Implications of Trends in Marine-derived Nutrient Influx to South Coastal British Columbia Salmonid Production

By Gillian A. Larkin and Pat A. Slaney

ABSTRACT

Marine nutrients and carbon transported by adult salmon are important to the productivity of the oligotrophic lakes and streams in which salmon spawn. Reduced carcass availability results in a decline in nutrient and carbon sources for stream-rearing salmonids. We examined 42 years of escapement records for five species of Pacific salmon for Georgia Strait, the west coast of Vancouver Island, and the mainland coast of British Columbia to estimate the status of this nutrient source. Salmon stocks from enhanced streams frequently dominated the total escapement of entire regions. As a result, most of the influx of marine nutrients is focused toward a few large stream systems already undergoing significant salmon enhancement, while nutrient influx to the more-numerous unenhanced streams is declining. In the large number of streams with smaller salmon escapements, stream-rearing species already in decline may decrease further from oligotrophication. Risk-averse escapement targets for wild salmon stocks need to include sufficient spawners to provide the nutrient influx linked to the maintenance of stream productivity. Declining trends in nutrient influx to wild salmon streams in most regions are a cause for concern and more intensive examination.

In spite of the oligotrophic nature of many watersheds that drain into the north Pacific Ocean, salmon production is high. Pacific salmon (*Oncorhynchus* spp.) secure the link between the marine and freshwater environment via the annual return of adults from the sea to spawn and die. An adult salmon's body weight is almost entirely of marine origin and is delivered to the freshwater ecosystem through excretion, gametes, and carcass decomposition (Brickell and Goering 1972; Mathisen et al. 1988; Schuldt and Hershey 1995). Anadromous species in the northern hemisphere evolved by capitalizing on the growth rate differential between marine and freshwater systems (Stearley 1992).

^{13}C and ^{15}N, at their natural abundance levels, have been used as stable isotope tracers to determine trophic associations and nutrient pathways in a variety of terrestrial and aquatic ecosystems (Peterson and Fry 1987). Phosphorus, a key limiting nutrient, has only one stable isotope but would have a similar trophic association (K. Hall, University of British Columbia, personal communication). Nitrogen and carbon in spawning salmon contain higher proportions of the heavier isotopic form of both elements due to their marine origin than N and C imported to streams from other sources (i.e., terrestrial, atmospheric) (Kline et al. 1990; Kline et al. 1993). Therefore, stable isotope analysis provides a means of tracing marine N and C derived from spawning salmon through the trophic system of the streams and lakes they use (Kline et al. 1990; Kline et al. 1993; Bilby et al. 1996).

There is ample evidence that marine nutrients transported from the sea by salmon escapements are significant and important to the productivity of the oligotrophic lakes and streams in which salmon spawn (Mathisen et al. 1988). Recent descriptive studies, confirmed with carcass introduction experiments, have demonstrated that in a heterotrophic headwater stream, up to 40% of the N and C in the food chain is marine-derived via coho salmon (*Oncorhynchus kisutch*) carcasses (Bilby et al. 1996). Pink (*O. gorbuscha*) and sockeye salmon (*O. nerka*), which typically spawn at high densities, have been well established as significant contributors of nutrients to the freshwater ecosystems they inhabit (Brickell and Goering 1972; Richey et al. 1975). Salmon carcasses also are an important source of nutrients for autotrophic production in streams (Richey et al. 1975). Schuldt and Hershey (1995) reported elevated N and P concentrations and periphyton biomass (as chlorophyll *a*) in a chinook salmon (*O. tschawytscha*) and trout stream after the experimental introduction of only 24 chinook carcasses. Since low levels of primary and secondary productivity are characteristic of many coastal streams in the Pacific Northwest, even modest inputs of nutrients and carbon may be important in driving primary production and maintaining trophic productivity.

