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Didymosphenia geminata (Gomphonemaceae)

A Review of the Ecology of *D. geminata* and the Physiochemical data of Endemic Catchments of Vancouver Island

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NHRI Contribution No. 93-005

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ABSTRACT

Didymosphenia geminata (Gomphonemaceae) blooms have been occurring on central Vancouver Island since 1988. Existing literature on *D. geminata* is restricted to general morphology. The occurrence of *D. geminata* accruals on Vancouver Island appears to be a novel event. Catchments with *D. geminata* were contrasted for similar geophysical and physicochemical trends. Alternatively, catchments with and without *D. geminata* were contrasted for dissimilarities. Qualitative inspection of general anthropogenic influence did not reveal any factors exclusive to catchments with *D. geminata*. Catchments with *D. geminata* are contained in humo-ferric podzol and exclusively on parent geology with poor buffering potential. Catchments without *D. geminata* are over or adjacent to areas with greater resistance to acidic deposition. Edaphic influence on acidic deposition within a catchment may be important. All catchments with *D. geminata* are bound within a 100-180 day frost free zone. No significant trends in the annual flow of affected rivers were apparent, however, monthly mean and maximum flows have been depressed since 1985. The influence of flow on scour efficiency, light levels, temperature, and bulk water chemistry may have contributed to the recent expansion of *D. geminata*. Precipitation chemistry data nearest catchments with *D. geminata* were most similar to data obtained from the southeast coast of the island. *D. geminata* would be expected to expand south if precipitation effects are significant. Bulk river chemistry data revealed the absence of annual trends for all examined parameters. Similarly, there were few patterns within affected catchments or differences between affected and control catchments. Differences in pH levels and alkaline ions between affected and control catchments were not significant. The data also suggested that nutrient enrichment (N+P) was not an important factor in *D. geminata* blooms. Dissolved aluminum levels and the ratio of dissolved to total iron were the greatest and lowest, respectively, in affected catchments. Silicon levels were elevated in all affected catchments and may control the magnitude of the bloom. River chemistry data resolution was generally to poor to analyze trace metal levels. Detailed analysis of physiochemical parameters influencing *D. geminata* growth was not possible because the database represents only bulk water chemistry. Spikes associated with point source pollution, diel changes, and precipitation events could not be detected. The impact of pulse loading is important in lotic community structure and should be considered in future monitoring.

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1. INTRODUCTION

Unusually high population levels of the diatom *Didymosphenia geminata* have been documented in several rivers on Vancouver Island. References to *D. geminata* in literature are rare and the species is not usually considered a nuisance algae. Since confirmation of the large diatomaceous accumulations in 1985, *D. geminata* blooms have been increasing in severity and geographic distribution. The presence of the algal mats appears to be limited solely to central Vancouver Island and often occurs in rivers which do not appear to be directly influenced by anthropogenic activity. In addition to aesthetic concerns, the impact of the unusually severe diatom blooms upon water quality and aquatic flora and fauna appears to be significant. Invertebrate diversity seems to be negatively correlated with increasing *D. geminata* populations. Of specific concern is the decrease in invertebrates that form a substantial portion of juvenile salmonid diet and the physical alteration of traditional spawning areas associated with thick diatomaceous mats.

The report objectives include the following:

- A complete literature review of *D. geminata* ecology
- Precipitation chemistry data review
- Lotic chemistry data review
- Hydrological data review
- Examination of effected watersheds with respect to unique geological and physiochemical properties
- Preliminary culture study
- Recommendations for 1993 monitoring/research program

The nature of existing relevant data is restricted to recent time periods and is confounded with numerous factors. Conclusions, however, will be drawn from the accumulation, evaluation, and synthesis of environmental data that are correlated to the recent occurrence of *D. geminata* in specific rivers on central Vancouver Island. The abundance of *D. geminata* as a function of nutrients, light, temperature, river discharge, and invertebrate grazing will be examined. Relevant information obtained from impacted drainage basins will be compared to lotic systems free of *D. geminata* blooms and geology of the watersheds. Results of analyses may confirm responses of *D. geminata* to anthropogenic impacts and/or natural phenomena. Recommendations will be drawn from the conclusions and form a focus for future quantitative research.

2. LOCALE

Vancouver Island, British Columbia, is located in the Cordillera physiographic region of the west coast. The Cordillera is predominantly mountainous with crystalline, sedimentary, and volcanic underlying geology. River patterns are determined primarily by topography and are typically dendrite or angular (Environment Canada 1978). A large area of coastal B.C. and Vancouver Island is dominated by shallow acidic soils overlying granite and shale bedrock (Wiens et al 1987).

Precipitation over Vancouver Island is influenced by frontal and orographic factors. Prevailing westerly winds release the majority of precipitation on west slopes. Unlike the central mainland, much of the winter precipitation is in the form of rain, rather than snow. The summer is characterized by heavy showers. The majority of precipitation occurs during the winter. Mean annual precipitation for Vancouver Island typically exceeds 250 mm for all regions except the North East coast. Approximately 75% of the average annual precipitation occurs between October and March on Vancouver Island. The period between October and March also corresponds to the maximum flow in most second order or larger streams on Vancouver Island (Farley 1979). Precipitation monitoring stations are located at Nanoose, Port Hardy, and Victoria. The station at Nanoose is located the closest to affected catchments.

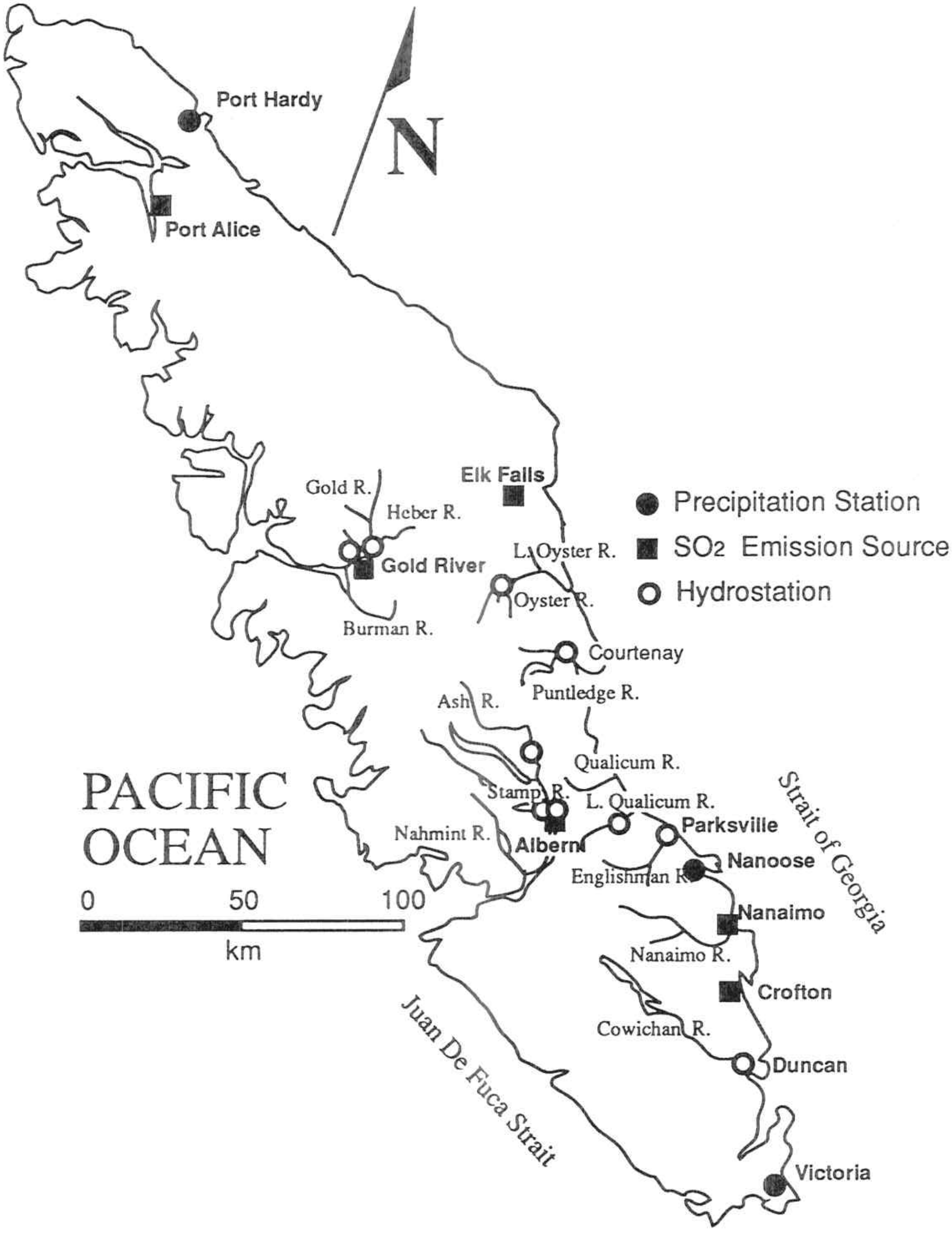

Fig. 1. Vancouver Island. Major rivers with *D. geminata* blooms are depicted. *D. geminata* mats were not found in the Cowichan River and Nanaimo River as of the summer, 1992. Precipitation stations, hydrostations, and point sources of SO_2 emissions referenced in the text are identified.

3. METHOD

3.1. LITERATURE REVIEW

A comprehensive literature search was conducted on the following databases:

- Biological Abstracts (1969-1992)
- Ecology Abstracts (1974-1992)
- Aquatic Science and Fisheries Abstracts (1985-1992)
- General Science Index (1988-1992).

Related references were obtained following a brief overview of information from the initial literature search. Database searches utilized the following key phrases in addition to information based on Genus and species of *D. geminata* and near relatives:

- Bloom and Diatom
- Nuisance and Diatom
- Ecology and Diatom
- Fertilizer and Diatom
- Deforestation or Clearcut and diatom

Searches based on *Gomphonema*, *Cymbella*, and *Encyonema* reflected morphological and physiological similarities between these families and *Didymosphenia* (Round *et al.* 1990, Kociolek & Stoermer 1988).

3.2. GEOPHYSICAL DATA

3.2.1. CATCHMENTS

Catchment areas for the following rivers were determined:

- Ash River
- Burman River
- Englishman River
- Gold River
- Nahmint River
- Oyster River
- Puntledge River
- Qualicum River
- Little Qualicum River
- Stamp River
- Sproat River
- Stamp River

Catchment areas were calculated using the following 1:250 000 scale maps (ASE EDITION 1-5: SERIES A 502):

- Alert Bay (92 L)
- Bute Inlet (92 K)
- Alberni (92 F)
- Nootka Sound (92 E)
- Cape Flattery (92 C)
- Victoria (92 B)

These areas were pieced together to form a single composite map. The catchment for each river system provided clear definitions of possible natural and anthropogenic influences. The pattern of anthropogenic point sources, such as townships, mines, and/or paper industries in each catchment were considered. Geophysical patterns, such as local geology, soil, and climatic patterns, were also compared for qualitative similarities. The Cowichan River and the Nanaimo River were used as a control sites for comparisons.

The catchments were superimposed on composites of the ASE maps to determine several levels of anthropogenic influence: The number of hard surface and secondary roads, townships, mines, and pulp mills. Potential influence of wet sulphate deposition in the immediate areas around major pulp mills were superimposed on the catchment map. Potential radius of deposition was based on emission rate per day (3 $km.ton^{-1}.d^{-1)}$ interpolated from data in Wiens (1987).

Maps depicting geophysical data were digitized and superimposed on the composite catchment map for direct comparison. Underlying geology, soil type, temperature, radiation, and precipitation were qualitatively compared with catchment maps in an attempt to identity common factors in areas that *D. geminata* has been documented.

3.2.2. FLOW

Approximately 75% of the average annual precipitation occurs between October and March on Vancouver Island. The period between October and March also corresponds to the maximum flow in most 2^{nd} order or greater streams on Vancouver Island (Farley 1979). The coincidence of these factors is a function of seasonal temperatures and accumulation of snow. Snow fed flow maximums in interior British Columbia, for example, occur during the summer months. River chemistry and precipitation chemistry data for Vancouver Island was subsequently divided into two levels: "low" and "high" months. Data averaged between October-March and April-September were grouped as "high" and "low", respectively, for analysis purposes. This interval also corresponds roughly with appearance and sloughing of the *D. geminata* mats in affected rivers (Rieberger 1991).

Flows ($m^3.s^{-1}$) were analyzed between 1975-1990 for the following rivers with hydrostations (Fig. 1):

- Ash R. below Moran Creek (49°22' N, 124°58' W: 378 km^2)
- Cowichan R. near Duncan (48°46' N, 123°42' W: 826 km^2)
- Englishman R. near Parksville (49°19' N, 124°16' W: 324 km^2)
- Gold R. below Ucona R. (49°42' N, 126°06' W: 1010 km^2)
- Little Qualicum R. at Cameron Lake (49°17' N, 124°35' W: 135 km^2)
- Oyster R. below Woodhus Creek (49°53' N, 125°14' W: 298 km^2)
- Puntledge R. at Courtenay (49°41' N, 125°01' W: 583 km^2)
- Somass R. near Alberni (49°17' N, 124°52' W: 1280 km^2)
- Sproat R. near Alberni (49°17' N, 124°54' W: 349 km^2)

Position and immediate catchment area is listed with each station. Data were obtained at a daily resolution from HYDAT (1990). The Cowichan River was used as a control site for flow comparisons with catchments affected with *D. geminata*. Possible impact of flow diversions (Deniseger 1992c) were considered.

Annual trends in flow levels within each site, between 1975 and 1990, were examined using simple linear regression. Subtle changes in seasonal flow regime and scouring capacity can influence diatom community structure. Subsequently, flow maximums and flow means were considered at a monthly resolution. Monthly flows were analyzed to determine if patterns had changed between the periods prior to documentation of *D. geminata* and after its establishment. Subsequently, data was grouped into "prior" (1979-1984) and "later" (1985-1990) temporal levels. Two-way analysis of variance with equal replication, blocking by month, was used to determine the significance of observed differences in flow (Wilkinson et al 1992 & Zar 1984).

3.2.3. PRECIPITATION CHEMISTRY

Precipitation data collected at Victoria, Nanoose, and Port Hardy (Fig. 1) were available for comparison between 1987-1991. The following parameters were analyzed for significant variation between stations:

- precipitation
- pH
- sulphate
- nitrate
- ammonia
- chloride
- calcium
- magnesium
- sodium
- potassium

The list also represents, in decreasing priority, the order that the parameters in the precipitation data base were collected and analyzed (BC MOE 1987). Data for each parameter were not available for each sampling period. To facilitate comparisons and analyses, precipitation chemistry data for Victoria, Nanoose, and Port Hardy were filtered into days with complete precipitation and pH data and subsequently grouped into periods of high and low flow. All analyses were based on low flow data only. The analysis restriction was an attempt to weight results that reflected the increased sensitivity of the river systems to precipitation and the seasonal blooming of *D. geminata* during low flow. The data were analyzed using two-way analysis of variance with the parameter and year as factors. If the parameters were significantly different between stations ($\alpha<0.05$), the Tukey test was used to determine the source of significant variation. The data was fitted using simple linear regression to determine if any trends were apparent within each site for all aforementioned parameters between 1986 and 1992. Significance of the regression slope was determined with ANOVA.

The precipitation data was recorded in total precipitation for each collection period. Precipitation (mm) was divided by the duration of collection (days) to determine a precipitation rate. Precipitation rates for each month were averaged to yield an average daily precipitation rate ($mm.d^{-1}$). Monthly precipitation data were averaged to find a mean monthly rate. Mean total annual and mean total monthly precipitation data were subsequently determined by considering the appropriate time constants.

