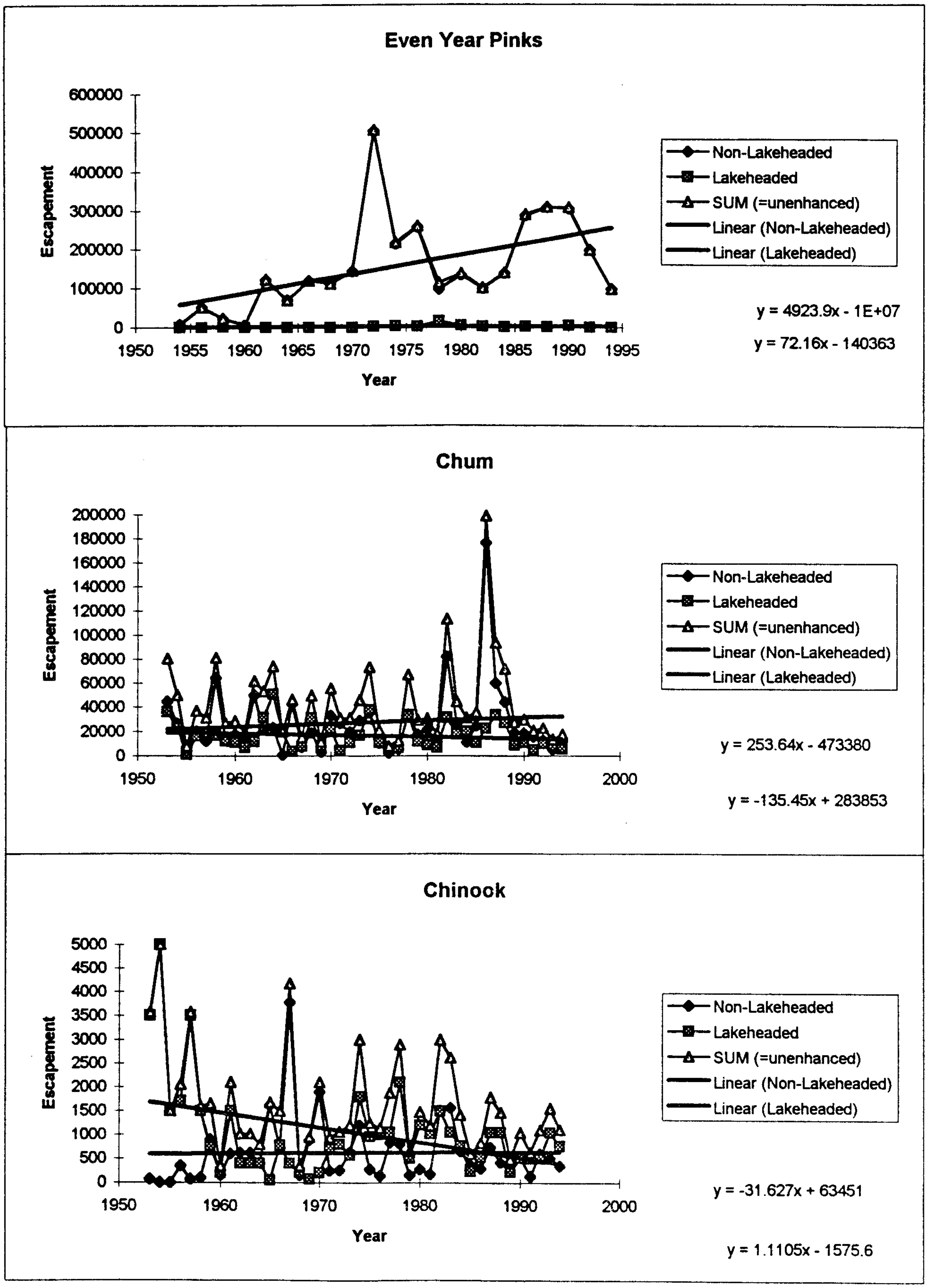


FIGURE A1d-A1f Escapement trends of Lakeheaded and Non-lakeheaded Streams in the Mainland Coast (Rivers and Smith Inlet) Region (d) Even Year Pinks, (e) Chum, (f) Chinook