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Past land-use practices and fish harvesting are known to have reduced the availability of salmonid carcasses to streams (Slaney and Martin 1997). Decreased availability of carcass material can reduce the marine nutrient influx to streams, thereby diminishing productivity. The resulting decrease in parr and smolt size can reduce overwinter and marine survival, reducing the number of returning adults and further depressing stream productivity (Bilby et al. 1996). Since a small increase in mean length of juvenile coho may substantially improve survival of pre-smolts through winter freshets to smolt stage (Scrivener and Brown 1993; Quinn and Peterson 1996), the abundance of spawners is potentially crucial to maintaining 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 and Martin 1997). Thus, a negative feed-back loop from nutrient-food chain impacts could be significant to stream- and lake-rearing species of fish. Identification of this "oligotrophication" process in nursery lakes prompted experimental fertilization in the 1950s (Nelson and Edmondson 1955) and 1960s (Parsons et al. 1972), and established the Lake Enrichment Program in British Columbia (Stockner and MacIsaac 1996) and Alaska (Kline et al. 1993).

Results of fertilization research provide evidence that an external nutrient source to oligotrophic streams and lakes, equivalent to the nutrient influx from returning spawners, is needed to maintain long-term productivity. Lake fertilization experiments in Great Central Lake, British Columbia, increased the zooplankton forage base and enhanced both fry growth and in-lake survival. The larger and more abundant smolts survived better at sea, elevating numbers of returning adults to spawn (Stockner and MacIsaac 1996). Experimental fertilization in oligotrophic streams also has been conducted to examine potential responses in the salmonid food chain. Algal chlorophyll *a*, fish growth, and standing crop of salmonids were all higher in fertilized stream sections when compared with control sections (Johnston et al. 1990; Slaney and Ward 1993). Similarly, benthic insect communities have responded strongly to low-level (2 ppb–4 ppb) increases in phosphorous and nitrate nitrogen (Mundie et al. 1991; Quamme 1994; Slaney et al. 1994a). The effects of fertilization on periphyton accrual have been measured large distances downstream of fertilization sites (up to 50 km; Slaney et al. 1994b), with delays in the peak periphyton response at far downstream sites providing evidence of nutrient spiraling (Newbold et al. 1981).

This study was 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), and by declining trends in returns of salmon and steelhead trout (*O. mykiss*) to Carnation Creek and the Keogh River as indicators of wild stocks in south coastal British Columbia (Tschaplinski et al.; B. R. Ward, B.C. Fisheries Branch, personal communication). Moreover, 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 salmon escapement and marine nutrient influx. We examined escapements for salmon populations returning to the Georgia basin, west coast of Vancouver Island, and Mainland Coast to estimate the status of marine nutrient influx to salmonid-rearing habitats. Escapements are under many influences, including cyclical fluctuations in marine survival, fish harvesting, habitat changes, and salmonid enhancement programs. This article is a summary from a broader species-specific report (Larkin and Slaney 1996), which was a preliminary investigation of escapement data to assess if marine nutrient influx shows evidence of declining trends in various south coastal regions.

Methods

We obtained salmon escapement data from Canada's Department of Fisheries and Oceans SEDS (Salmon Escapement Database and reporting System) database for 5 species of salmon—sockeye (*O. nerka*), coho (*O. kisutch*), pink (*O. gorbuscha*), chum (*O. keta*), and chinook (*O. tschawytshca*)—for Pacific Region statistical areas 9–29 for all available years (1953 to 1994). Statistical areas were combined into groups representing different regions of the study area (Table 1; Figure 1).

To estimate the influx of nutrients from marine sources, we converted escapements for each region from numbers to weights. We multiplied escapements for each species by an average adult weight (Ricker 1981) and approximate percent body composition (L. Haywood-Farmer, B.C. Fisheries Branch, personal communication) (Table 2), to obtain the mass of nitrogen and phosphorus that the carcasses potentially contribute. Steelhead trout are not included because only a portion die after spawning in the late winter or spring, and historic abundances are not known for most streams.

We added together the totals in kg for each species to acquire the total N and P influx to each coastal stream region and then plotted the nutrients (in kg) within each of the regions for the last 42 years. Linear regressions through the data reveal the influx trend.