Application of precipitation data on the affected catchments was determined by drawing a 25 km radius zone around the three precipitation stations. Given the variability of local weather patterns influenced by topography and the ocean, the assumption of similar weather patterns within 25 km radius of each precipitation station is generous. However, it is reasonable to assume that some precipitation factors might be similar within such a radius and a qualitative comparison is not unjustified.

3.3. RIVER CHEMISTRY

River chemistry data were analyzed for catchments containing the following stations:

- Englishman River at Highway #1 (1986-1987)
- Gold River at Highway (1989-1990)
- Heber River just upstream of Gold River (1989-1990)
- Oyster River above Oyster Bowl Camp (1986)
- Oyster River at Highway (1980-1990)
- Oyster River at a logging road bridge (1986-1988)
- Oyster River south of Adrian Creek (1988)
- Little Oyster River at York Rd. (1988-1989)
- Puntledge River at CF Bridge (1971-1985)
- Puntledge River at Condensory Bridge (1979-1990)
- Stamp River at Stamp Falls Park (1986-1990)
- Nanaimo River at Highway #1 (1989-1992)
- Nanaimo River at Camp (1990-1992)
- Nanaimo River at South Fork (1990-1992)
- Nanaimo River at Teepee Bridge (1990-1992)
- Nanaimo River at Cedar Bridge (1991-1992)
- Cowichan River upstream of PE-247 (1976-1992)
- Cowichan River downstream of PE-247 (1985-1992)
- Cowichan River at a weir (1985-1992)

The river chemistry data were generally not comprehensive enough to allow statistical analysis on a monthly level between stations. Consequently, river chemistry data was also grouped into periods of "high" and "low" flow corresponding to months of October to March and April to September, respectively. Soluble and total forms of chemical analytes were considered for periods of low flow (Table 1). Data recorded at less than or equal to minimum detectable level were given a dummy value equal to the minimum detectable level. If two minimum detectable levels were used within a data set, the lowest detectable level was used to avoid artificially inflating the data.

Table 1. River chemistry analytes. River chemistry parameters examined for temporal trends and/or significant differences between sites. Soluble, total, and dissolved form considered where applicable if the data were above minimum detection limits.

- Alkalinity
- Aluminum
- Ammonia
- Arsenic
- Boron
- Cadmium
- Calcium
- Chloride
- Chromium
- Copper
- DO
- Hardness
- Iron
- Lead
- Magnesium
- Manganese
- Molybdenum
- Nickel
- Nitrite
- Nitrate+Nitrite
- pH
- Orthophosphate
- Phosphate
- Potassium
- Silica
- Sodium
- Sulfate
- Temp
- Vanadium
- Zinc

Data from Oyster River at logging road bridge and Puntledge River at CF and Condensory bridge were comprehensive enough to determine if any annual trends existed for most of the aforementioned parameters. Data, grouped by periods of low flow, were fitted using simple linear regression if data were available for more than 6 years. Significance of the regression slope was tested using ANOVA. Data from the Puntledge catchment were pooled to provide an extended database. MANOVA was used to determine whether pooling the data was a reasonable assumption. Two factors in the MANOVA analysis were considered for each parameter: Site (CF and Condensory) and Year (1979-1985) for periods of low flow. ANOVA was used to determine whether significant differences in parameter concentration existed between sample sites. If the data were not comprehensive enough to test between sites, the data within a catchment were pooled and catchments were compared. The stations were grouped into the following catchments:

- Gold/Heber
- Oyster
- Puntledge
- Cowichan
- Nanaimo

If the parameters were significantly different between sites or catchments ($\alpha<0.05$), the Tukey test was used to determine the source of significant variation. Stations along the Nanaimo and the Cowichan rivers were used as a control for comparisons.

3.4. *DIDYMOSPHENIA GEMINATA* CULTURE

Two attempts were made to culture *D. geminata* from samples obtained at Stamp River, 08/92. Several replicates of isolate *D. geminata* cells were rinsed in prepared media and placed in culture tubes with ~15 ml of media . Additionally, portions of a *D. geminata* mat were placed in 125 ml flasks with 50 ml of media. Both cultures were incubated at a constant ~15°C on shaker tables under fluorescent grow lights. The procedure was repeated one week later. The effectiveness of the method and media were validated by viable cultures of *Gomphonema* sp. isolates from the Thompson River, British Columbia (08/92). Culture methodology and media detailed in Eppley (1977), Stein (1973), and Guillard & Lorenzen (1972).

4. RESULTS & DISCUSSION

4.1. *D. GEMINATA* IN LITERATURE

4.1.1. NOMENCLATURE

The diatoms forming the matrix of the observed diatomaceous mats have been positively identified (Zenon Environmental Inc. 1990, Hoagland 1992) as *Didymosphenia geminata* (Lyngb.) M. Schm. var. *geminata* (1989) of the family Gomphonemaceae. *Didymosphenia geminata* has been renamed from *Gomphonema geminata.* (Lyngb.)

1824 and *Echinella geminata* Lyngb. 1819. Additionally, *Didymosphenia* is occasionally spelled as "Didymosphaenia" by some authors (Dawson 1973a, 1973b). Unless qualified, *D. geminata* will refer to *Didymosphenia geminata* throughout the report.

Specific references to *D. geminata* were virtually absent from all the aforementioned databases. Similarly, literature on algae blooms within Gomphonemaceae and Cymbellaceae was limited or non applicable. With respect to documentation, the phenomena of *D. geminata* blooms on Vancouver Island appears to be a novel event.

4.1.2. GENERAL MORPHOLOGY AND ECOLOGY

Valve and girdle views of *D. geminata* are provided in Patrick and Reimer (1975). A complete description of morphology is given by Dawson (1973b). Dawson (1973a & 1973b) points out similarities between *Gomphonema* and *Didymosphenia.* Kociolek and Stoermer (1998) suggest that *Didymosphenia* is more related to *Cymbella* and *Encyonema* than to *Gomphonema* and *Gomphoneis*. Characteristic of Gomphonemaceae and Cymbellaceae families is the formation of mucilage stalks (Huntsman 1966). It has been demonstrated that mucilage stalks are particularly adaptive in vertical growth and firm attachment to substrate in lotic systems (Roemer *et al.* 1984). Subsequently, a mucilage matrix promotes colonization of substrate in lotic systems in epilithic periphyton (Steinman & McIntire 1990) .

Patrick (1977) states that flow regime, temperature, light levels, nutrients, trace metals, alkaline ions, and community structure are important in determining diatom growth patterns. Information on the general ecology of *D. geminata*, itself, was limited to data and observations previously made on Vancouver Island and to references by Antoine and Benson-Evans (1986, 1983). Factors suspected of influencing the ecology of *D. geminata* were synthesized from data pertaining to the Gomphonemaceae and

Cymbellaceae families. Information specific to *D. geminata* will be discussed under appropriate sections later in the text.

D. geminata was always observed growing epilithically with other epiphytic gomphonemoid diatoms in a lotic systems (Dawson 1973a, Rieberger 1991, Antoine & Benson-Evans 1983). Interactions between heterotrophs and autotrophs in the matrix may be essential in maintaining a community. Factors that directly influence the growth of periphyton following colonization (Steinman & McIntire 1990) include:

- Production & growth rate
- Life history strategy
- Competitive ability
- Defense against herbivory

The possibility that *D. geminata* blooms are directly or indirectly dependent on the presence of one or more interspecific taxa has yet to be documented.

4.1.3. GRAZING

Biomass and fecundity of macroinvertebrate grazers is typically a function of abiotic constraints on periphytic productive capacity (Lamberti et al 1989). In streams with cyclic disturbance, stream periphyton is typically nutrient limited while grazing insects are limited by food resources (Hart & Robinson 1990). Alternatively, during periods of flow homogeneity the effects of macroinvertebrate grazing may be significant (DeNicola et al 1990). Increased grazing, however, is not synonymous with decreased biomass. *Gomphonema* sp. and *Synedra* sp., for example, increase in relative abundance with selective grazing pressure of more palatable diatoms (Hill & Knight 1987). Furthermore, Rieberger (1990) reports that some grazers, such as *Dicomoecus* sp., may find *D. geminata* unpalatable. The indirect effects of water chemistry on invertebrate populations and *D. geminata* will be discussed later in the text where applicable.

4.2. ANALYSIS OF GEOPHYSICAL FACTORS

4.2.1. GEOGRAPHIC POSITION OF AFFECTED CATCHMENTS

The headwaters of all affected river systems were restricted to central Vancouver Island (Fig. 2). Fig. 2. was complied from the 1:250 000 maps (Fig. A1-A6.) in Appendix A. Inspection of each catchment did not reveal any qualitative difference in distribution of roads, paper and pulp, and mines.

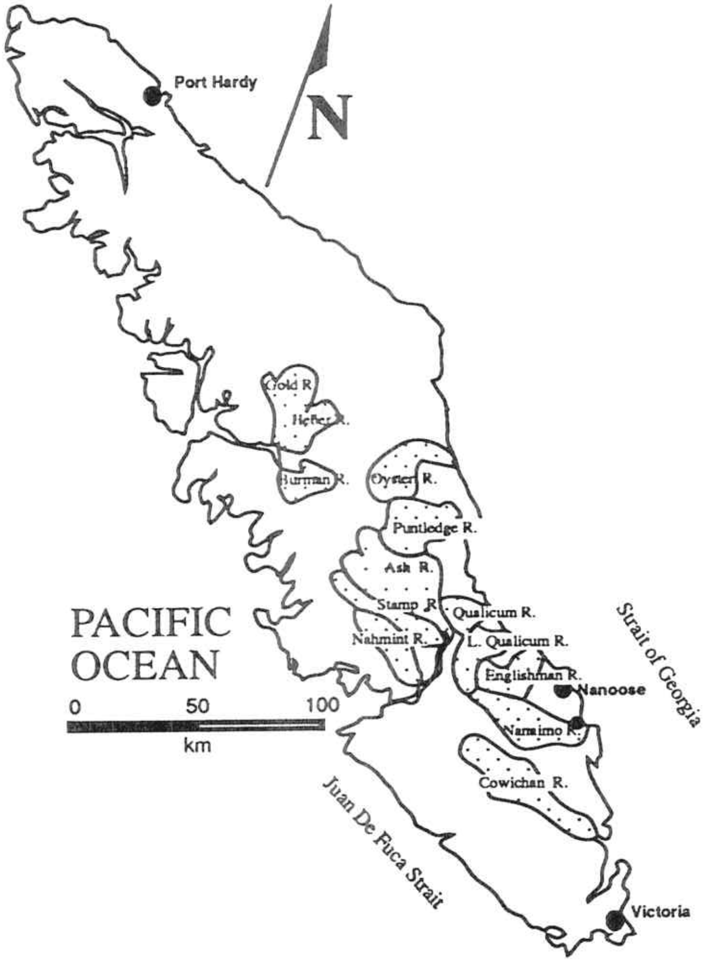

Fig. 2. Catchments of affected and control rivers. Location of the Nanaimo and Cowichan catchments were contrasted against systems that have reported *D. geminata* blooms since 1988. The figure is compiled from 1:250 000 maps in Appendix A.

Both control rivers, the Cowichan and the Nanaimo, had a higher township density within their respective catchments. The fact that the Nanaimo and Cowichan catchments had higher a townships density than the affected areas suggests that cultural eutrophication of the river systems is not a significant factor in *D. geminata* blooms. Literature on the effects of forestry practices on lotic systems with *Didymosphenia*, *Gomphonema*, or *Cymbella* was nonexistent. Similarly, literature linking fertilization and/or pesticide application with algae blooms in general was not specifically related nor applicable to the situation on Vancouver Island. Documentation of fertilizer and/or pesticide application (Deniseger 1992a) was reviewed with respect to influence on the aforementioned catchments. Studies that link forestry practices and nuisance algae in associated catchments are numerous, however, most data indicate conditions favorable to Chlorophyta and Cyanophyta, rather than diatoms (Hansmann & Phinney 1973). Though it is possible that forestry practices may act as a catalyst for *D. geminata* growth, it is unlikely that this is the sole cause of the diatom bloom. Forestry, fertilization, and/or pesticide practices are standard throughout Western Canada. In contrast, *D. geminata* blooms are a highly localized phenomena and have been observed in catchments free from recent anthropogenic influence.

The apparent restriction of *D. geminata* to central Vancouver Island suggests that unique localized geophysical conditions may contribute to the bloom phenomena. Inspection of precipitation levels and net solar radiation throughout Vancouver Island during the summer months did not reveal any dissimilarities between affected and control catchments (Farley 1979, Environment Canada 1978). Temperature patterns also did not distinguish between catchments with and without *D. geminata* (Fig. 3), however, all affected catchments were contained within a zone with less than 180 frost free days. Seasonal temperature profiles may influence continued expansion of *D. geminata*. If *D. geminata* is restricted to temperature contours observed in central and south Vancouver Island, then blooms will be absent from north Vancouver Island.

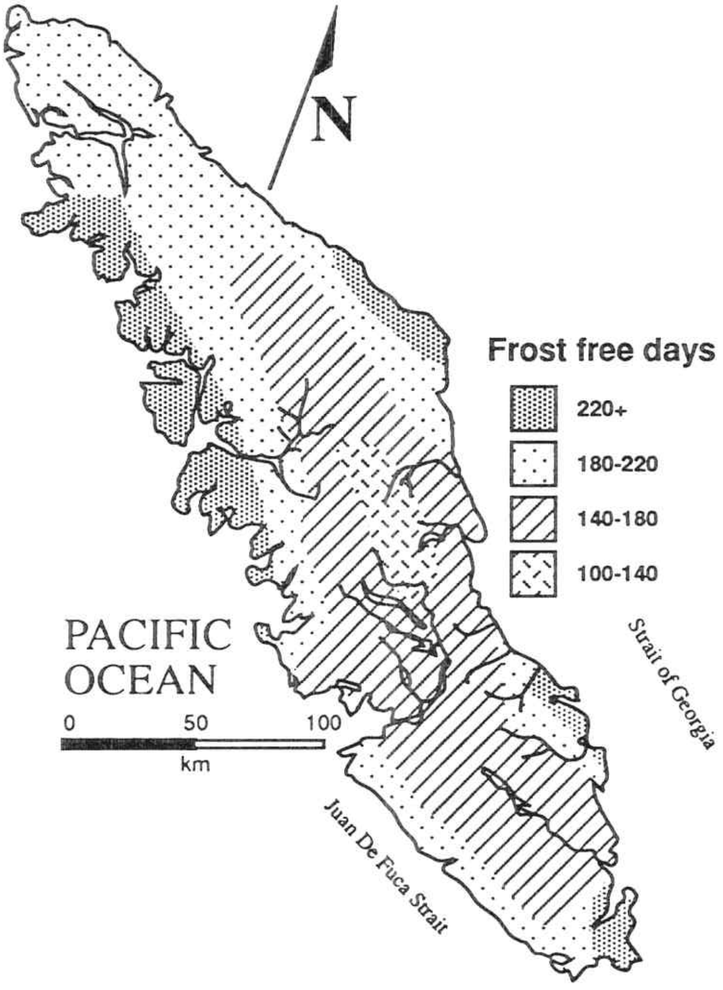

Fig. 3. Frost free days. Temperature profiles throughout Vancouver Island did not contrast affected and control catchments. Location of the Nanaimo and Cowichan catchments were contrasted against systems that have reported *D. geminata* blooms since 1988. Adapted from Farley (1979).

Vancouver Island soil can be divided into three general classes: Dystric brunisol, humo-ferric podzol, and ferro-humic podzol (Fig. 4). Podzol soils are classified as a well drained matrix subject to extreme leaching of clay, organic matter, iron, and aluminum. Organic matter accumulates in the subsoil. Dystric brunisol soils are associated with moderate leaching of calcium carbonate and other soluble salts. Catchments with observed *D. geminata* blooms all originate in the humo-ferric podzol zone. Parent geology of central Vancouver Island consists mainly of intrusive (granite, granodiorite, and diorite) and volcanic (andesite, basalt, rhyolite) formations (Fig. 5). The northeast and southwest coast are characterized by sedimentary rock consisting mostly of limestone and dolomite. Catchments with *D. geminata* all originated in volcanic and/or intrusive formations (Fig. 5).