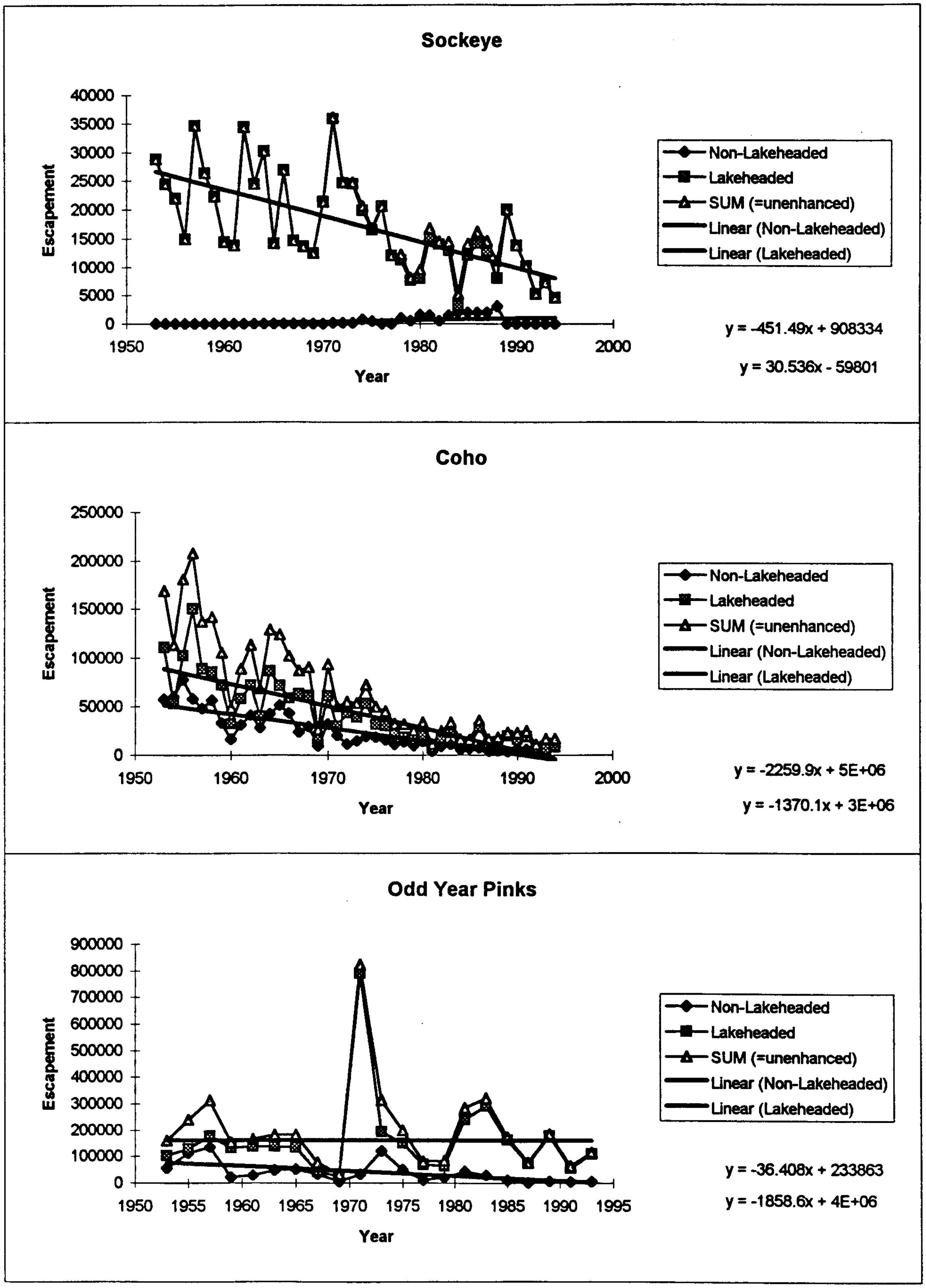


FIGURE A2a-A2c Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the Johnstone / Queen Charlotte Strait Region (a) Sockeye, (b) Coho, (c) Odd Year Pinks

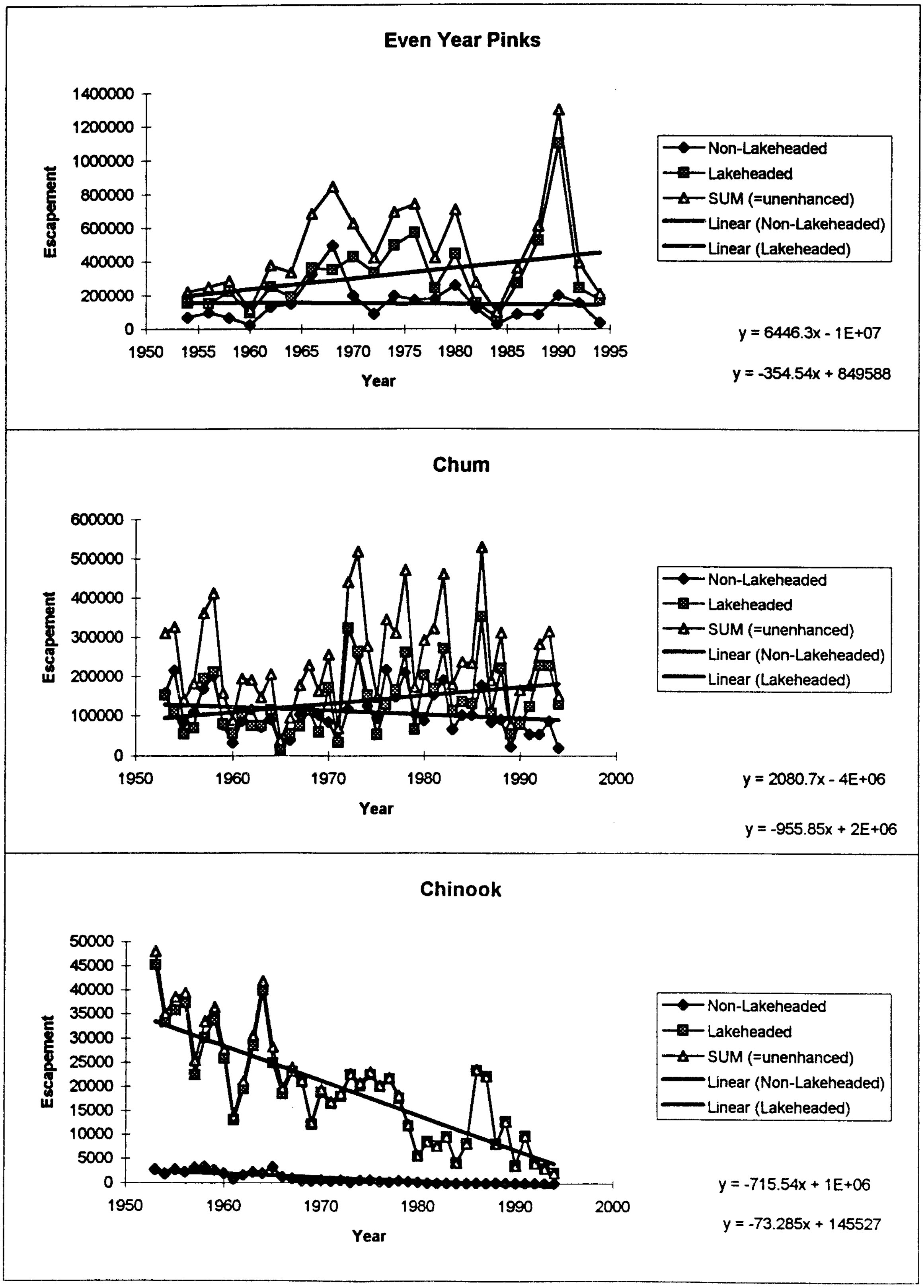


FIGURE A2d-A2f Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the Johnstone / Queen Charlotte Strait Region (d) Even Year Pinks, (e) Chum, (f) Chinook