◆

Table 1 shows grouping of statistical areas into regions (Larkin and Slaney 1996).

Region	Statistical areas
Mainland Coast (Rivers Inlet and Smith Inlet)	9 and 10
Johnstone/Queen Charlotte Strait	11, 12, and 13
Georgia Strait	14–19
Lower Fraser River/Howe Sound	28 to 29 (A–E)
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

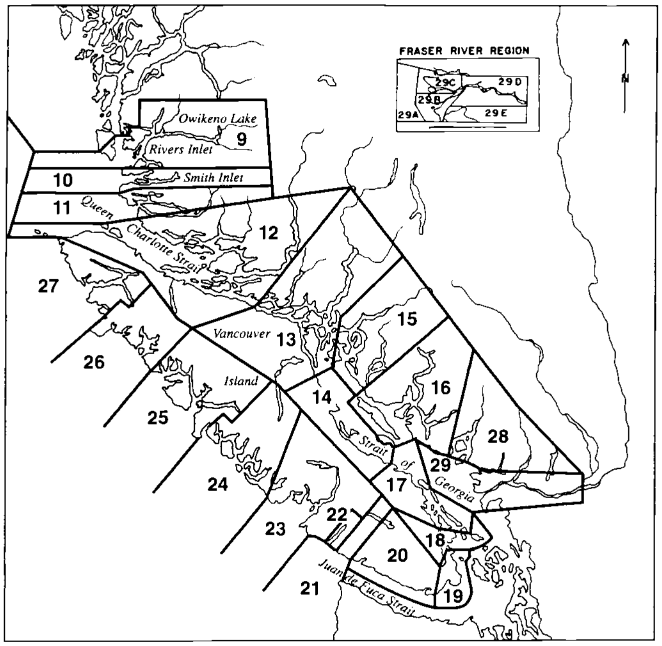

Figure 1 illustrates the boundaries of Pacific Regions Statistical Areas of the Department of Fisheries and Oceans.

Although the total nutrient influx to a region is dictated by species with larger escapements, examining trends throughout several decades can give insight into the nutrient status in streams of the region as a whole.

The SEDS data is generated with the following disclaimer: *"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."*

Therefore, the dependability of the data was suspect in several instances, although useful to indicate broad trends. Many estimates from some of the earlier years may be "dashboard surveys" with fisheries officers taking their best guess, often without leaving their vehicle or perhaps even their office, relying more on local reports (P. A. Larkin, University of British Columbia, personal communication). Methods of enumeration are inconsistent from year to year, stream to stream, and species to species. Coho data is particularly suspect in recent years since the fish are usually not counted directly; if any happen to be present during counts of other species, enumerators guess as to the probable total number of spawners (R. Cook and B. Adkins, Department of Fisheries and Oceans, personal communication). Nevertheless, examination of long-term trends can still have merit, particularly if differences are large (Levy et al. 1996).

Table 2 cites the percent body composition and average weight for salmonids used in calculation of marine N and P influx.

Information	Species	Value
Percent N in body weight	Average for all, adult	3.04
Percent P in body weight	Average for all, adult	0.36
Average adult weight	Sockeye	5.96 lbs=2.70 kg
	Coho	7.00 lbs=3.18 kg
	Odd Year Pink	4.72 lbs=2.14 kg
	Even Year Pink	3.34 lbs=1.52 kg
	Chum	10.97 lbs=4.98 kg
	Chinook	11.32 lbs=5.13 kg

We encountered some problems during data compilation. Counts for all five species were not made for every stream, and as a result, the escapement record for each species can be comprised from varying numbers of streams (coho and chum have the largest number of streams reporting escapements). In addition, counts were not taken consistently for the entire 42 years. Streams with less than four years of recorded escapements 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 data also have gaps, and in obvious cases where a stream record was intact except for a few years, we tried to complete the database by filling in holes with average or regular step values from escapement data prior to and after the gap. Only data gaps with SEDS codes for "unknown," "stream not inspected for this species," and "adults present" were interpolated. We left the most incomplete stream records untouched because filling the gaps by interpolation would have resulted in unreliable regional escapement estimates. After omitting the streams with poor escapement records and interpolating minor discontinuities, we obtained nutrient influx trends from this *adjusted* data.