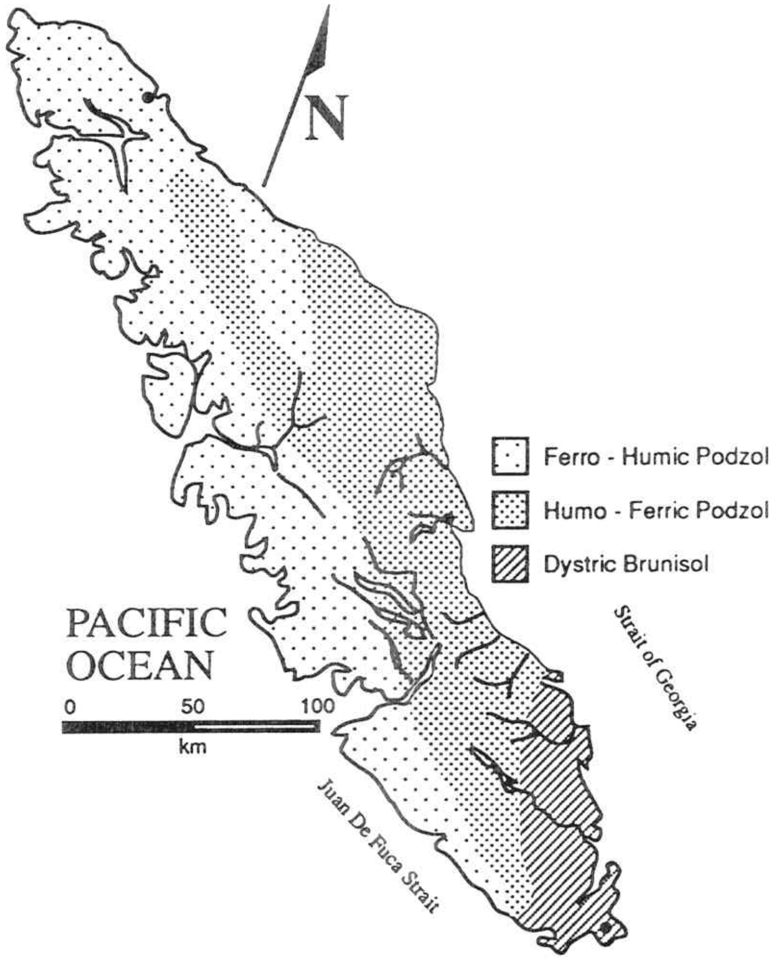

Fig. 4. Distribution of soils on Vancouver Island. Catchments with observed *D. geminata* blooms all originate in the humo-ferric podzol zone.

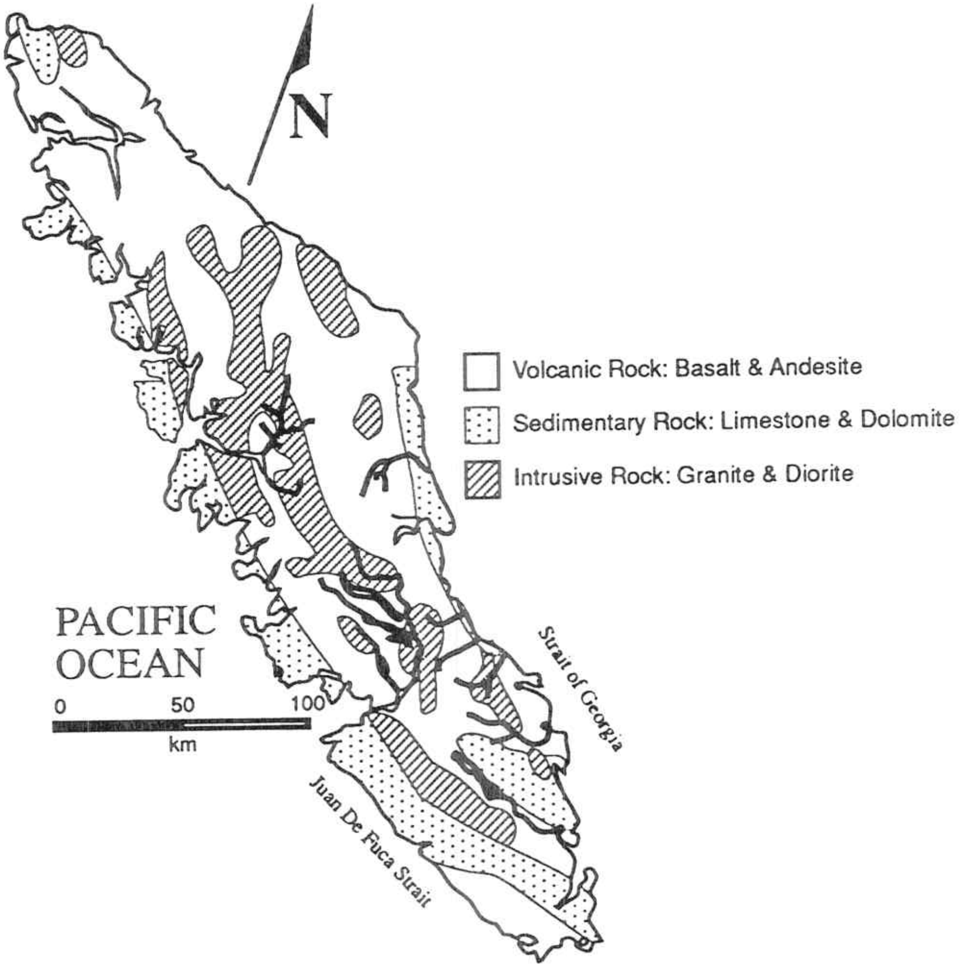

Fig. 5. Geological map of Vancouver Island. Affected catchments are associated with intrusive and volcanic rock formations. Adapted from BC MEMRP (1983).

Several factors, solely or synergistically, may explain the absence of similar blooms from northern and southern reaches of the island and from the mainland. Maps detailing the buffering capacity of the geology and the susceptibility of the soil to acidic inputs (Wiens 1987) were analyzed for patterns consistent with the location of *D. geminata* blooms. The combined potential of the parent geology (Fig. 5) and the soil (Fig. 4) to buffer acidic deposition have been summarized by Wiens (1987). All catchments with *D. geminata* are contained in zones with low buffer potential (Fig. 6). The Cowichan system is included in this zone, but the Nanaimo is not. Wiens also proposed areas where the soil would be most susceptible to chemical alteration (Fig. 7). The Nanaimo catchment is the only river system in an area of moderate sensitivity. The remaining affected catchments and the Cowichan are in zones classified as highly sensitive to acidic deposition.

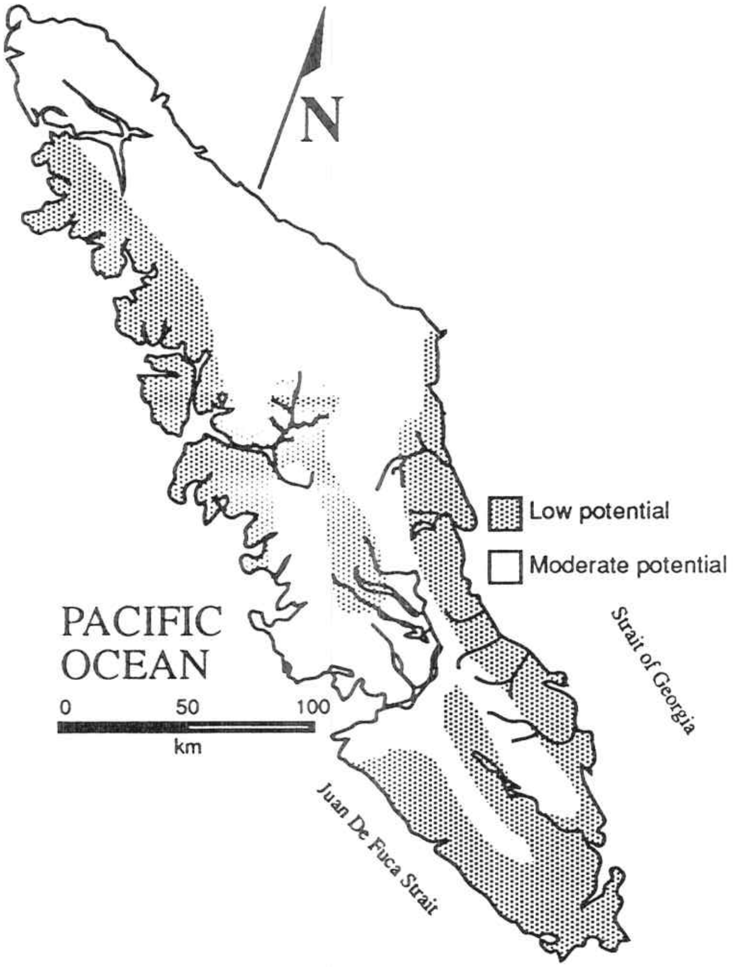

Fig. 6. Potential of soil and geology to reduce acidic deposition. Affected river systems and the Cowichan are in zones with poor buffering potential. Maps based on soil and geology data, in addition to drainage patterns, soil depth, and dominant vegetation. Adapted from Wiens (1987).

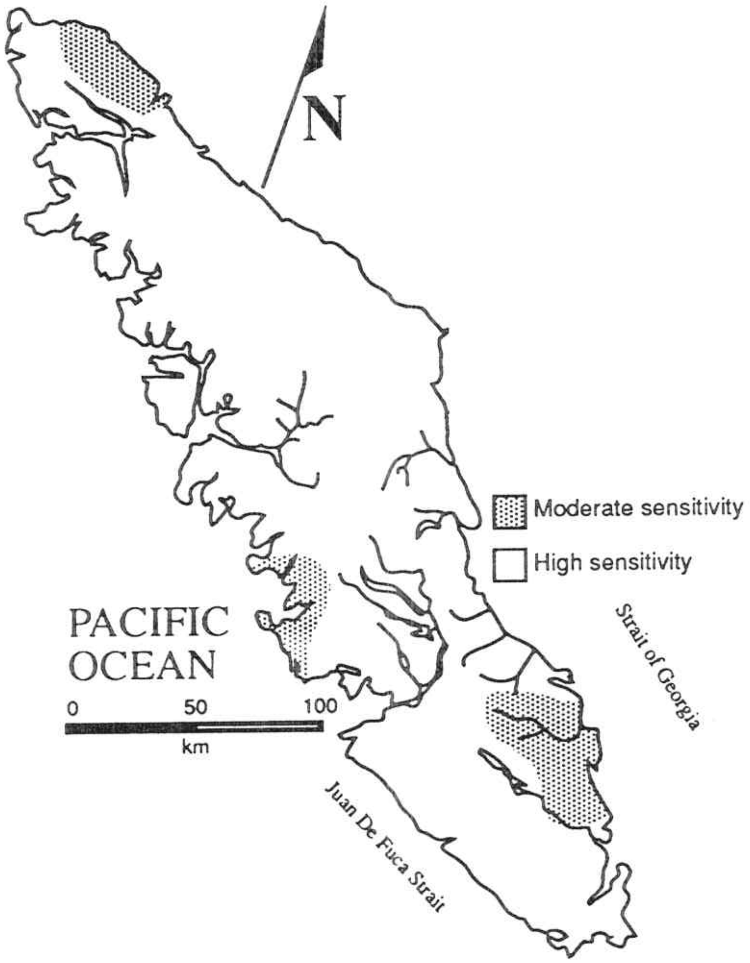

Fig. 7. Sensitivity of soil to acidic precipitation. Affected rivers system and the Cowichan are in highly sensitive zones. Maps based on soil and geology data, in addition to drainage patterns, soil depth, and dominant vegetation. Adapted from Wiens (1987).

4.2.2. HYDROLOGICAL DATA

No significant annual trends (Fig. 8) were apparent in affected and control river systems (ANOVA, n=16, P>0.30 for all sites). Qualitative inspection of Fig. 8 demonstrates that annual flow patterns were consistent between affected rivers and the Cowichan River. Flow, monthly maximum and mean, between the years 1979-1984 and 1985-1990, however, were significantly different for several sites. Table 2 summarizes data for affected rivers and the Cowichan. Mean and maximum flows between the months of April and September were all lower in the 1985-1990 time group (Fig. 9-13).

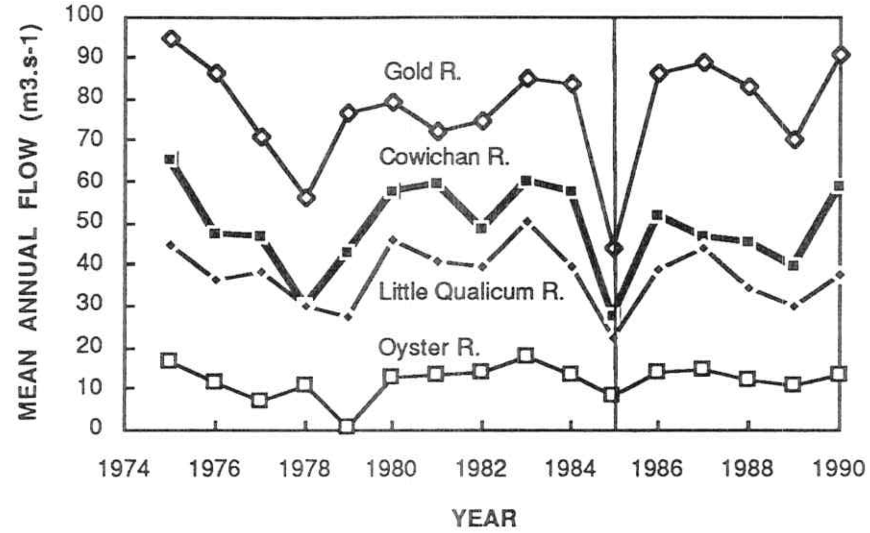

Fig. 8. Mean annual flow 1975-1990. Data collected from Gold R. below Ucona R., Little Qualicum R. at Cameron Lake, Oyster R. below Woodhus Creek, and Cowichan R. near Duncan. The division at 1985 marks the beginning of documented blooms of *D. geminata*. No significant annual trends are apparent.

Table 2. Mean and maximum monthly flow. Mean flow based on monthly data between the years 1979-1984 (PRIOR) and 1985-1990 (LATER). Maximum flow represents the mean of flow maximums for each month in the two periods. Value and standard error (n=72) are reported. 2-Factor ANOVA with equal replication (n=6), blocked by month, determined the significance of differences between 1979-1984 and 1985-1990. Sites that show significant difference in mean and maximum flows (α=0.10) are bolded.