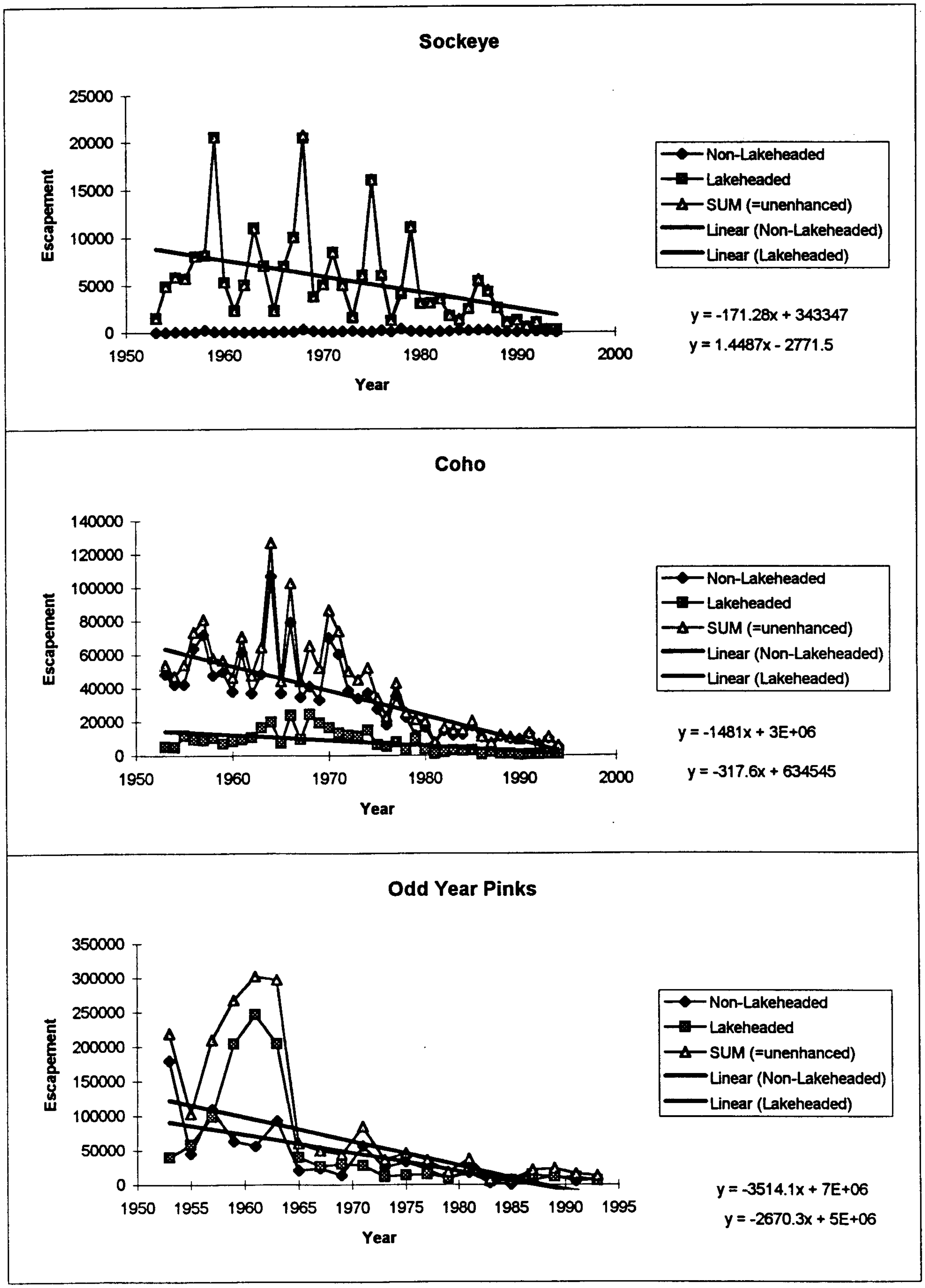


FIGURE A3a-A3c Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the Georgia Strait Region (a) Sockeye, (b) Coho, (c) Odd Year Pinks

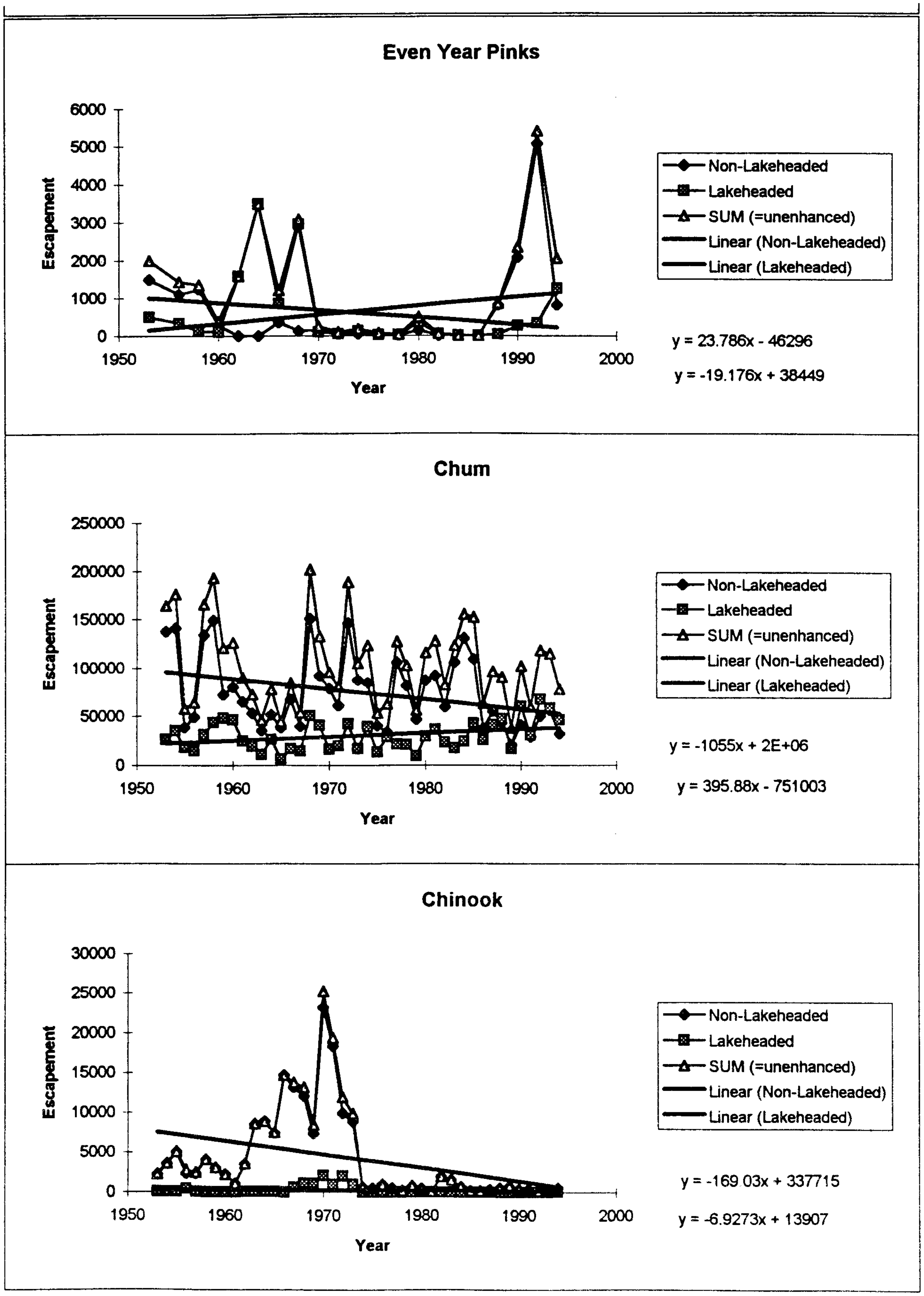


FIGURE A3d-A3f Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the Georgia Strait Region (d) Even Year Pinks, (e) Chum, (f) Chinook