Many escapements within the study area are influenced by enhancement programs, particularly the Department of Fisheries and Oceans (DFO) Salmonid Enhancement Program (SEP). Although hatchery fish are not a target of escapement counts (B. Adkins, DFO, personal communication), they are commonly included because there is no means to exclude them. To eliminate the influence of enhancement on nutrient influx trends of wild salmon, we removed the escapement data from streams that would contain enhanced stocks (from hatchery fish, sockeye-lake fertilization, spawning channel creation, and other methods) from the adjusted data for the entire 42 years of their record (only for the species that were enhanced; SEP Annual Summary Reports). Unfortunately, enhanced streams are often among the few that have complete, more reliable escapement records. Escapements for some species in some regions frequently were dominated by enhanced streams, to the extent that few streams remained to be summed after removal of those affected. Although we note that escapements from some unenhanced streams may be influenced by strays from neighboring enhanced streams, their escapement records were not removed since any effect on regional escapement trends should have been minimal. After removing escapement data from enhanced streams, nutrient influx trends were determined from the remaining *unenhanced* stream data. Escapement numbers from the two data sets should not be directly compared, but examining trends may provide valuable insight into the division of marine nutrient influx from wild stocks v hatchery stocks.

Results

Results are a condensation of the species-specific discussion from Larkin and Slaney (1996).

Mainland Coast (Rivers Inlet and Smith Inlet) Region (Areas 9, 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). Records for 47 streams are included in this region (Table 3). The trend determined for all of the salmon species combined indicates an increase in the influx of marine-derived nutrients to this region from 1952 to 1994 (Figure 2a). Sockeye escapements dominate the total salmon escapement to this region and do so without the aid of significant enhancement activity. The cyclic pattern is due to the dominance of the sockeye salmon escapements. Of concern is that the last decade provides evidence of substantial decline; this decline is clear in trends from each of the individual species, except chinook stocks, which are influenced by recent enhancement activity.

Johnstone/Queen Charlotte Strait Region (Areas 11, 12, 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. Records for 165 streams are included in this region (Table 3). Most escapement records for these streams are nearly complete and, hence, trends should reliably reflect nutrient influx. The trend from unenhanced stocks is one of gradual decline (Figure 2b). Enhanced stocks are contributing nutrients to the extent that when they are included (adjusted data), nutrient influx to the region is increasing. Large even-year pink escapements are responsible for the undulations in the total nutrient influx record for the last 10 years. Coho and chinook stocks decline substantially throughout the duration of their escapement records.

Georgia Strait Region (Areas 14, 15, 16, 17, 18, 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. Records for 149 streams are included in this region (Table 3). The trend from the adjusted data shows a considerable increase in nutrient influx during the last 42 years (Figure 2c). In contrast, the trend from unenhanced stream escapements indicates a marked decline. Enhanced stocks have been responsible for so much of the nutrient influx that the trendlines notably diverge. Total nutrient influx to the region is dominated by large chum escapements that overwhelm the contributions of other species.

Lower Fraser River/Howe Sound Region (Areas 28A, B, 29B, C, D, 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. Records for 249 streams are included in this region (Table 3). There was no reporting for any species in this region for 1994; all 1994 escapements have been based on data from previous years. The trend from the adjusted data shows a considerable increase in nutrient influx during the last 42 years (Figure 2d). Influx to unenhanced streams is relatively constant, which implies that all of the increase in nutrient influx is due to enhancement activity and concentrated to enhanced streams. Enhanced stocks are especially dominant in sockeye escapements. Total nutrient influx to the region is dominated by large chum escapements that overwhelm the contributions of other species.

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

The West Coast of Vancouver Island, south region, extends from approximately Nitinat Lake south to Victoria. Records for 34 streams are included in this region (Table 3). Nutrient influx has increased considerably during the past 42 years, as indicated by the trend from the adjusted data (Figure 2e). The influx to unenhanced streams is more consistent and in mild decline, indicating that any increases are a result of enhancement activity. Total nutrient influx to the region is dominated by large chum escapements that overwhelm the contributions of other species.