	Mean Flow			Maximum Flow		
Hydrostation & River	PRIOR	LATER	P	PRIOR	LATER	P
Ash River Below Moran Creek	17 ± 0.2	13 ± 0.2	0.105	62 ± 0.9	51 ± 0.9	0.220
Cowichan River Near Duncan	**54 ± 0.7**	**45 ± 0.6**	**0.025**	**99 ± 1.3**	**77 ± 1.1**	**0.017**
Englishman River Near Parksville	**16 ± 0.2**	**12 ± 0.2**	**0.023**	**77 ± 1.4**	**49 ± 0.9**	**0.016**
Gold River Below Ucona River	79 ± 0.7	77 ± 0.8	0.873	303 ± 4	321 ± 5	0.683
Little Qualicum R. At Cameron L.	**9 ± 0.1**	**7 ± 0.1**	**0.012**	**26 ± 0.4**	**18 ± 0.3**	**0.032**
Oyster River Below Woodhus Creek	12 ± 0.2	12 ± 0.1	0.863	42 ± 0.7	40 ± 0.6	0.808
Puntledge River At Courtenay	**41 ± 0.3**	**35 ± 0.3**	**0.053**	**93 ± 1.1**	**81 ± 1.1**	**0.035**
Somass River Near Alberni	**127 ± 1**	**103 ± 1**	**0.012**	**266 ± 3**	**216 ± 3**	**0.063**
Sproat River Near Alberni	**39 ± 0.4**	**32 ± 0.4**	**0.023**	**73 ± 0.9**	**57 ± 0.7**	**0.031**

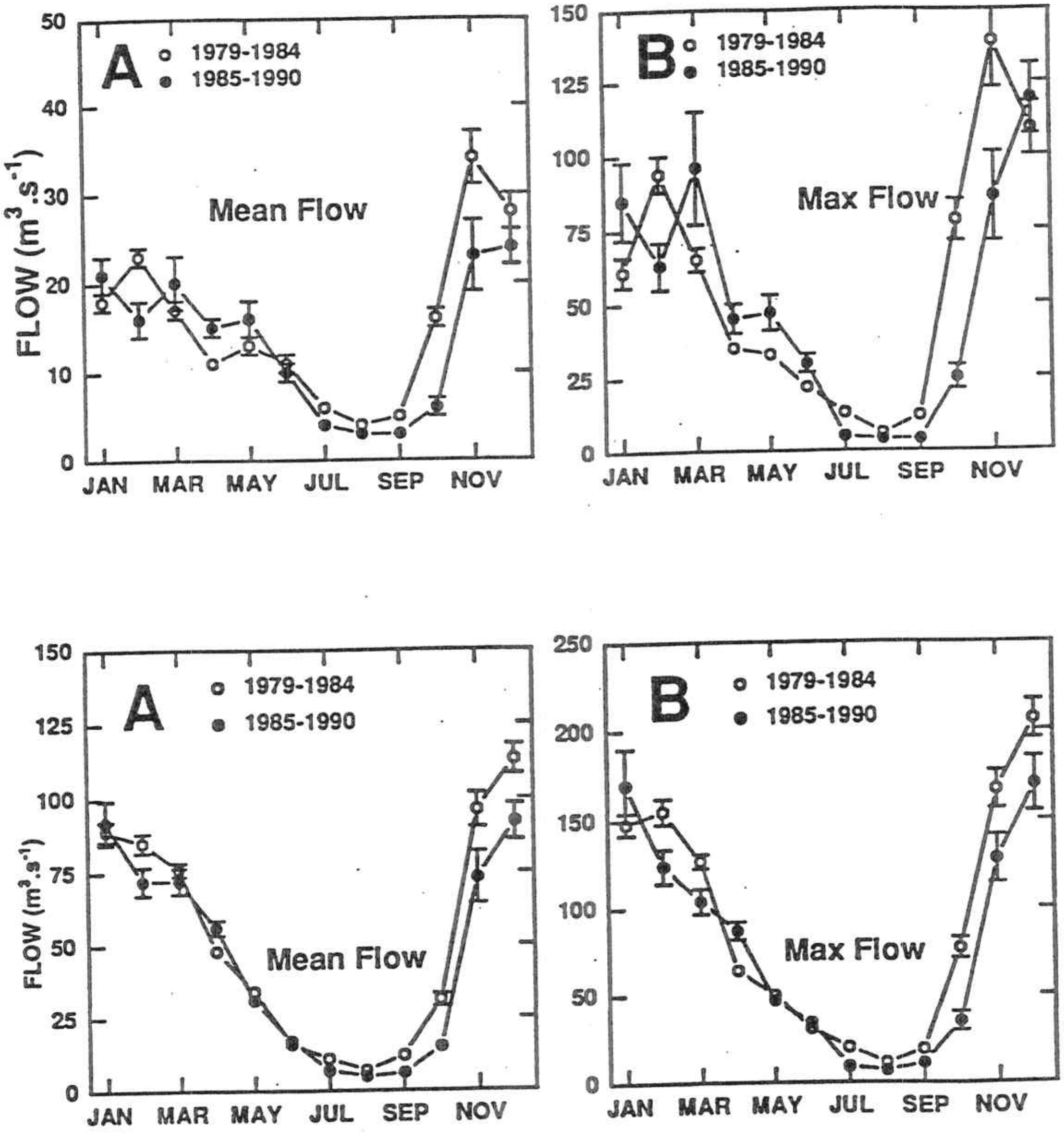

Fig. 9. Monthly flow at Ash River and Cowichan River. (TOP) Ash River below Moran Creek and (BOTTOM) Cowichan River near Duncan. (A) Mean monthly flow and (B) Maximum flow. Mean values were calculated between the years 1979-1985 and 1985-1990, respectively, for each month. Maximum flow represents the mean of monthly flow maximums between the years 1979-1985 and 1985-1990, respectively.

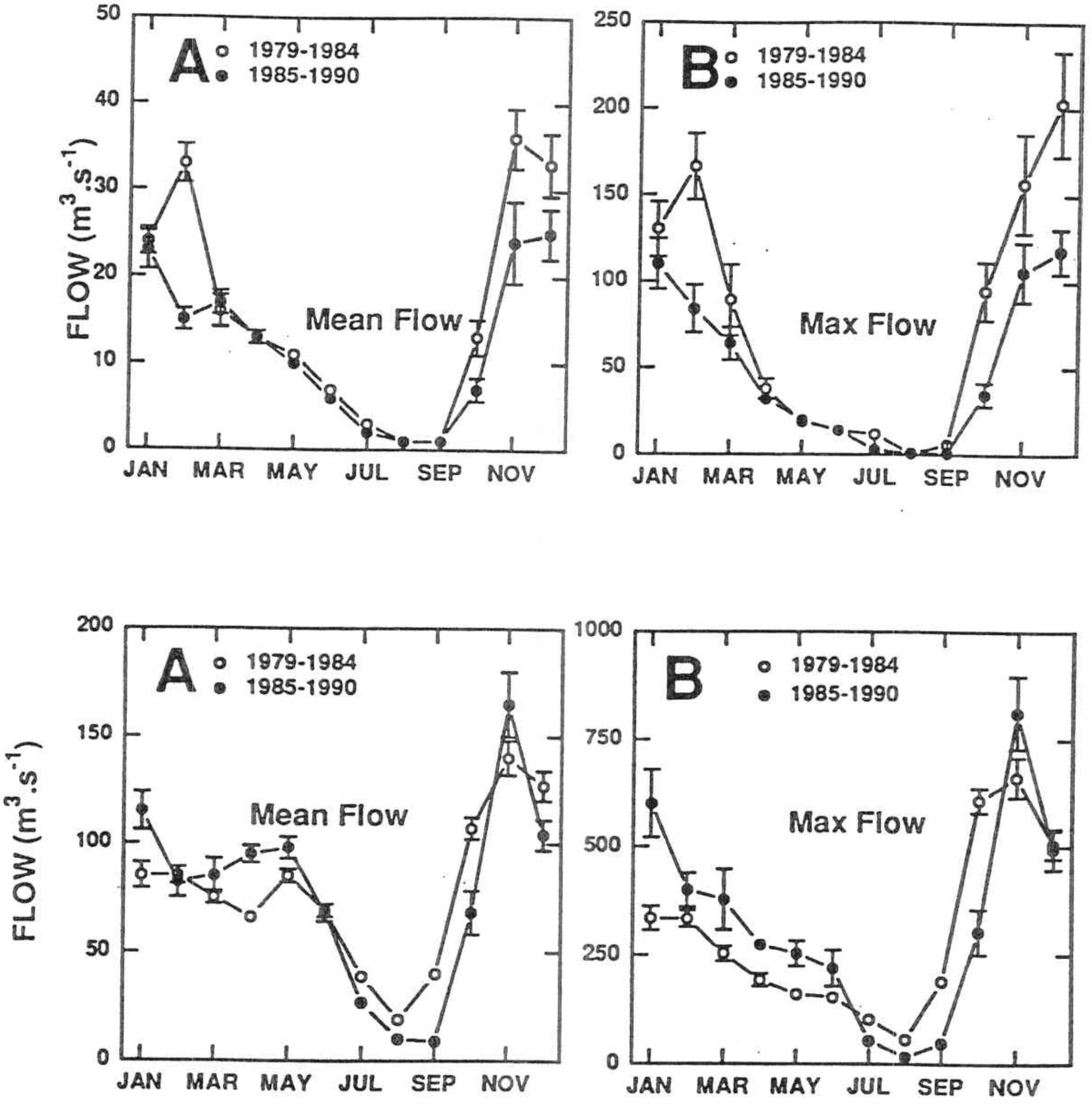

Fig. 10. Monthly flow at Englishman River and Gold River. (TOP) Englishman River near Parksville and (BOTTOM) Gold River below Ucona River. (A) Mean monthly flow and (B) Maximum flow. Mean values were calculated between the years 1979-1985 and 1985-1990, respectively, for each month. Maximum flow represents the mean of monthly flow maximums between the years 1979-1985 and 1985-1990, respectively.

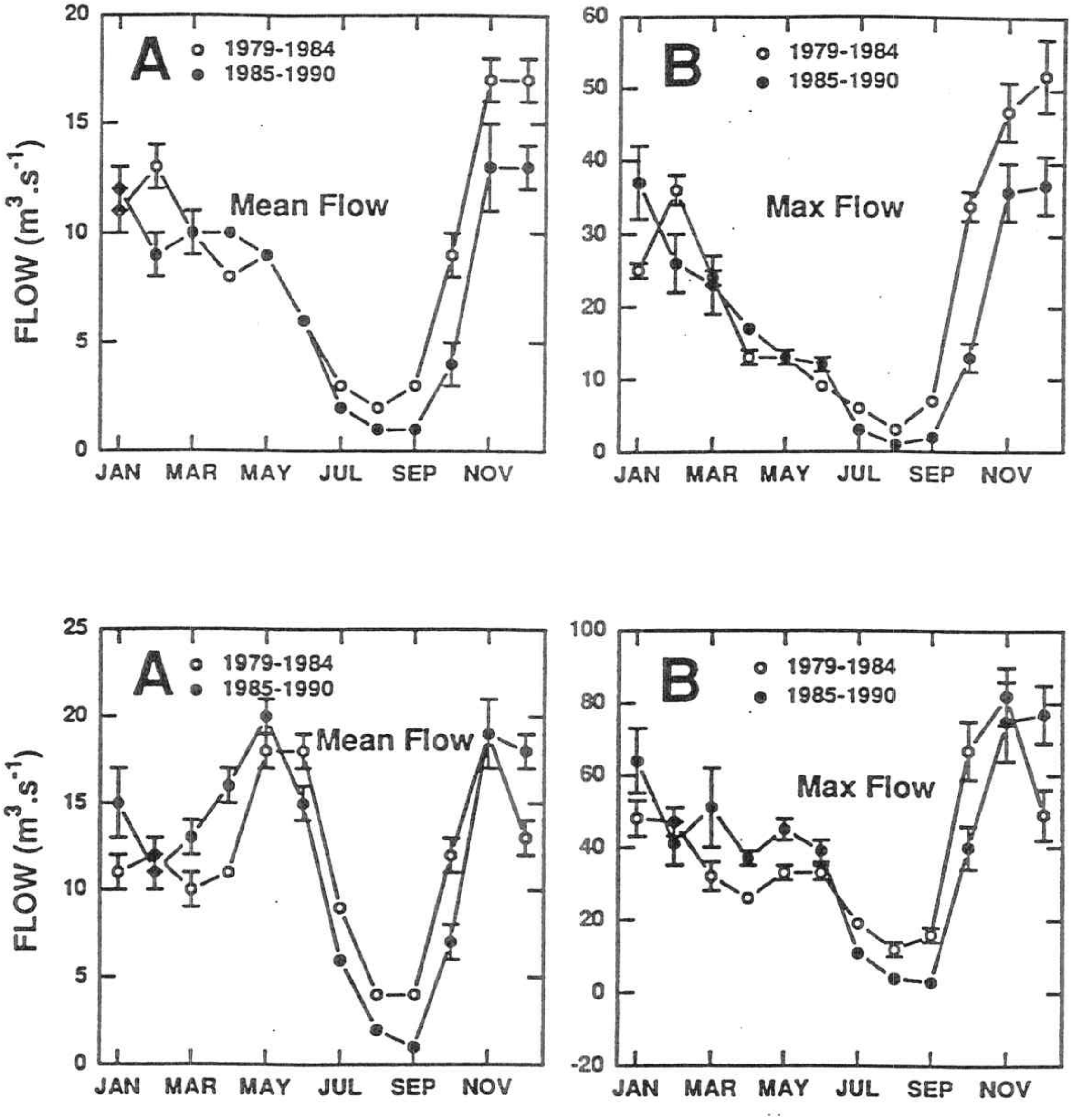

Fig. 11. Monthly flow at Little Qualicum River and Oyster River. (TOP) Little Qualicum River at Cameron Lake and (BOTTOM) Oyster River below Woodhus Creek. (A) Mean monthly flow and (B) Maximum flow. Mean values were calculated between the years 1979-1985 and 1985-1990, respectively, for each month. Maximum flow represents the mean of monthly flow maximums between the years 1979-1985 and 1985-1990, respectively.

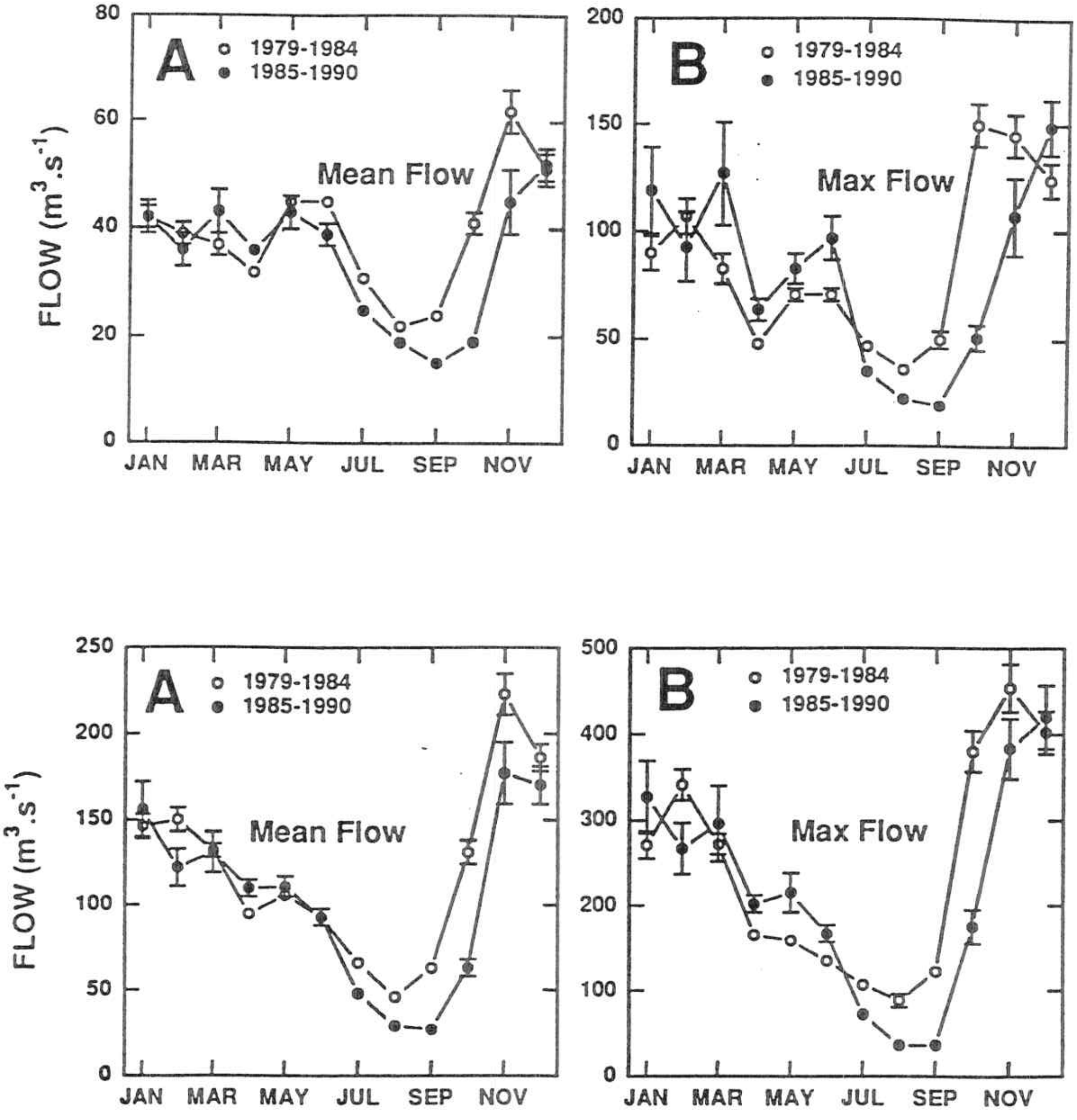

Fig. 12. Monthly flow at Puntledge River and Somass River. (TOP) Puntledge River at Courtenay and (BOTTOM) Somass River near Alberni. (A) Mean monthly flow and (B) Maximum flow. Mean values were calculated between the years 1979-1985 and 1985-1990, respectively, for each month. Maximum flow represents the mean of monthly flow maximums between the years 1979-1985 and 1985-1990, respectively.