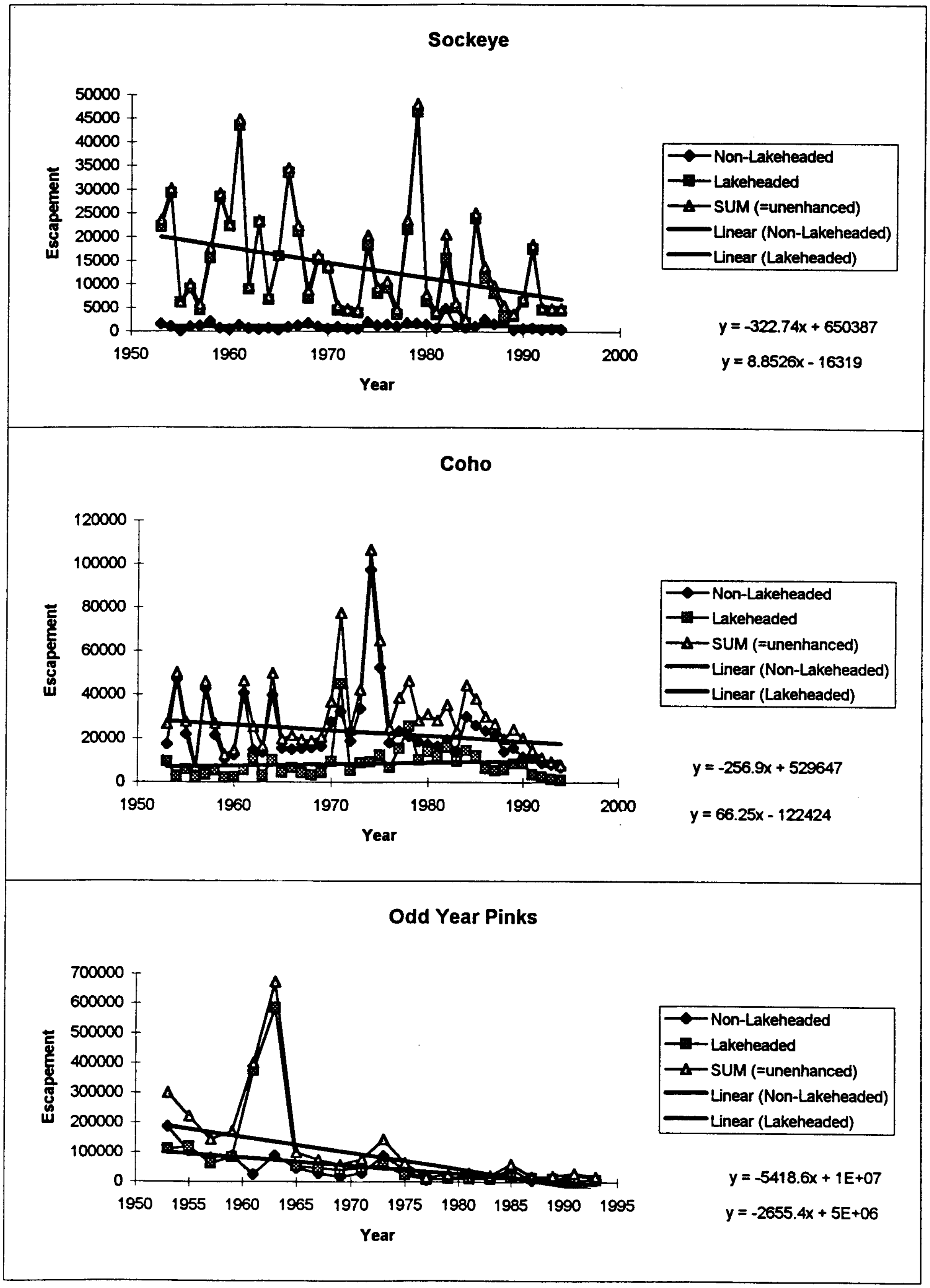


FIGURE A4a-A4c Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the Lower Fraser River / Howe Sound Region (a) Sockeye, (b) Coho, (c) Odd Year Pinks