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

The West Coast of Vancouver Island, mid region, extends from Eatevan Point (south end of Nootka Sound) south to Nitinat Lake. Records for 104 streams are included in this region (Table 3). The trend from the adjusted data shows nutrient influx has increased considerably in the last 42 years (Figure 2f). However, influx to unenhanced streams has been declining markedly. Enhanced stocks are responsible for so much of the nutrient influx that the trendlines notably diverge. Total nutrient influx to the region is not dominated by any species; however, in recent years, much of the influx is due to the enhanced chinook runs from the Somass River.

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

The West Coast of Vancouver Island, north region, extends from Cape Scott south to Eatevan Point. Records for 144 streams are included in this region (Table 3). Trends show relatively constant levels of nutrient influx to the region (Figure 2g). The adjusted and unenhanced escapements are similar, and enhanced 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

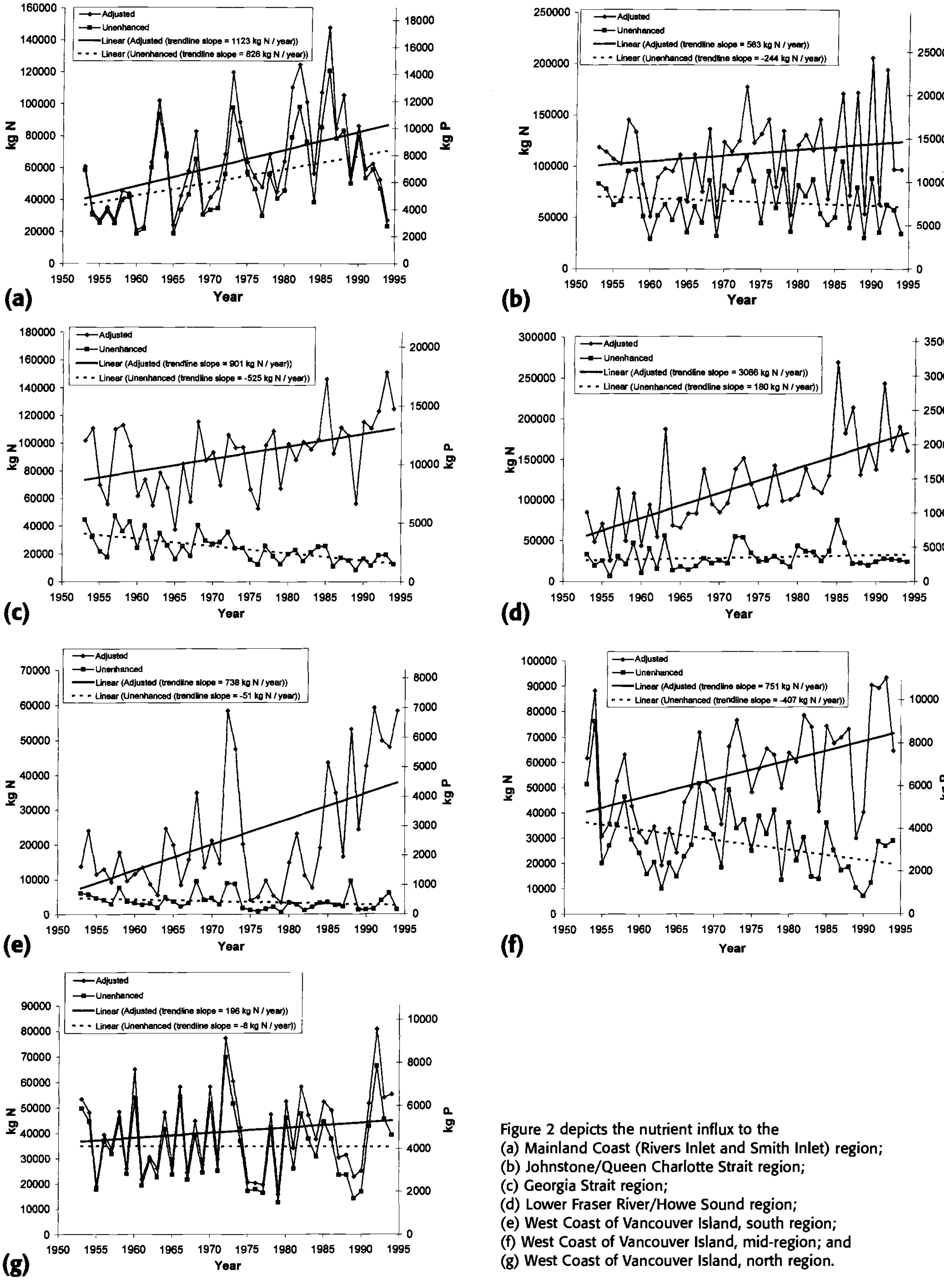

Figure 2 depicts the nutrient influx to the
(a) Mainland Coast (Rivers Inlet and Smith Inlet) region;
(b) Johnstone/Queen Charlotte Strait region;
(c) Georgia Strait region;
(d) Lower Fraser River/Howe Sound region;
(e) West Coast of Vancouver Island, south region;
(f) West Coast of Vancouver Island, mid-region; and
(g) West Coast of Vancouver Island, north region.

escapements, with little influence from the small and unreliable records of the other species in the region.

Discussion and Management Implications

Conclusions drawn from comparisons between marine nutrient influx trends from unenhanced stream data and from adjusted data need to be considered in view of the presentation of the data. The adjusted data set, for practical purposes of discussion, includes all streams in a given region. The unenhanced data set only includes those streams whose stocks have not been influenced by enhancement activity to date. Large-scale enhancement programs in British Columbia did not begin in earnest until the 1970s, and, therefore, most streams in the adjusted data set are truly unenhanced to that point. If the unenhanced data are not separated from the adjusted data until 1970 in Figures 2a through 2g, the result is a reduction in slope in all of the unenhanced trendlines. Thus, as presented, the trendlines are conservative with respect to declining trends in nutrient influx from unenhanced stream salmon escapements.