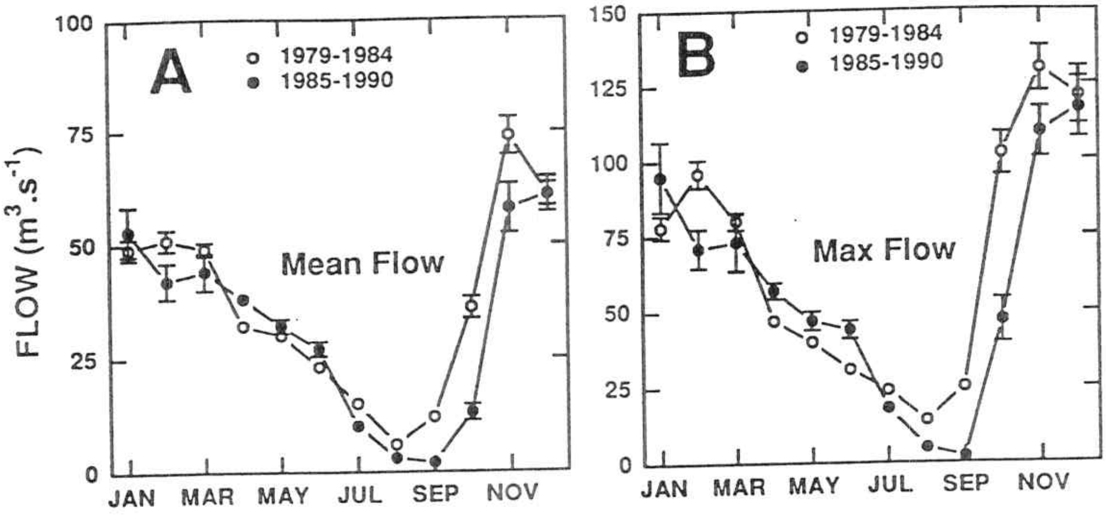

Fig. 13. Monthly flow at Sproat River. Sproat River near Alberni. (A) Mean monthly flow and (B) Maximum flow. Mean values were calculated between the years 1979-1985 and 1985-1990, respectively, for each month. Maximum flow represents the mean of monthly flow maximums between the years 1979-1985 and 1985-1990, respectively.

The volume of flow diversions were negligible with respect to total flow in each river system. The Ash River, however, is an exception where ~40 000 acre-feet of water are diverted for BC Hydro and Power Authority. The impact of this diversion can not be determined without further data on source, residence time, and exit point of the diverted flow. The fact, however, that the Ash River is only one of several rivers affected with *D. geminata* suggests that the diversion, itself, is independent of the diatom blooms.

Beyond influencing the physical structure of the periphyton matrix (Peterson 1987), flow velocity in lotic systems is essential for nutrient supply and metabolic waste product removal. Autotoxic and/or allelochemic effects from *D. geminata* may be influential in maintaining community dominance once a critical population density is established. Intuitively, the slower and/or lower flows observed since 1985 (Fig. 9-13) would enhance these factors. Literature on allelochemic properties of *Didymosphenia*, *Gomphonema*, and/or *Cymbella* were unavailable. Flow levels are also responsible for seasonal scouring events. However, scour event efficiency may be influenced more by the pre-flood biomass than the magnitude of event itself (Biggs & Close 1989). Biggs observed that large accruals were able to resist scouring under normal seasonal flows once established. Additionally, substrate heterogeneity associated with thick accruals may enhance refuge from herbivory and resistance from winter scouring disturbances (Dudley & D'Antonio 1991). These concepts entertain the possibility that *D. geminata* mats established in low flow periods may not be subsequently eliminated in higher flows.

The influence of riparian vegetation on light input into a lotic ecosystem can drastically alter the community structure (Triska *et al.* 1983). Increased light levels and associated changes in temperature, however, typically favor Chlorophyta and Cyanophyta communities (Hansmann & Phinney 1973). Bothwell *et al.* (1993) demonstrated that community succession may be influenced by the presence or absence of natural ultraviolet radiation (<400 nm). It is of particular interest that communities of mucilage stalked diatoms, *Gomphoneis* spp. and *Cymbella* spp., were favored under exposure to UV light. Water depth associated with low flow periods may increase UV exposure to the periphytic community. This contrasts the observation of Rieberger (1990) concerning the influence of UV light on *D. geminata*. The influence of light, flow velocity, and scour efficiency in conjunction with sustained lower levels of mean and maximum flow (Fig. 8-13) may be important in the recent success and expansion of *D. geminata*.

4.2.3. PRECIPITATION CHEMISTRY

No significant trends were found within the sample period (1986-1992: April-September) at each station for precipitation, pH, ammonia, chloride, calcium, sodium, and potassium (Simple linear regression, n=58 Port Hardy and Nanoose & n=46 Victoria, P>0.10 for all parameters). Mean and minimum pH levels during low flow were determined between 1986 and 1992 (Fig. 14). Sulphate concentration in precipitation was observed to significantly decrease at Nanoose and Victoria (ANOVA, n=58 & 46, P=0.036 & P=0.001, respectively) over the 6 year sample period during low flow (Fig. 15).

Parameter concentrations between sites during low flow were significantly different for calcium, ammonia, sulphate, nitrate, pH, and precipitation (MANOVA, n=75, P<0.01) between 1986 and 1992 (Fig. 16). Given that Nanoose is geographically closest to affected catchments (Fig. 2), multiple comparison tests were used to determine if parameter concentrations at Nanoose were different than concentrations found at both Port Hardy and Victoria. In all cases, parameters at Nanoose were not significantly different from parameters at both Port Hardy and Victoria. Nitrate, sulphate, and pH levels, however, at Victoria and Nanoose were significantly different than those found at Port Hardy. General observations confirm sulphate deposition is most extreme at Victoria Station and least extreme at Nanoose station and Port Hardy.

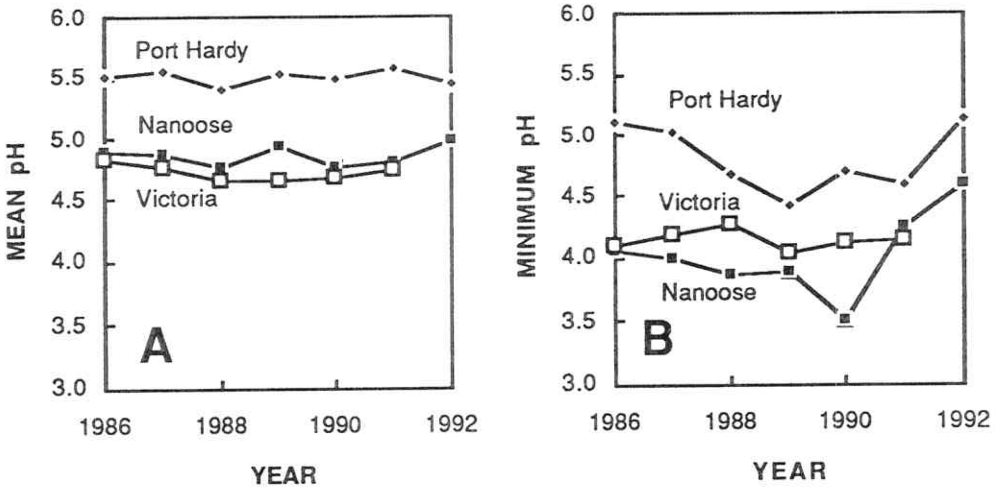

Fig. 14. Precipitation pH levels. (A) Mean and (B) minimum pH during low flow: April-September. Data collected at Port Hardy, Nanoose, and Victoria. There were no trends in pH levels at each site. The Nanoose station is geographically closest to catchments affected with *D. geminata*. Minimum values reflect the pH during one collection period (~1 week) during the year.

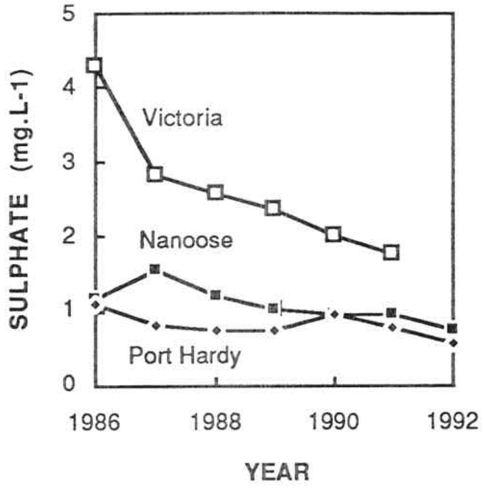

Fig. 15. Precipitation sulphate levels. Data collected at Port Hardy, Nanoose, and Victoria. The Nanoose station is geographically closest to catchments affected with *D. geminata*.

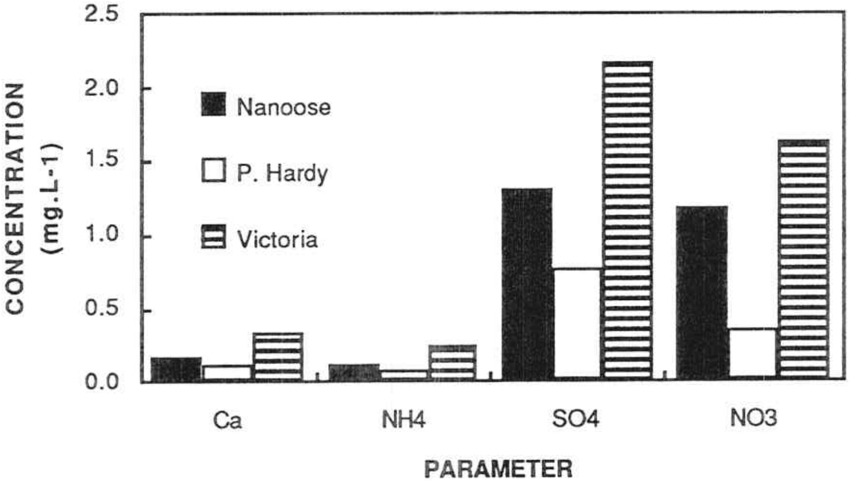

Fig. 16. General precipitation parameters. Mean concentrations of precipitation parameters between April and September, 1986-1992. Parameters are significantly different between sites, however, no parameter concentration at Nanoose is significantly different from both Port Hardy and Victoria.

Mean annual precipitation along the northeast coast of Vancouver Island in the regions of Nanoose and Victoria (75-100 cm.yr^{-1}) is significantly less than precipitation levels immediately inland (100-150 cm.yr^{-1}). Precipitation levels at Port Hardy range between 150-250 cm.yr^{-1} (Farley 1979). This difference alone precludes any direct application of the precipitation chemistry data to catchments in central Vancouver Island. Location of precipitation stations do not reflect precipitation chemistry directly in the central watersheds (Fig. 1).

4.2.4. DISCUSSION OF GEOPHYSICAL, FLOW, AND PRECIPITATION DATA

The phenomenon associated with wet or dry deposition of atmospheric pollutants that are acidic or have to the potential to become acidic is referred to as acid rain (Wiens 1988). Oxides of sulfur and nitrogen are the major emissions that affect the composition of acid rain. Gaseous and particulate sulfur and nitrogen do not have a long atmosphere residence time and dry deposition typically occurs within the immediate area of the source. Oxidized forms, however, may remain in the atmosphere for several days and are subject to transport thousands of kilometers from the point source. The impact of acidic deposition is a function of acidic concentration and the sensitivity of the geology and soil. Similarly, river chemistry is influenced by the soil and parent geology associated with the catchment (Whitton 1975).

Several pulp mills on Vancouver Island are responsible for the majority of sulphur dioxide emissions (Fig. 17). Storm trajectories from Oregon, the Alaska Gulf, and interior British Columbia are responsible for additional inputs. The topography of local areas is paramount in determining precipitation release and dry deposition. Dry deposition is the dominant form of acidic deposition between the months of April and September during reduced precipitation levels and low winds (Wiens 1988). Wet sulphate and pH values observed (Fig. 15-16) are higher than those found along coastal British Columbia. This phenomenon is a function of high coastal emissions, deposition rates associated with local topography, and the absence of airborne calcium ions. Particulate calcium sulphate is associated with the soils found in the interior, but not on the coast. Additionally, a portion of the sulphate found in the precipitation along the coastal regions originates from seasalt (MOE 1987).

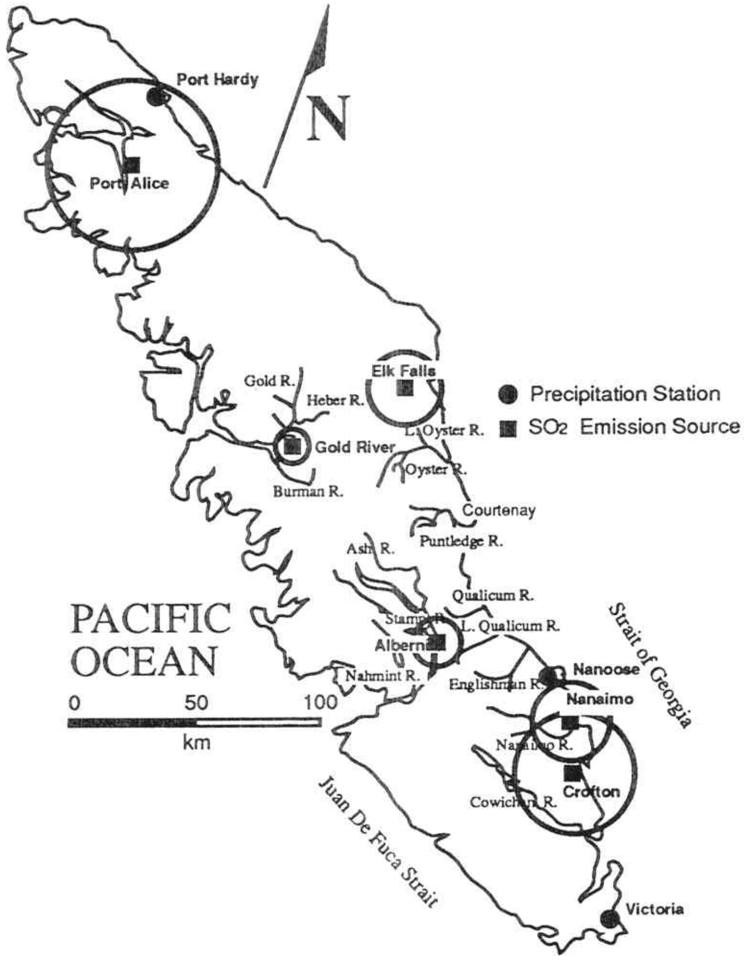

Fig. 17. Sulphur dioxide emissions. Affected catchments are relatively free from dry deposition influence of SO_2. Data based on Wiens (1988). Emission diameters correspond to 3 $km.ton^{-1}.d^{-1}$.

pH, sulphate, and nitrate levels are most similar between Nanoose and Victoria (Fig. 14-17). If these parameters, alone, influence the growth of *D. geminata*, the diatom would be predicted to expand southward. However, river chemistry is influenced by the soil and parent geology associated with the catchment (Whitton 1975). The aquatic impact of acidic deposition is a function of concentration and the sensitivity of affected geology and soil (Fig. 4-7). Geographic sensitivity to acidic deposition is a qualitative scale that measures the rate of environmental response to acidification. Current acidic sensitivity scales for Western Canada are based on the long term capacity of geology and soils to buffer acidic deposition and the rate of change associated with soils. Factors important to sensitivity scale:

- Exchangeable base cation loss by leaching
- pH reduction
- reduction in organic matter decomposition
- increased mineral weathering
- solubility of trace metals, specifically aluminum

Limestone, dolomite, calcareous clastic rocks, and other carbonate rocks have a high potential to reduce acidity. Alternatively, volcanic rock, shale, and granite have a low potential. Soil depth, soil drainage, and topography are also important. Shallow soils (<250 mm), rapid soil drainage, and steep topography are characterized by low potential to reduce acidity. Soils with <10% clay are associated with a low concentration of exchangeable bases.