Even Year Pinks are not considered for this region

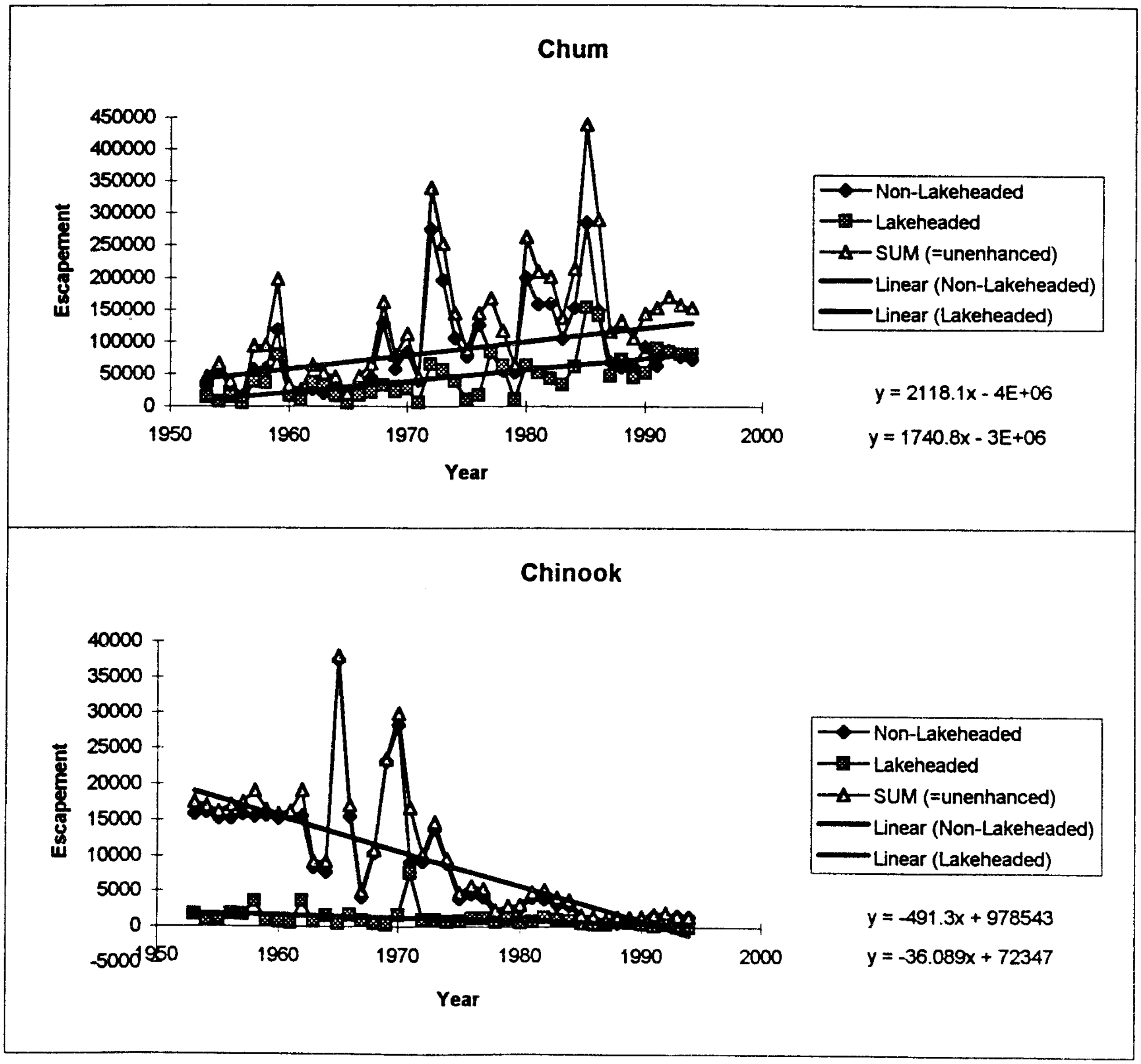
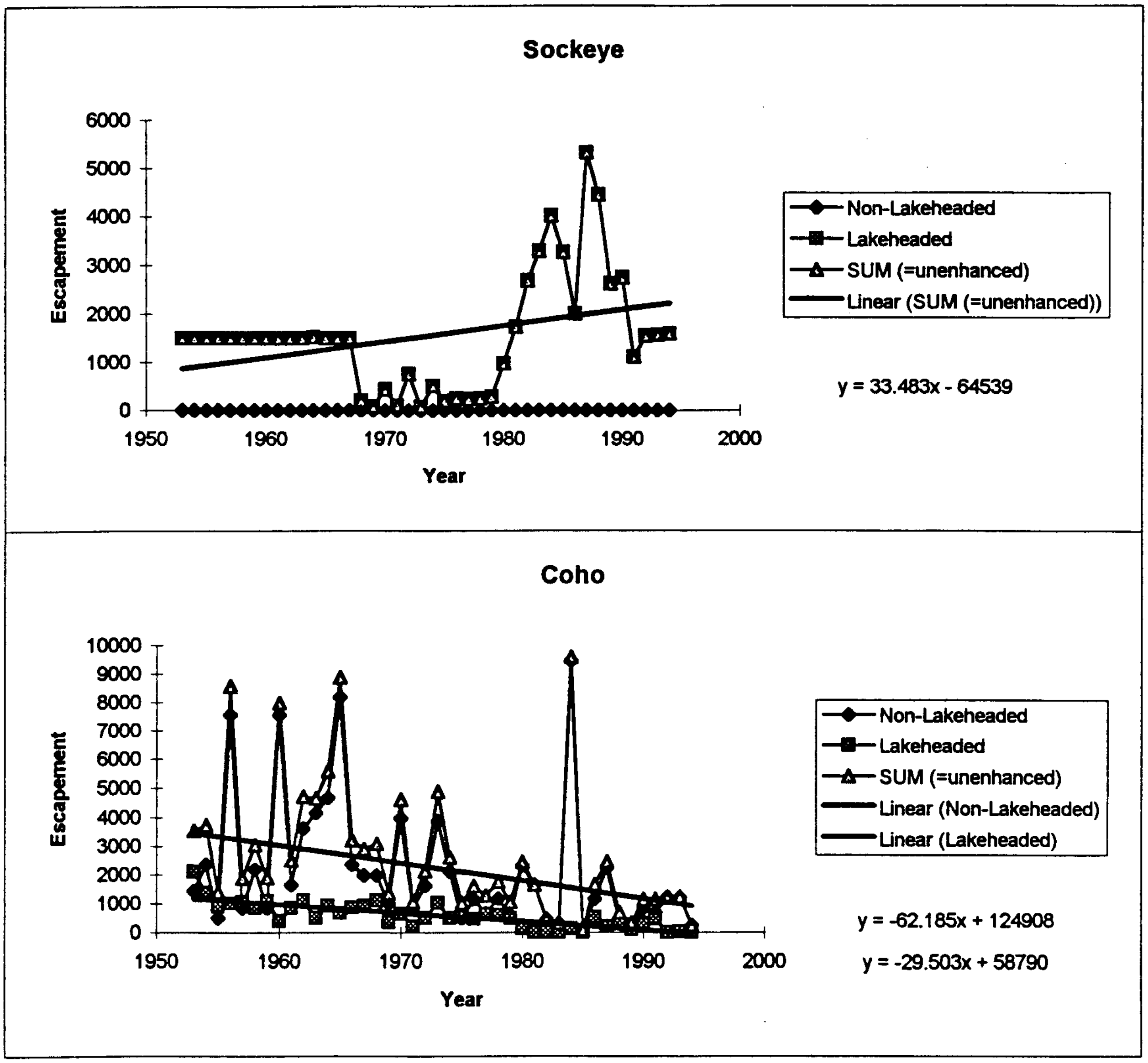


FIGURE A4d-A4e Escapement trends of Lakeheaded and Non-Lakeheaded Steams in the Lower Fraser River / Howe Sound Region (d) Chum, (e) Chinook



Odd Year Pinks are not considered for this region

FIGURE A5a-A5b Escapement trends of Lakheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, South Region (a), Sockeye, (b) Coho