We also considered long-term trends in the size and age at maturity of Pacific salmon in our estimates of nutrient influx. Ricker (1981) reported a decrease in the size of fish caught for all five species from 1951 to 1975. From 1976 to 1991, declining weight trends for pink, coho and chinook slowed, stopped, or reversed (Ricker 1995). Sockeye and chum have shown no sustained trends since 1951. None of the observed changes in fish size has yet been correlated with changes in environmental and other long-term factors. However, sustained declining trends for pinks and cohos suggest unintentional selection by commercial fisheries over many generations (i.e., a genetic effect, Ricker 1981, 1995). We used the tabulated weight data for salmon caught in British Columbia's coastal waters in Ricker (1981), averaged

Table 3 indicates the breakdown of streams for each of the 7 regions (Larkin and Slaney 1996).

Region	# of streams in region	Species	Streams reporting any escapement for species	# of streams included in adjusted data	# of streams included in unenhanced data
Mainland Coast (Rivers Inlet and Smith Inlet)	47	Sockeye	25	16	15
		Coho	37	27	27
		Pinks (odd/even)	30/31	26/26	25/25
		Chum	28	21	20
		Chinook	15	12	11
Johnstone/ Queen Charlotte Strait	165	Sockeye	37	20	17
		Coho	134	112	105
		Pinks (odd/even)	91/105	69/81	60/72
		Chum	128	109	100
		Chinook	41	25	21
Georgia Strait	149	Sockeye	17	8	8
		Coho	125	105	84
		Pinks (odd/even)	91/105	34/21	26/13
		Chum	120	104	85
		Chinook	31	16	8
Lower Fraser River/Howe Sound	249	Sockeye	75	28	23
		Coho	225	171	136
		Pinks (odd/even)	104/14	57/2	47/2
		Chum	174	113	84
		Chinook	53	29	21
West Coast of Vancouver Island, South	34	Sockeye	8	5	3
		Coho	29	21	18
		Pinks (odd/even)	3/4	2/4	1/3
		Chum	23	19	16
		Chinook	12	6	4
West Coast of Vancouver Island, Mid	104	Sockeye	43	21	15
		Coho	79	64	60
		Pinks (odd/even)	17/22	5/14	5/14
		Chum	81	72	71
		Chinook	42	23	21
West Coast of Vancouver Island, North	144	Sockeye	61	32	32
		Coho	132	101	96
		Pinks (odd/even)	45/88	22/63	22/63
		Chum	134	118	113
		Chinook	69	44	41