Stream acidification can significantly alter periphyton composition, chlorophyll a, and productivity (Mulholland *et al.* 1986, Planas 1989). Planas and Moreau (1986) demonstrated that acidification can increase lotic periphyton biomass via the following mechanisms:

- Increased SRP from P-resolubilization bound in the sediment
- S-SO_4 uptake by the algae
- Elimination of benthic grazers

Though, dry deposition of SO_2 does not seem to be influential in areas with *D. geminata* (Fig. 17), the role of wet deposition (Fig. 14) in sensitive areas (Fig. 6-7) is likely significant. The influence of water chemistry from seepage and ground water inputs is also more significant during periods of low flow (Biggs 1985). Thus, it appears that pH and the edaphic buffering system may be an important factor. Assuming that edaphic influence is one factor in determining *D. geminata* growth and expansion, river systems within zones of high sensitivity and low buffer potential (Fig. 6-7) should continue to show novel blooms of *D. geminata* if low flow levels continue (Fig. 9-13). Additionally, the Cowichan catchment is located in the same physiogeographic zones as all other affected rivers. As of 1992, the Cowichan River, however, was not documented with

D. geminata blooms. If acidic deposition factors are influential, then *D. geminata* should eventually appear in the Cowichan. Alternatively, the exclusion of the Nanaimo catchment from highly sensitive zones should preclude the expansion of *D. geminata* into the Nanaimo river system.

4.2.5. COMPARISON OF VANCOUVER ISLAND AND THE MAINLAND

The only documented case of *D. geminata* on the mainland of British Columbia occurred in the Fulton River on the west coast (Rieberger 1991). West coast geology of British Columbia is primarily intrusive in nature. Mineralization rates and buffering capacity of the formations are subsequently alike between central Vancouver Island and the mainland west coast. The immediate west coast of British Columbia also has the same soil as central Vancouver Island. Similarly, precipitation patterns, radiation levels, and temperature profiles are nearly identical (Environment Canada 1978). Thus, the current absence of *D. geminata* from the adjacent coastal mainland is not likely a function of these geophysical factors. Mainland discharge profiles, however, sharply contrast with Vancouver Island.

Discharge profiles of Vancouver Island streams generally peak during December and January (Fig. 9-13). Discharge profiles for most mainland streams, however, are snow fed and experience maximum flows in July following winter snow melt (Fraser R., Homathko R., & Bella Coola R.: Farley 1979). Periods of low flow and high flow are opposite. Given that *D. geminata* has been correlated with years of lower flow, its absence from rivers that peak in summer months is not surprising. Interior British Columbia has significantly different geology, precipitation, and soil pattern. Assuming geophysical factors associated with Vancouver Island are critical, it is unlikely that *D. geminata* will be observed in the interior.

The southern reaches of the Queen Charlotte Islands are uniquely similar to central Vancouver Island in the aforementioned qualities. Furthermore, distinct areas exist both influenced and free from anthropogenic activity. Observation of *D. geminata* on the Charlotte Islands would provide qualitative proof of geology, soil, discharge, and temperature effects on growth habits.

4.3. ANALYSIS OF RIVER WATER CHEMISTRY

4.3.1. GENERAL OBSERVATIONS ON THE EXISTING DATABASE

Data from Oyster River above Oyster Bowl Camp, Oyster River south of Adrian Creek, Englishman River at Highway #1, and the Stamp River at Stamp Falls Park were too temporally incomplete or inconsistent for statistical comparisons with the other sites. Subsequently, no quantitative or qualitative conclusion can be drawn from these sites until future data is collected. Mean, standard deviation, and sample size for all other river chemistry is summarized in Appendix C: Table C1-C4. Minimum detection limits for each parameter are also listed in Tables C1-C4. The Cowichan and the Nanaimo were used as control stations in ANOVA comparisons between all sites. All data analyzed were obtained from low flow months (April - September).

Particular attention was paid to data concerning pH, temperature, nitrate, phosphorus, silica, and calcium levels. Additionally, literature on mucilage stalked diatoms directed interest on the trace metals aluminum, cadmium, iron, magnesium, and zinc. There was insufficient data to compare and contrast alkalinity, dissolved oxygen, nitrite, potassium, sodium, sulphate, and temperature. Levels of orthophosphate and dissolved phosphorus were generally below minimum detection limits (Table C1-C4) and could not be compared. In general, data were collected independent of precipitation events and diel changes. Consequently, chemistry of surface and subsurface flow entering the stream was not directly reflected in the data set. The presence or absence of acidic pulses or rapid nutrient inputs, for example, can not be interpreted using the existing database.

The absence of a historical temperature data base is unfortunate. It is suggested that *D. geminata* prefers cool water (Patrick & Reimer 1975, Rieberger 1991). Bulk water temperatures, however, are maximized during low summer flows. In contrast to Rieberger, Antoine & Benson-Evans (1986) state that *D. geminata* was found in a confluence with above average temperatures. Patrick (1977) also reports that several species of *Gomphonema* remain viable at temperatures >30°C and will dominate a community (Patrick 1977). Perhaps the effects of temperature are more influential on inhibiting other competitive periphytic species, rather than directly inhibiting or enhancing *D. geminata*. Further speculation will require more extensive temperature data.

4.3.2. RIVER CHEMISTRY TREND ANALYSIS

MANOVA analysis of both Puntledge river sites indicated that there was no significant difference between sites, each year, for all parameters with sample sizes greater than 10 (P>0.2 for all cases). This result justified pooling the data set for regression analysis. Out of the thirty chemical parameters tested in both the Oyster River and the Puntledge River, the following could not be fitted to a linear regression because of insufficient data or values consistently below minimum detection limits:

- arsenic
- cadmium
- phosphorus
- boron
- molybdenum
- nitrite
- nitrate and nitrite
- potassium
- sodium
- sulphate
- vanadium

All the remaining parameters (Table 1) did not exhibit any linear change (ANOVA, n>10, P>0.05 for all cases) in either the Puntledge (1971-1992) or the Oyster River (1980-1990).

The absence of annual trends can have several interpretations with respect to the *D. geminata* phenomena. First, the data represent only the "bulk" concentrations of analytes sampled over time. Thus, subtle changes in analyte concentrations are likely to go undetected. Trends in diel fluctuations or changes associated with river spates are also not reflected in the database. While the measured concentration of dissolved aluminum, for example, may not have changed since 1985, the concentration associated with subsurface runoff during precipitation events may have increased. It is also important to note that several of the parameters could not be fitted for linear trends because the data collected were below analysis detection limits. There is much documentation (Patrick 1977, Round *et al.* 1990, Stein 1973) on the influence of trace elements on periphyton growth at concentrations below analysis limits.

4.3.3. RIVER PH LEVELS

pH levels were significantly different between catchments (ANOVA, n=305, P<0.000), however, there was no unifying trend among river stations with *D. geminata* (Fig. 18). pH levels were the lowest in the Nanaimo River and the highest at the Heber River station. *D. geminata* was observed to bloom in waters with pH ranging from 7.2-7.7 (Fig. 18). Bulk values for all sites fall within the recommended range (6.5-9.0) for preservation of aquatic life (CCREM 1987). The difference observed between pH levels in the Puntledge and the Oyster stations with respect to the Gold/Heber catchment suggest that bulk pH levels are not a critical factor in *D. geminata* ecology.

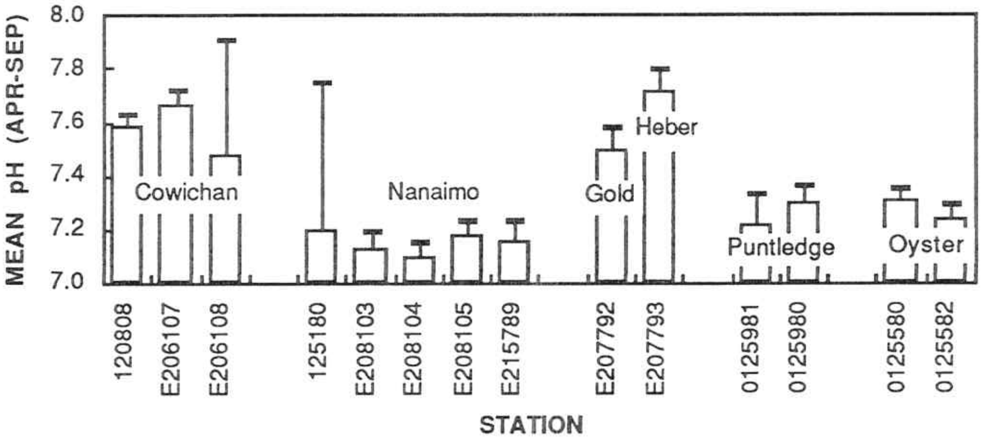

Fig. 18. River pH levels. Mean pH during low flow for the Cowichan, Nanaimo, Gold, Heber, Oyster, and Puntledge river sampling stations. Data pooled from 1985 to 1992. Mean and standard deviation reported.

Precipitation pH levels vary significantly throughout the island (Fig. 14). River chemistry data resolution, however, is not fine enough to reflect pH spikes that may be associated with precipitation events. Biggs (1982) reports that large periphyton accrual, specifically that composed of a *Gomphonema* sp. and *Cymbella* sp. matrix, can also cause major diel pH changes in poorly buffered waters. Temporary fluctuations of pH can alter the toxicity of other elements and must be considered before pH can be eliminated as one causal factor. If *D. geminata* regulates diel toxicity fluctuations, the cumulation of physiogeographic factors and biotic regulation mechanisms may serve to maintain the dominance of *D. geminata* once established in a reach.

The susceptibility of macroinvertebrate grazers to long term or pulse acidification must also be considered. Orthocladiinae and Ephemeroptera are typically highly sensitive to low pH levels. Alternatively, Chironomini and Tanypodiane are more resistant (Allard & Moreau 1987). Resistance is generally a function of physiology and position in the periphytic matrix. Allard and Moreau (1987) demonstrate that invertebrate grazers inhabiting the interior of the matrix are typically less sensitive to changes in pH. The absence and presence of caddisfly and chironomids, respectively, from established *D. geminata* communities (Rieberger 1991) may be a function of pH levels in addition to grazing preferences. Absence of data monitoring diel changes in pH precludes any quantification of possible critical levels.

4.3.4. NITRATE, PHOSPHORUS, & AMMONIA

The principle water quality factor that regulates the growth of large periphytic accruals is nutrient concentration. In lotic systems the amount and flux of dissolved nutrients during low flow are crucial synergistic factors (Biggs 1985). Specific attention is given to phosphorus, nitrate, and silica. While numerous sources have demonstrated that nutrient enrichment will generally increase biomass (Bothwell 1989), there is no particular reference to increased levels of *Didymosphenia, Gomphonema*, or *Cymbella* spp. in response to low or high levels of nutrient regimes. Total nitrate and nitrite levels

(ANOVA, n=97, P<0.000), total phosphorus (ANOVA, n=97, P<0.000), and total ammonia (ANOVA, n=176, P<0.000) were significantly different between catchments. No pattern, however, marked the catchments with *D. geminata* from the control stations (Fig. 19). Recorded levels of each parameter fall within expected ranges for lotic systems in western Canada (Bothwell 1985). The high phosphorus content of the Nanaimo is likely related to cultural eutrophication directly upstream of the sample sites.

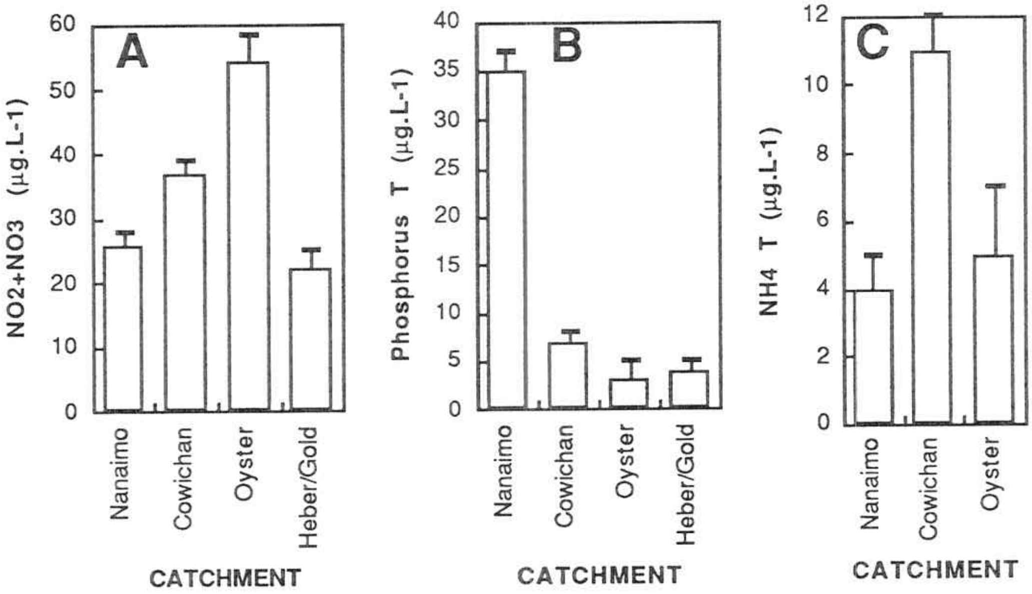

Fig. 19. River nutrient levels. (A) Total nitrate and nitrite, (B) total phosphorus, and (C) total ammonia. Mean and standard deviation reported for months of April-September: 1985-1992.

Bothwell (1985) has demonstrated that periphyton growth rates saturate at phosphorus levels <1 $\mu g.L^{-1}$. This observation and the absence of *D. geminata* from the Nanaimo suggests that *D. geminata* blooms are not in response to elevated phosphorus levels. Nitrate and nitrite levels are within ranges that may limit periphyton growth during low flow periods, but there is no pattern between nitrogen levels (Fig. 19A & 19C) in sites with and without *D. geminata*. The ratio of nitrogen to phosphorus is equally important in considering community structure and growth response (Bothwell 1985, Pringle & Bowers 1984). Based on observed data (Fig. 20), if higher ratios of NO_2+NO_3:SRP favour *D. geminata* growth, then *D. geminata* populations should be maximized in the Oyster, similar in the Heber/Gold and the Cowichan, and minimized in the Nanaimo catchment. The absence of *D. geminata* from the Cowichan, however, does not support this hypothesis.