Even Year Pinks are not considered for this region

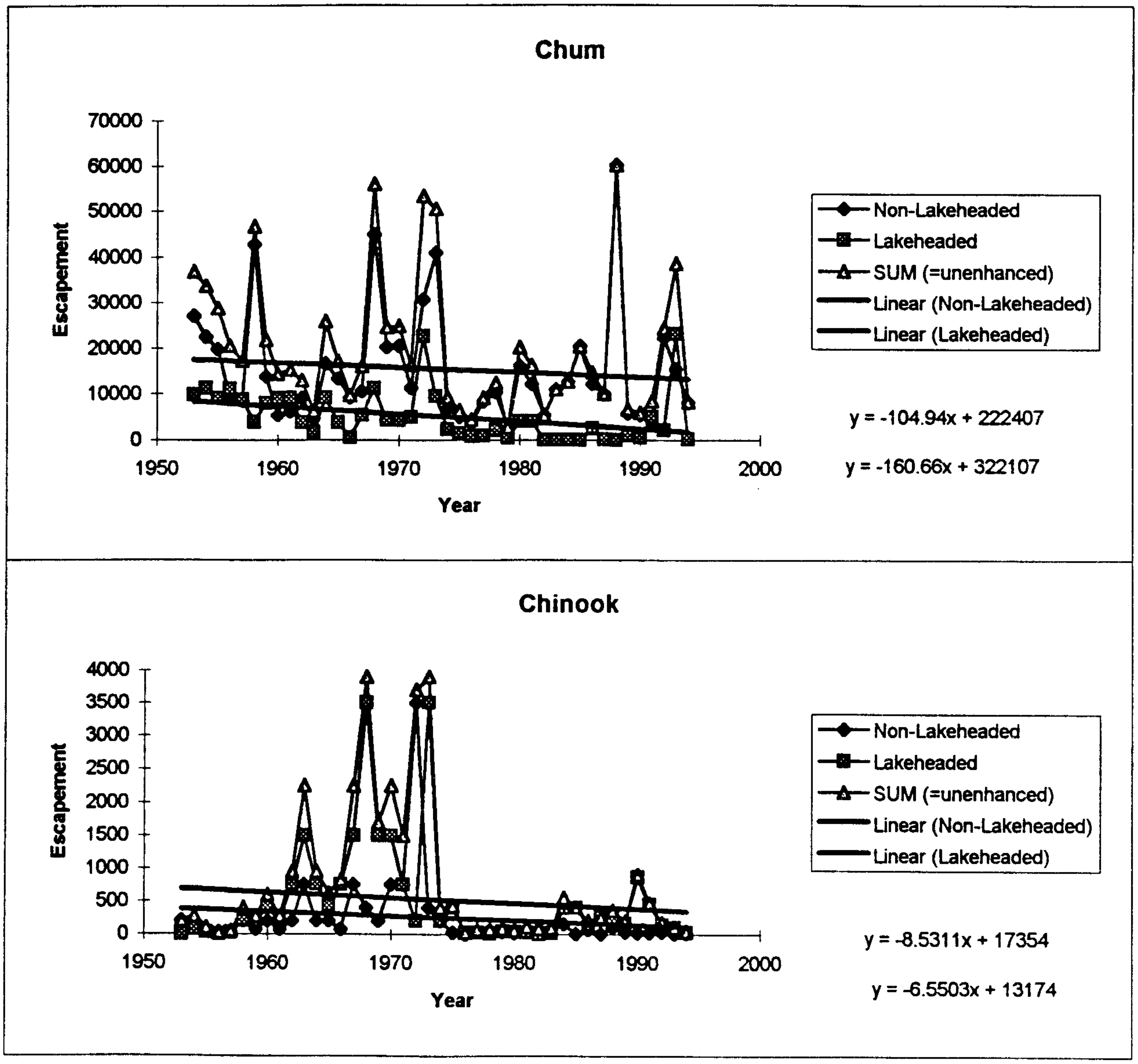
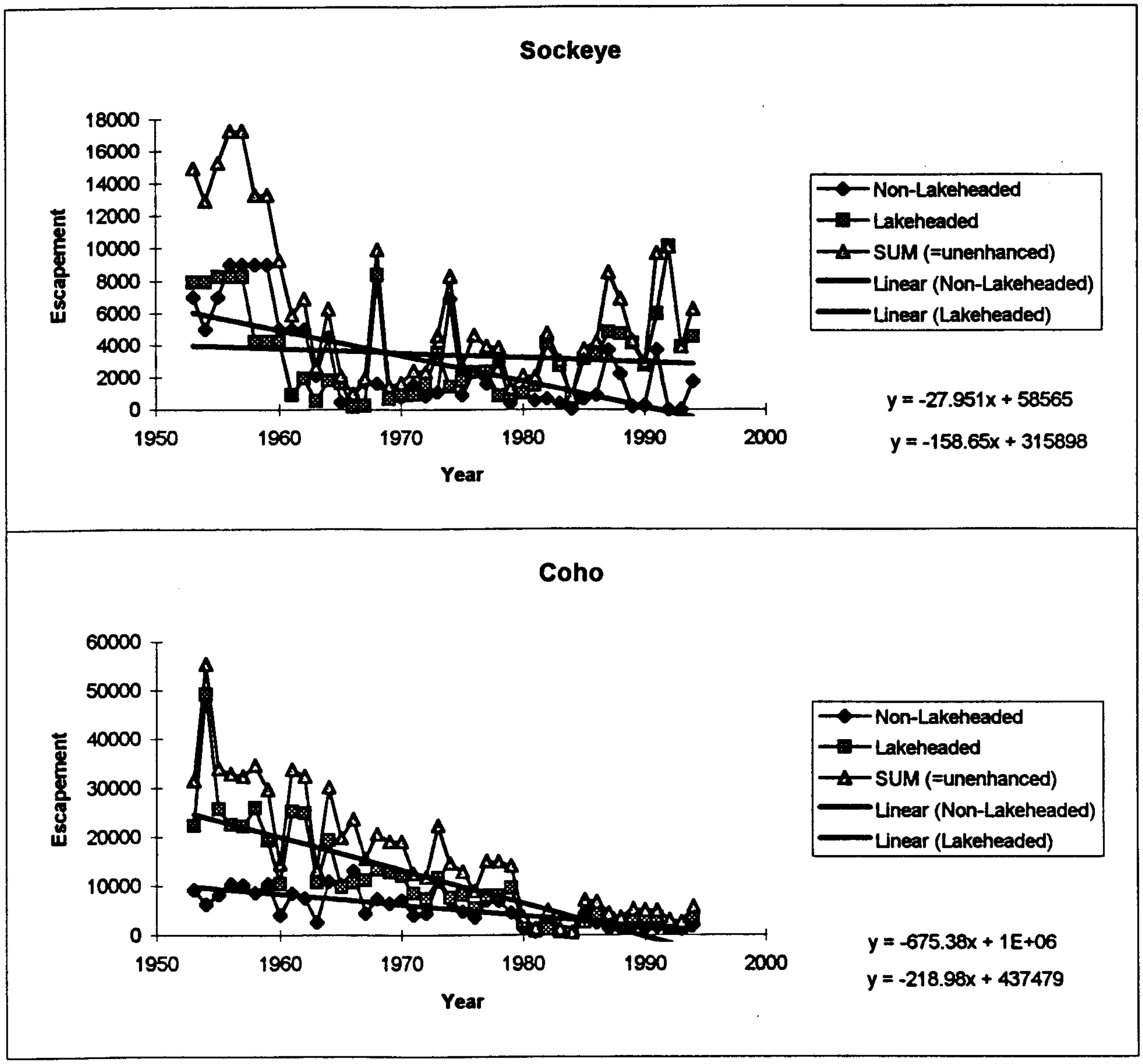