for up to three gear types, in our calculations. Thus, our estimates of marine nutrient influx are conservative since in the earlier years of the record when average fish size was substantially larger, each carcass would have represented more potential N and P input to streams.

Enhanced south coastal streams of British Columbia often dominate the total regional escapements and provide most of the nutrient influx. Regarding individual species, nutrient influx often declines considerably, even to near zero, when only stocks from unenhanced streams are considered (Larkin and Slaney 1996). Although regional trends from adjusted data suggest that nutrient influx to most regions is increasing, trendlines from wild salmon escapements (unenhanced streams) do not depict the same degree of increase and, for some regions, strongly indicate a substantial decrease in marine nutrient influx. The dominance of the enhanced streams results in most of the marine nutrient influx focusing toward larger stream systems already undergoing significant enhancement. Large returns often concentrate to hatcheries or very short stream segments, and hence influxes of nutrients are not distributed throughout the catchment. We hypothesize that a trough in marine conditions (Beamish and Bouillon 1993), combined 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. In streams with small salmon escapements, stocks already in decline are likely to decrease further in a negative feedback loop (due to lessened biological productivity/oligotrophication) and the size-survival dependence of stream-rearing species of salmonids (Ward and Slaney 1988; Scrivener and Brown 1993).

The effects of nutrient loss via the process of oligotrophication... seriously threaten freshwater stocks

Examination of the nutrient influx trends reveals the significance of enhancement activity in maintaining species escapements and marine nutrient influx in some areas of south coastal British Columbia. Many wild salmon stocks are identified as at risk and have been the focus of recent publications (Walters 1995; Slaney et al. 1996). Arguments have suggested that large-scale enhancement can result in overfishing of weaker stocks (Larkin 1974) and introgression of wild stocks with hatchery fish, thereby decreasing genetic diversity (Hilborn 1991). Habitat restoration efforts should concentrate on improving the abundance of wild stocks of each species where declines in historical escapements are evident or suggested by trends in existing escapement data. Also, escapement targets used in salmon stock management need to include a risk-averse allotment of spawners to provide the nutrient influx essential to maintain stream productivity in the much more numerous wild salmon streams. This is a fundamental change from the conventional stock-recruitment method of harvest allocation, which ignores implications of overharvesting the "nutrient capital" of many nursery lakes and streams. Decisions regarding escapement numbers for one species need to consider impacts on and interactions with other species. Nutrient influx from dominant pink salmon runs influences the recruit-per-spawner, smolt size and number, and ocean survival of other rearing salmonids present (Ward and Slaney 1988; Michael 1995). Harvest management using traditional stock-recruitment paradigms, especially of weak stocks, needs to be reconsidered in light of the significant risk of nutrient food chain impacts on stock productivities.