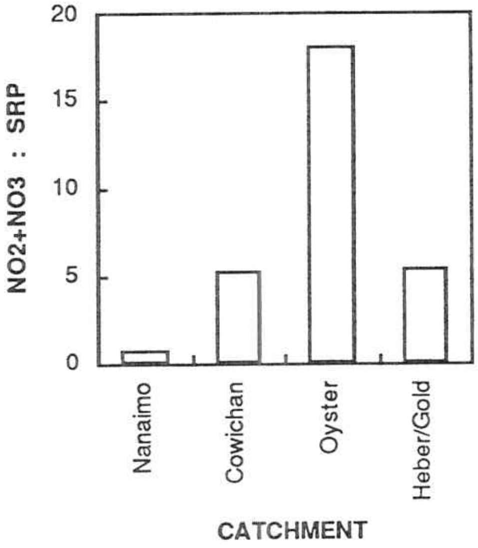

Fig. 20. NO_2+NO_3/SRP. (A) Total nitrate and nitrite, (B) total phosphorus, and (C) total ammonia. Mean and standard deviation reported for months of April-September: 1985-1992.

4.3.5. ALUMINUM

Levels of dissolved and total aluminum were not significantly different within all catchments (ANOVA, $n>5$, $P>0.500$ for all catchments), subsequently, only dissolved levels were considered for station comparisons. Levels of dissolved aluminum differed significantly between catchments (ANOVA, $n=109$, $P=0.021$). A multiple comparison test demonstrated that the source of significant variation was attributed solely to the Oyster catchment (Fig. 21). Data from the Puntledge and Gold/Heber catchments were insufficient for statistical comparison.

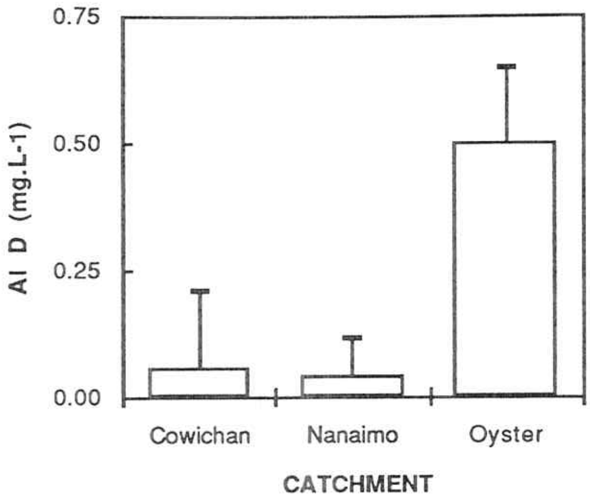

Fig. 21. Aluminum concentrations. Mean and standard deviation reported for low flow periods (1985-1992). Concentrations in the Oyster catchment were significantly different than the control sites and exceeded the CCREM criteria.

CCREM criteria for freshwater aquatic life suggests that total aluminum should not exceed 100 and 50 mg.L^{-1} in waters with pH ≥6.5 and <6.5 respectively. Aluminum is easily mobilized from soils and sediments by natural weathering and ground water percolation associated with wet acidic depositions. Though it is obvious that the Oyster catchment grossly exceeds this recommendation, given the geology and soil of the area, values may range naturally from 6-3000 μg.L^{-1} (CCREM 1987). Primary point sources of anthropogenic aluminum include alum flocculates and coal combustion associated with industry.

Aluminum is not considered as one of the trace metals essential for diatom growth (Patrick 1977) and elevated levels of aluminum seem to be less deleterious to algae and macrophytes than to aquatic fauna. Extremes in pH and aluminum at levels exceeding the guidelines, however, have been correlated with increased invertebrate mortality and migration (Lamb & Bailey 1981). Diel or spate peaks in pH minimums accompanied with increased aluminum toxicity may remove key invertebrate predators and/or grazers from river systems with naturally high concentrations of dissolved aluminum. Reduced diversity of invertebrates from reaches with *D. geminata* (Rieberger 1991) could be explained by such a hypothesis rather than an aversion for *D. geminata*. Additionally, the absence of such invertebrates could be one causal event that encourages *D. geminata* blooms. Diel and spate measures of dissolved aluminum and pH are needed to confirm this conjecture.

4.3.6. SILICON

Levels of dissolved silicon were lower in the Oyster, Puntledge and Heber/Gold catchments with respect to the Cowichan river system (ANOVA, n=25, P=0.100). Comparison of the data indicated that only the Puntledge was significantly different from the other catchments. There was insufficient data to include the Nanaimo system in the comparison. Silica levels observed (Fig. 22) were within values expected for the Pacific region (CCREM 1987). Silicon is required for frustule formation in diatoms and minor shifts in silicon concentration will be reflected in community transformations toward species better adapted for different uptake rates and levels (Werner 1977).

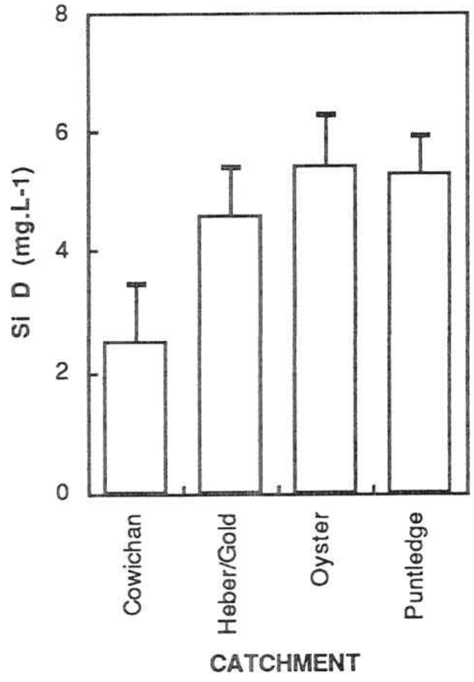

Fig. 22. River silicon levels. Mean concentration and standard deviation shown (April-September: 1985-1992). Catchments with *D. geminata* had higher levels of silicon.

Despite the increased uptake of silicate that must be associated with the *D. geminata* mats, silicon levels were still higher in rivers with *D. geminata* (Fig. 22). The observed pattern of silicon concentration suggests that *D. geminata* growth may be enhanced by higher concentrations of silicate. Silicate data, however, was limited (n=25) and strong conclusions can not be drawn without further data or comparison with other rivers without *D. geminata.* The ratio of silicate to phosphorus or nitrate is also crucial in determining diatom community structure (Patrick 1977). Current data, however, was insufficient to allow ratio comparisons. Future monitoring should attempt to include analysis of all three variable simultaneously within sites to facilitate ratio comparisons.

4.3.7. ALKALINE IONS

Synedra sp., *Achnanthes minutissima, Gomphonema olivaceum,* and *Cymbella* sp. all require considerable amounts of calcium with respect to other lotic diatom species (Round *et al.* 1990) Polluted waters with high conductivity may be characteristic of specific diatom taxa and Patrick & Reimer (1975) suggest that *D. geminata* prefers water of low conductivity. Alternatively, Antoine & Benson-Evans (1986) state that *D. geminata* was observed in reaches with higher conductivity levels.

Total calcium concentration (Fig. 23A) differed significantly between catchments (ANOVA, n=183, P<0.000). No significant difference between the control and affected catchments were apparent. Total calcium levels for all stations were within ranges typically encountered in western Canada (CCREM 1987). Some stalked diatom growth, *Cymbella* spp. and *Gomphonema olivaceum*, is reported to be enhanced by increased levels of calcium. The varied levels observed between control and affected rivers, however, precludes this observation from direct application to the *D. geminata* phenomenon. In addition to carbonate-bicarbonate buffering, calcium is essential in precipitation of many metals. Combinations of calcium and dissolved metal concentrations within each catchment could influence *D. geminata* growth. Current metal data is insufficient or too insensitive to use in multivariate comparisons between sites.

Dissolved and total magnesium concentrations were not significantly different within each station. Total magnesium differed between stations (ANOVA, n=181, $P<0.000$), but no significant trends between sites with and without *D. geminata* could be drawn (Fig. 23B). Levels observed (0.49-0.83 $mg.L^{-1}$) are below typical values observed for the Pacific region (14.0-18.0 $mg.L^{-1}$) (CCREM 1987). If magnesium levels are a limiting factor, *D. geminata* biomass would be expected to maximize in the Oyster catchment. Alternatively, the Cowichan system should see *D. geminata* prior to the Nanaimo river system. These predictions require data on biomass levels between each catchment.

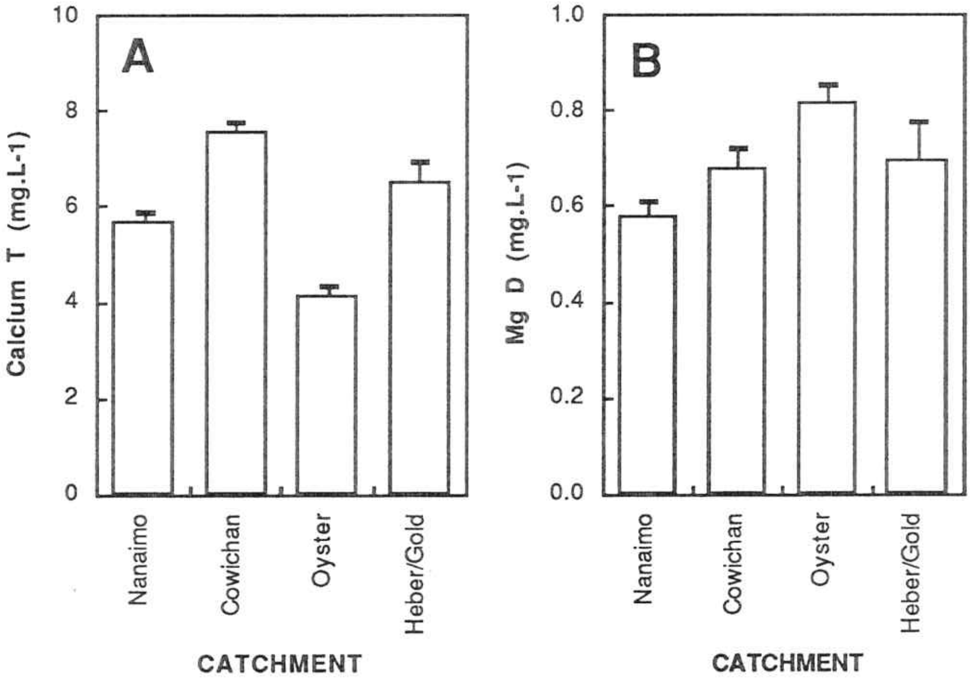

Fig. 23. River calcium and magnesium concentrations. (A) Total calcium and (B) dissolved magnesium. Mean concentration and standard deviation shown (April-September: 1985-1992).

4.3.8. IRON

The levels of total iron were not significantly different (ANOVA, n=171, P=0.484) between stations along the Oyster River and control stations. Levels of dissolved iron differed significantly (ANOVA, n=128, P=0.001), however, multiple comparisons of the sites did not single out stations with or without *D. geminata* (Fig. 24A). Comparison of the ratio of dissolved iron to total iron (Fe D: Fe T), however, revealed that the two Oyster River stations were significantly different than all of the other six stations on the Nanaimo and Cowichan rivers. Furthermore, none of the control stations were significantly different from each other, nor were the Oyster River sites significantly different from each other (Fig. 24B). Insufficient data prevented comparison of Fe D: Fe T in any of the other affected catchments.

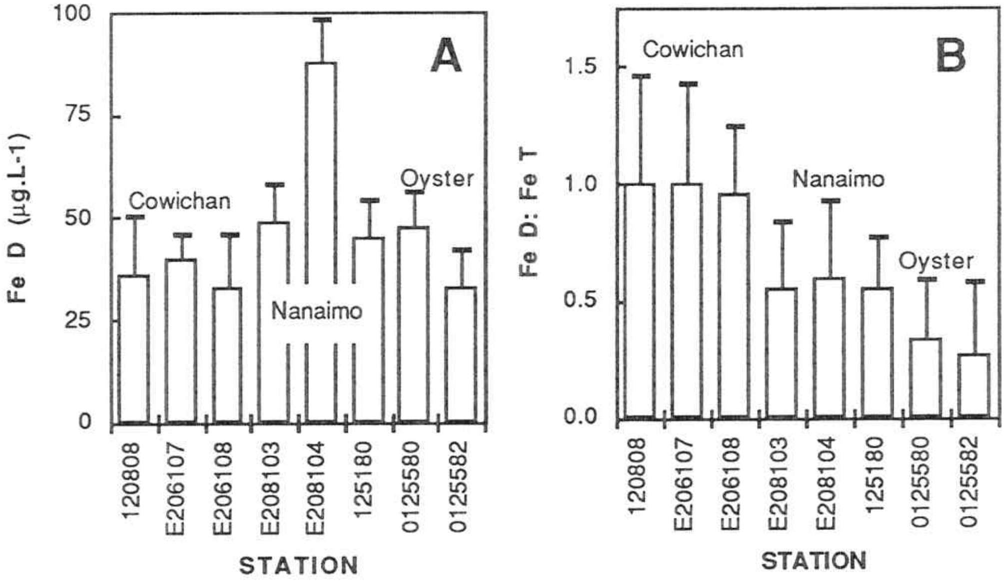

Fig. 24. River iron concentrations. (A) Concentration of dissolved iron and (B) the ratio of dissolved iron to total iron. Mean and standard deviation reported for stations on the Cowichan, Nanaimo, and Oyster River. Stations on the Oyster River were significantly lower than the control sites. The lowered levels of dissolved iron likely reflect increased uptake rates by thick periphyton mats.

Iron is an important trace metal in periphyton physiology. Given that the total and dissolved iron concentrations are not significantly different between sites with and without *D. geminata*, it is unlikely that iron concentration, itself, is a proximate cause of

D. geminata blooms. Several stalked diatoms, such as *Gomphonema acuminatum*, have either demonstrated enhanced growth or toleration to high iron concentrations (Patrick 1977). This statement leads to the prediction that systems with *D. geminata* might have higher total iron. The mean total iron (mg.L^{-1}) found in the each catchment was:

• Puntledge	0.115
• Gold/Heber	0.032
• Oyster	0.207
• Cowichan	0.093
• Nanaimo	0.049

Total iron is not considered "unusually" high until concentrations exceed 0.3 mg.L^{-1} (CCREM 1987). This fact and the low iron concentration in the Gold/Heber catchment rejects the hypothesis of enhanced *D. geminata* growth from elevated iron levels. Furthermore, there was no evidence of any significant changes in total iron concentration over time in either the Oyster or Puntledge catchments (ANOVA, n=32 & n=24, P=0.896 & P=0.272, respectively) that would have triggered recent blooms. The lower ratio of Fe D:Fe T (Fig. 24A) probably reflects increased iron uptake associated with the periphyton blooms in catchments with *D. geminata*.

4.3.9. OTHER TRACE METALS

Say (1987) observed that certain *Gomphonema* spp. have been found in rivers with high Zn, Cd, and suspended matter levels. The exact nature, however, of metal influence on *Gomphonema* spp. remains confounded. Data has yet to consider interaction between flow regime, contaminant mixtures, nutrient concentrations, and suspended particulates (Whitton 1984). It is important to note that reports of *D. geminata* are associated with metalliferous catchments (Antoine & Benson-Evans 1986, Ergashev & Alimzhanova 1989, Kykhaleishivili 1985, Levadnaya & Kuz'mina 1974).

For all stations, boron, chromium, cobalt, molybdenum, manganese, and vanadium levels were either below minimum detection limits or just above. These trace metals are all considered essential for algal growth. Minimum detection levels, however, all exceeded that which might limit diatom growth. The observed shifts in diatom communities on affected rivers might be influenced by trace metal concentrations, but current monitoring quality would not detect this.