FIGURE A5c-A5d Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, South Region (c) Chum, (d) Chinook



Odd Year Pinks are not considered for this region

FIGURE A6a-A6b Escapement trends of Lakheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, Mid-Region (a), Sockeye, (b) Coho

Even Year Pinks are not considered for this region

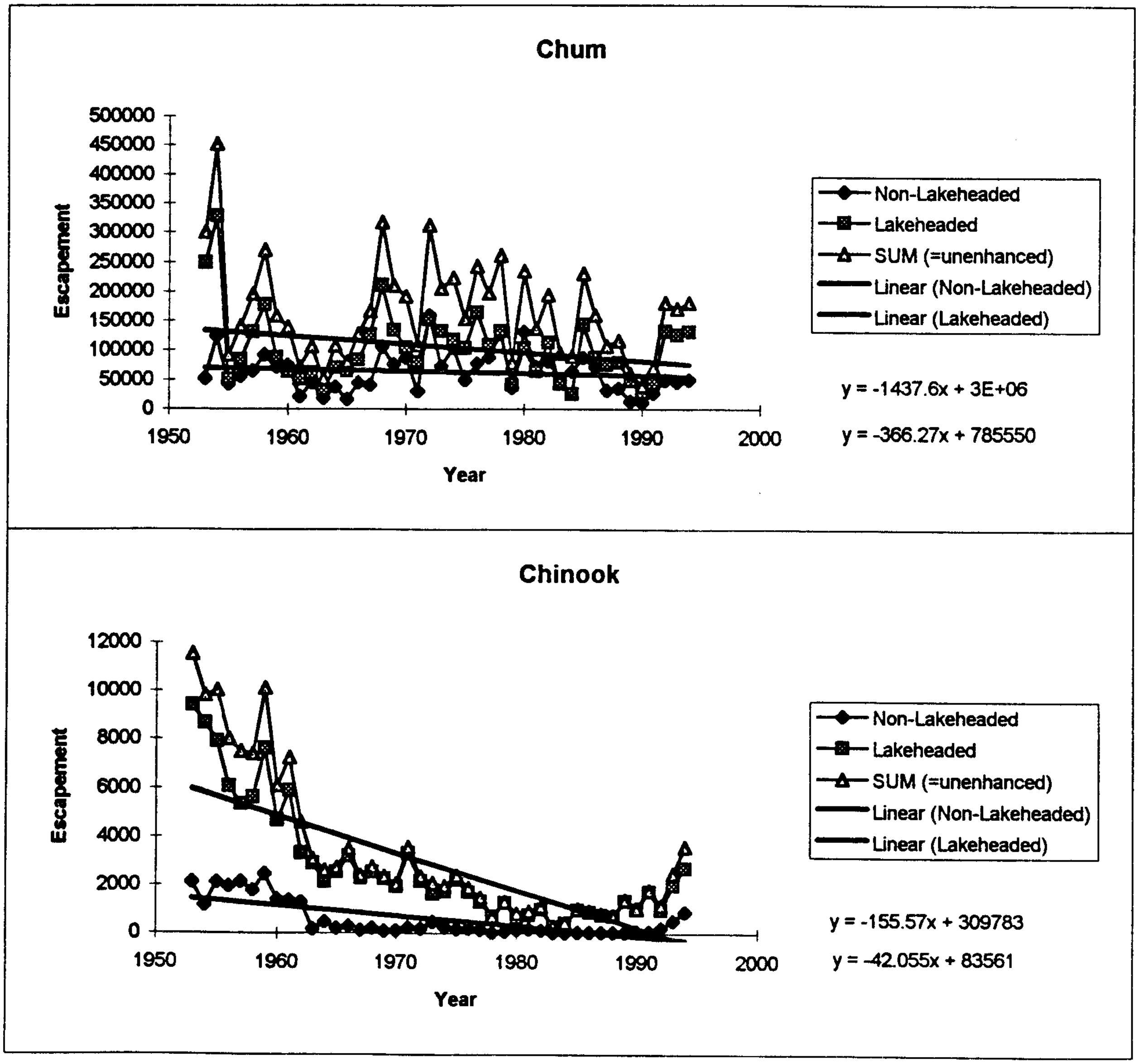
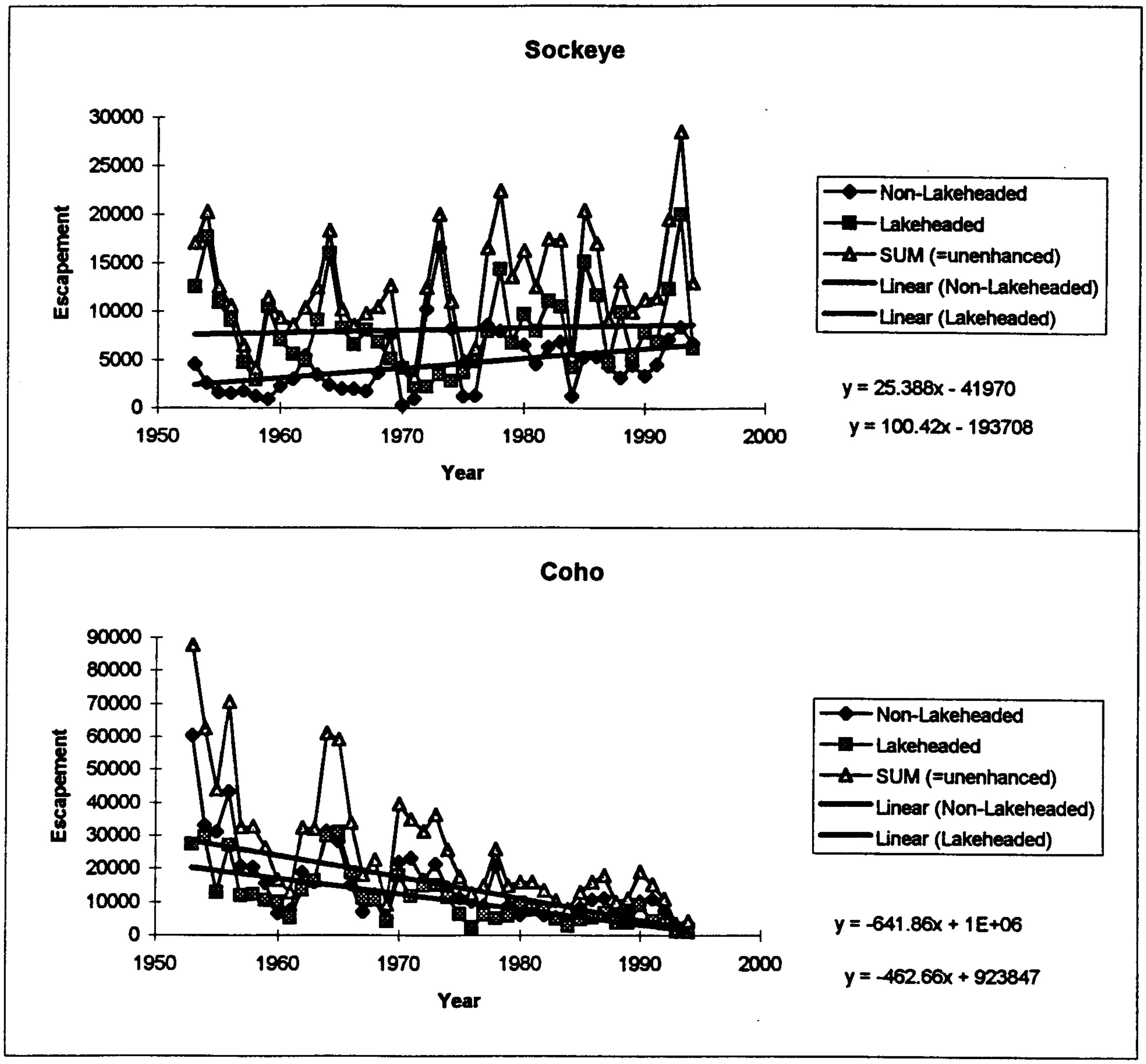