Further work is needed to demonstrate whether the nutrients derived from salmon carcasses directly result in increased fish production (such as by controlled carcass introduction and depletion experiments; C. Walters, University of British Columbia, personal communication). Isotope signatures only reveal the movement of nutrients through the food chain and do not establish that nutrients from any source drive production. Recent stable isotope data from upper Fraser River tributaries demonstrate that insect body loads of marine-origin N vary directly with salmon abundance (Johnston et al. 1997) and strongly suggest that instream secondary production depends on the magnitude of salmon inputs. However, enough information has been gathered from isotope studies and fertilization experiments to conclude that wild stocks may be at risk, and, therefore, we argue for an immediate management response. Allowing for larger numbers of returning spawners would at least buy time to further determine the magnitude of the role of carcass-derived nutrient and carbon supplies in salmonid production. Decreases in allowable catch could be a small price compared with the consequences of no action, whereby weak stocks further decline via oligotrophication, and the opportunity to reverse the process is potentially lost through species extinction (Slaney et al. 1996). Hatchery-smolt marking programs (e.g., Georgia Strait coho) also could be employed to achieve much lower harvests of wild stocks and allow greater escapements to small wild-salmon streams.

The marine nutrient influx data collected to date, although not definitive, have sufficient merit and have identified such a significant risk to wild salmon production that they should be expanded into a complete review of all B.C. stocks at medium risk (78), at high risk (624), and of special concern (230) (Slaney et al. 1996). The trend analysis should be conducted over a longer period since both commercial fishing and habitat degradation from forest harvesting practices were well established at the turn of the century. B.C. commercial salmon catches routinely exceeded 20,000 t by 1896, and reached peaks as high as 104,000 t in 1930 (Hilborn and Winton 1993), despite a lack of modern electronics and fishing gear.

As well as managing for greater salmon escapements, we selectively need external organic and inorganic nutrient sources to oligotrophic streams with depressed salmon runs to increase biological productivity until the nutrient influx from spawners is returned to historic levels. In a stream with a mean mid-August-to-mid-October flow of 1 m^3s^{-1}, an odd-year pink salmon escapement of 60,000 would be equivalent to the introduction of 18 μgL^{-1} N and 2 μgL^{-1} P during that 2 months. Once-annual inputs of slow-release nutrient briquettes are an option that has been successfully tested in several coastal B.C. streams (Mouldey and Ashley 1996; Ashley and Slaney 1997) and have application until salmon escapements recover. Fertilization technologies also could compensate for productivity losses caused by historical river regulation since reservoirs can act as nutrient traps or sinks (Stockner and MacIsaac 1996; Ashley et al. 1997). Transporting excess salmon carcasses from hatcheries and spawning channels is another option supported by Schuldt and Hershey (1995) but requires caution to ensure no movement occurs outside local drainages to prevent disease transfer. Carcasses may also be an important source of trace elements, enhancing primary productivity beyond that of inorganic N and P alone (Wuhrmann and Eichenberger 1975).

In land-use-affected watersheds, any form of accelerated watershed recovery, including hillslope stabilization, streambank stabilization, replacement of overwintering instream cover, provision of spawning areas for non-rearing species, or off-channel habitat restoration and mitigation, 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 since entrainment of carcasses requires an adequate level of complexity in the stream environment (Michael 1995). The frequency of large woody debris (LWD) in streams greatly affects retention of salmon carcasses, particularly in high-gradient coastal streams (Cederholm and Peterson 1985; Cederholm et al. 1989). The capacity of many streams to retain carcasses may be greatly reduced by past logging practices that simultaneously alter stream hydrographs and riparian vegetation, and thus reduce instream LWD recruitment and retention; without habitat restoration, this would require a century or more to recover naturally (Slaney and Martin 1997). Trapped carcasses may be removed from the stream for consumption by terrestrial animals and subsequent nutrient cycling through the terrestrial ecosystem, with some of the energy from the terrestrial system returning as food for salmonids (Cederholm et al. 1989; Michael 1995; Willson and Halupka 1995).

Nutrient loss via the process of oligotrophication is more subtle than the obvious environmental and fisheries harm caused by excessive nutrients and eutrophication, but the effects still seriously threaten freshwater stocks (Stockner and MacIsaac 1996). Without a broad-based, integrated strategy of renewal by intensifying research on nutrient-salmon interdependence, habitat protection efforts, extensive restoration and mitigation of impacted fish habitat, and risk-averse fisheries exploitation, we are confronted with unsustainability and continued decline of weaker stocks of coastal wild anadromous salmonids, of which 142 have already become extinct (Slaney et al. 1996).

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