FIGURE A6c-A6d Escapement trends of Lakeheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, Mid-Region (c) Chum, (d) Chinook



Odd Year Pinks are not considered for this region

FIGURE A7a-A7b Escapement trends of Lakheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, North Region (a), Sockeye, (b) Coho

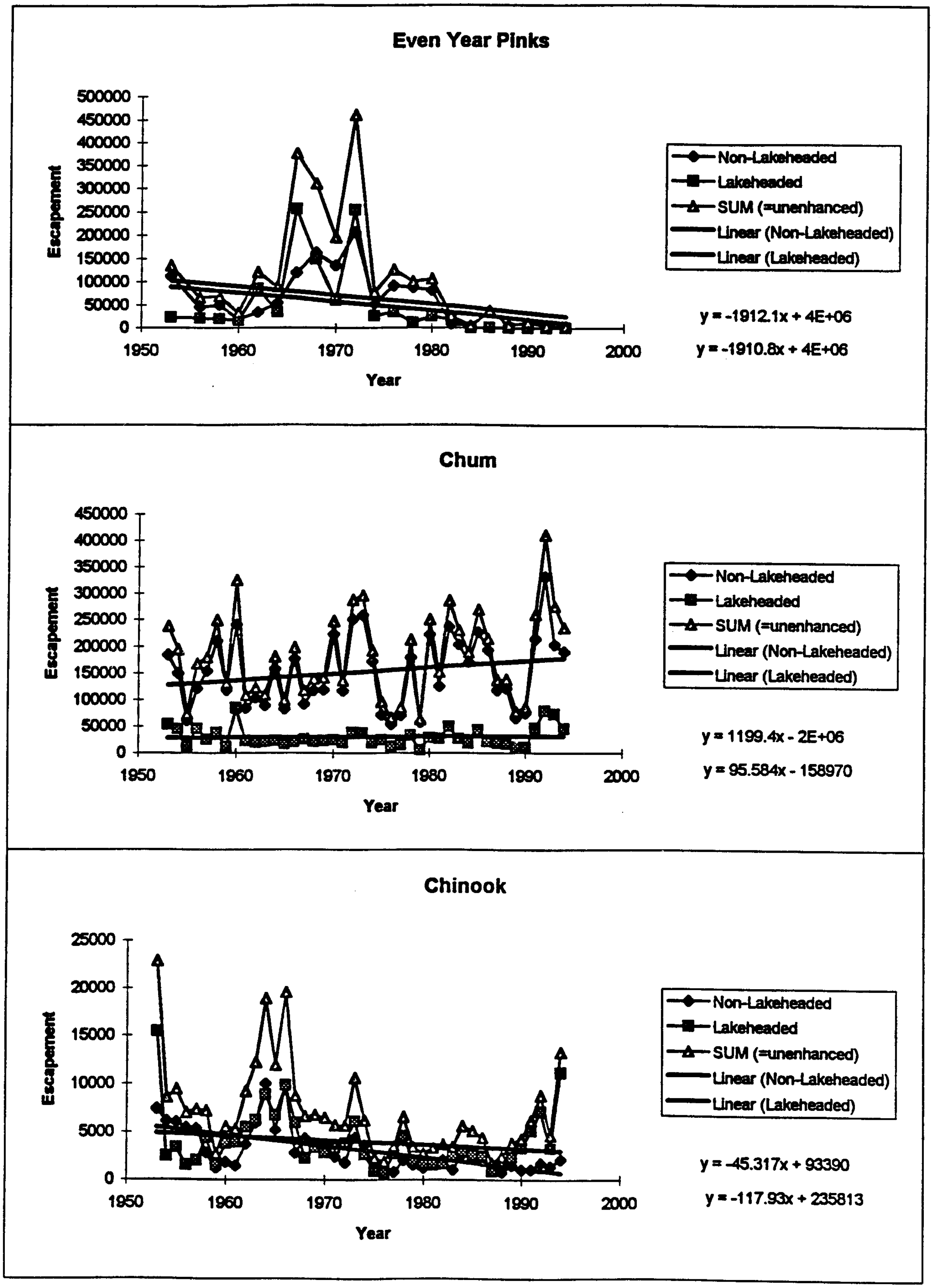


FIGURE A7c-A7e Escapement trends of Lakheaded and Non-Lakeheaded Streams in the West Coast of Vancouver Island, North Region (c) Even Year Pinks, (d) Chum, (e) Chinook