Copper concentrations <10 µg.L^{-1} are required for diatom metabolism. Increasing copper concentrations >10 µg.L^{-1} have been correlated with population shifts from Cyanophyta to Chlorophyta and Bacillariophyta (Demayo & Taylor 1981). The potential for toxicity increases with copper concentrations above 10 µg.L^{-1}. Some stalked diatoms, *Cymbella ventricosa* and *Gomphonema parvulum*, are particularly resistant to copper toxicity (Patrick 1977). Diel or spate fluctuations in copper may influence the community structures apparent in affected rivers. Although data analysis indicated that there was no difference in concentrations (0.002-0.008 mg.L^{-1}) between sites (ANOVA, n=180, P=0.590), this conclusion is suspect given that most of the data were barely above minimum detectable levels. Again, more sensitive testing is required before exact conclusions can be drawn.

Levels of zinc exceeding 1.3 mg.L^{-1} are detrimental to diatom growth (Patrick 1977). Concentration of total zinc was not significantly different between river stations (ANOVA, n=181, P=0.867) in the Oyster, Heber/Gold, Cowichan, and Puntledge catchments. Additionally, general levels of zinc (Table C1-C4) did not exceed recommended levels at any stations within the hardness range of 0-50 mg.L^{-1} $CaC0_3$. Thus, it is unlikely that zinc concentrations are a proximate cause in recent blooms.

4.4. CULTURE SUCCESS

Neither of the two attempts to isolate and culture *D. geminata* were successful. All samples, however, were characterized by viable populations of *Phormidium* sp. The inability to successfully culture *D. geminata* could be a function of unique media requirements and/or poor vigor of the seed populations. Qualitative analysis of literature and existing data suggests that culture of mucilage diatoms may require unusually specific control of flow velocity, temperature, pH, and/or trace metals (Huntsman 1966). Successful culture of *D. geminata* will undoubtedly require a large quantity of healthy seed population and patient experimentation with physiochemical factors over an extended period of time.

5. MONITORING RECOMMENDATIONS

Any monitoring program designed to substantiate the particular ecology of *D. geminata* must first consider problems with the existing database. Current monitoring of lotic systems with and without *D. geminata* is too generalized and does not reflect pulse loading associated with spates or diel changes in flow, temperature, nutrients, trace metals, and pH. The monitoring that does exist, in many cases, is not sensitive enough to determine analyte levels that may influence diatom growth. The success of *D. geminata* may be directly or indirectly linked to the presence or absence of key periphyton and invertebrate species, but no seasonal taxonomic data exists describing community succession and invertebrate populations. Finally, no longitudinal surveys of rivers with specific reaches of *D. geminata* have been conducted.

Future monitoring of river chemistry should be conducted at least once a week consistently between sites with and without *D. geminata*. This data would best be contrasted to more detailed sets collected at a diel resolution periodically throughout periods of low flow. Additionally, longitudinal surveys along the length of rivers and associated tributaries could reveal gradients in nutrients and other parameters that may be influential in *D. geminata* growth. The effects of precipitation directly on catchments with *D. geminata* is best analyzed form data collected within the catchment, rather than interpolating from existing coastal stations. Another pertinent goal would include detailed image analysis of Vancouver Island with respect to *D. geminata* blooms. Precise maps of *D. geminata* locations would provide a qualitative reference on the potential rate of expansion and possible geophysical limits.

A series of well documented experiments is another route to learning more about *D. geminata* ecology. Manipulating nutrient and other parameters using *in situ* flumes and *in vitro* cultures could begin to quantify specific aspects of *D. geminata* ecology without the confounding factors and problems of pseudo replication associated with current monitoring. Initial stages should attempt to sustain viable cultures of *D. geminata in vitro* as isolates and/or in a mat. Once either form of the culture is established direct manipulation of pH, trace metals, light levels, and/or nutrients is possible.

6. CONCLUSIONS

Literature on *Didymosphenia geminata* (Gomphonemaceae) is restricted to general morphology. Data regarding blooms or nuisance accruals is not discussed or regarded as a possibility. Subsequently, the blooms on Vancouver Island appear to be a novel event. In the absence of literature on the genus, any comparisons should consider drawing analogies from related families: Gomphonemaceae and Cymbellaceae. The recent occurrence of *D. geminata* is likely a function of many environmental and anthropogenic factors. The absence of other documented *D. geminata* blooms suggests that several novel catalysts are likely responsible, in addition to a general environmental predisposition, for recent growth on Vancouver Island.

The catchments of rivers with and without *D. geminata* were contrasted for similar geophysical and physiochemical similarities. Parameters within catchments with *D. geminata* (Gold, Heber, Oyster, Nahmint, Ash, Sproat, Burman, Somass, & Puntledge) that were significantly dissimilar were considered independent of the recent blooms. Parameters that were similar within affected catchments were then contrasted to control catchments without *D. geminata* (Cowichan & Nanaimo). Geophysical and physiochemical parameters common to affected catchments, but significantly different from the control catchments, were examined for potential impact on diatom physiology.

Qualitative inspection of anthropogenic influence of affected and control catchments did not reveal any differences in the distribution of road, mines, and large industry. Township density was greater in the control catchments suggesting that cultural eutrophication was not likely a factor in recent blooms. The potential of sulphur dioxide dry deposition from industry was minimum in the affected catchments.

Qualitative inspection of soil and parent geology revealed that all affected and control catchments were contained in humo-ferric podzol soil. However, only the affected catchments were contained over parent geology of granite and diorite. Maps detailing the sensitivity of the soil and geology to acidic deposition demonstrated that all affected catchments were contained within zones with a poor buffer potential. The control catchments, the Nanaimo and the Cowichan, were excluded from or bordered these areas, respectively. If the edaphic influence of soil and geology with acidic deposition is important, then the Nanaimo should never see *D. geminata* blooms and the Cowichan should see them in less moderation than the other affected rivers. The Queen Charlotte Islands are uniquely similar to the geophysical characters of the affected catchments and should be inspected for *D. geminata*. All affected and control catchments were bound within temperature contours marking 100-180 frost free days. Temperature profiles may represent possible boundaries to expansion.

No trends in annual flow were detected between 1975 and 1990, however, monthly mean and maximum flows for the months of April to September were significantly lower. The influence of lower flows on scour efficiency, light levels, and temperature may be one factor in the recent expansion of *D. geminata*. The Nanoose precipitation station, geographically closet to affected catchments, was contrasted to stations north (Port Hardy) and south (Victoria). Contrasts, however, were interpreted with caution as precipitation patterns are highly localized events. No significant annual trends were observed in precipitation chemistry data with the exception of sulphate, where it was observed to decrease at the Victoria station. Additionally, no parameters at both control stations were significantly different than those at Nanoose. Data from Nanoose and Victoria, however, were similar in many respects: Minimum pH, $S0_4$, and

Ca. If precipitation influences *D. geminata* growth, continued expansion is predicted southward.

Analysis of bulk river chemistry demonstrated that there has been no annual trend for all parameters inspected. pH levels between catchments are significantly different, however, not between control and affected catchments. Nutrient enrichment (N+P) suggests that phosphorus loading, alone, is not a factor in *D. geminata* growth. Examination of nutrient ratios is also inconclusive. Dissolved aluminum was greatest in an affected catchment, however, levels are not out bounds expected for the geology of the region. Silicon levels were higher in affected catchments and suggest that elevated levels may be essential for the magnitude of the bloom. The ratio of dissolved iron to total iron was lowest in an affected catchment and may reflect increased uptake rates associated with the periphyton blooms. Trace metal analyses were generally inconclusive because the data were not sensitive enough.

In general, detailed analysis of river chemical parameters was not possible because of the resolution and consistency of the existing database was low. Additionally, the influence of bulk water chemistry is often secondary to spikes associated with point source pollution, diel changes, and precipitation events on the entire lotic community. The existing database, at best, represents bulk chemical ranges. Precise information on physiochemical parameters that influence *D. geminata* growth will require a dedicated monitoring program.

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APPENDICES

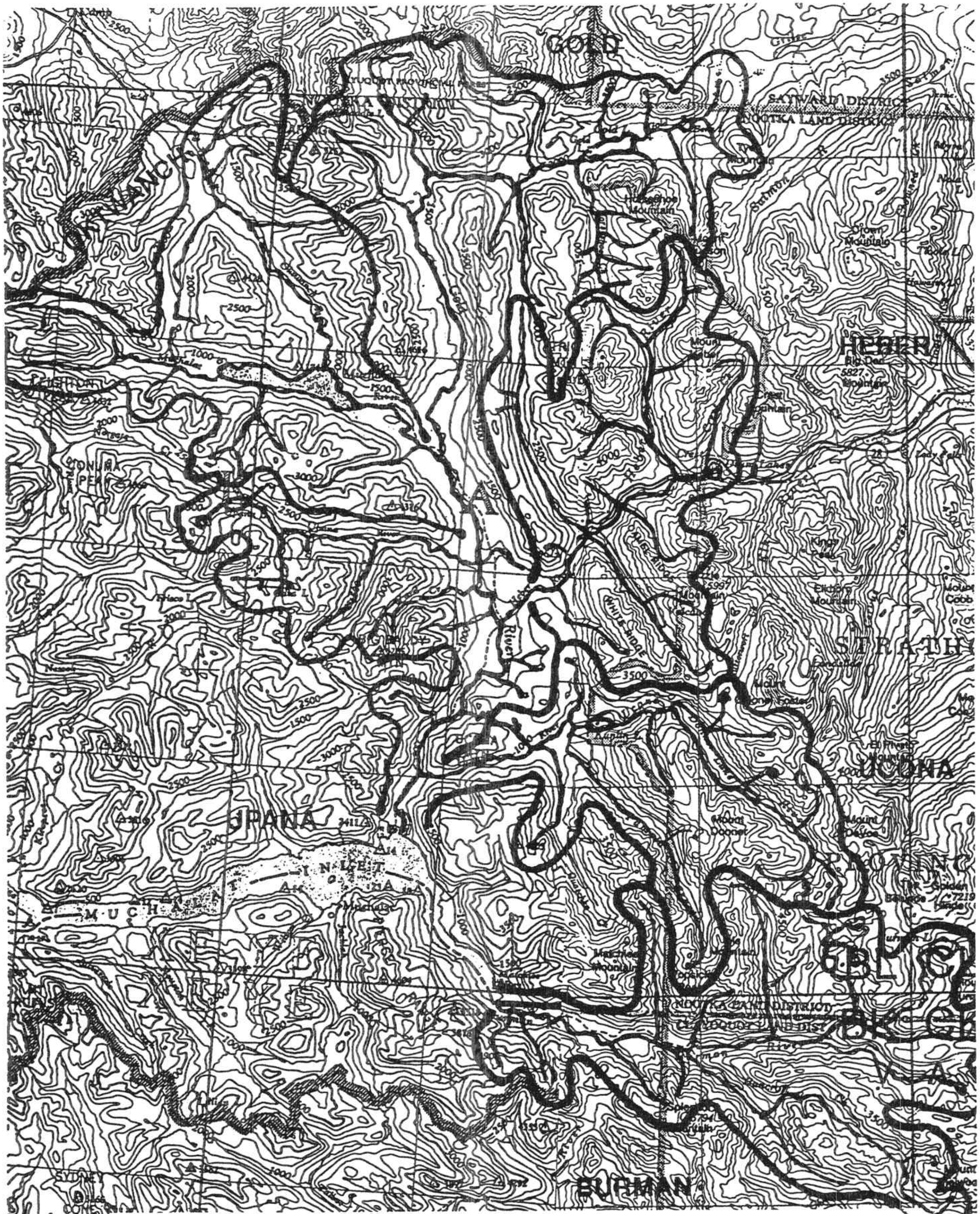

Fig. A1. Catchment for Heber River and Gold River. Figure superimposed on maps ASE EDITION 4: SERIES A 502 Port Alberni (92F), ASE EDITION 1: SERIES A 502 Bute Inlet (92K), ASE EDITION 1: SERIES A 502 Alert Bay (92L), and ASE EDITION 1: SERIES A 502 Nootka Sound (92E).

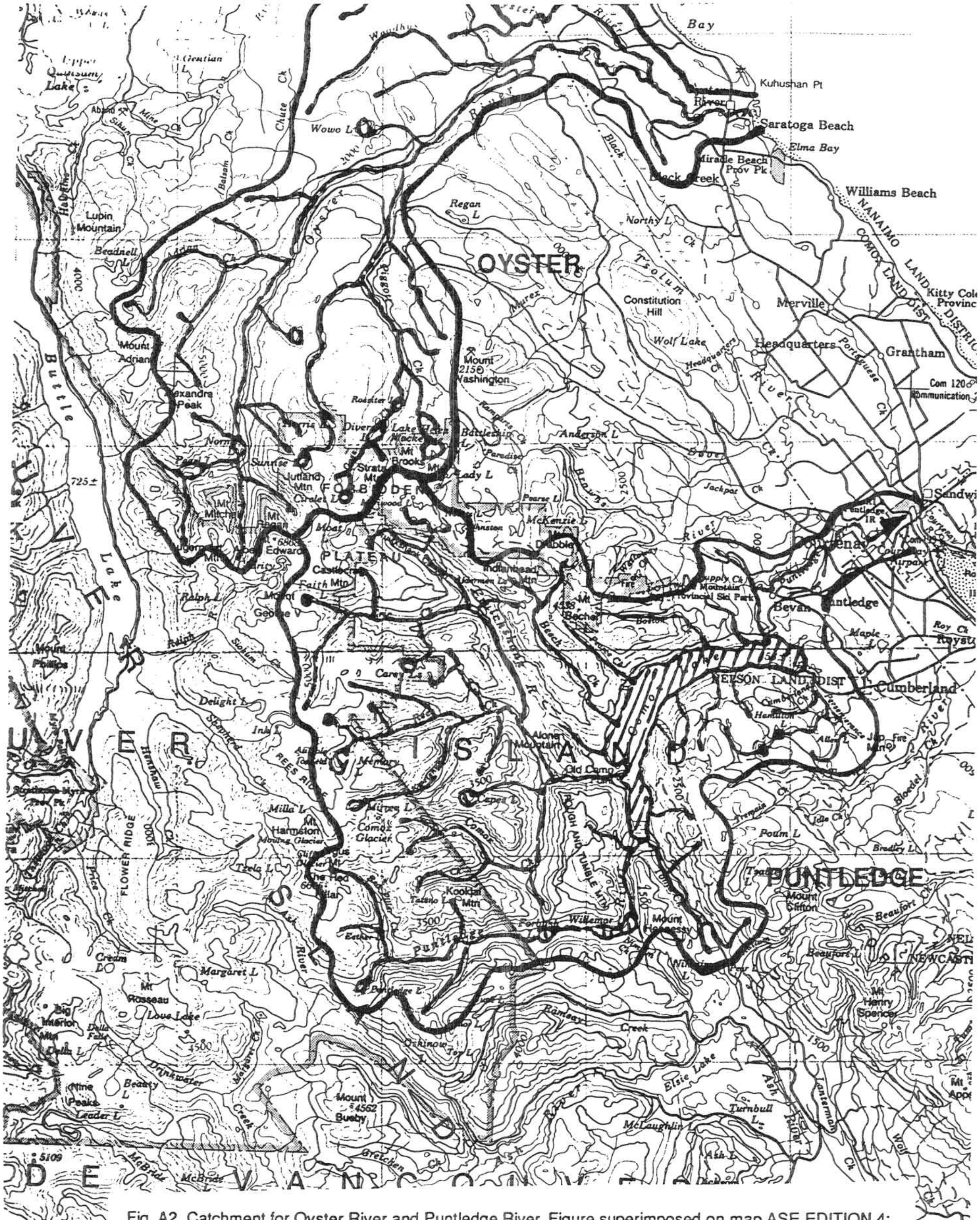

Fig. A2. Catchment for Oyster River and Puntledge River. Figure superimposed on map ASE EDITION 4: SERIES A 502 Port Alberni (92F).

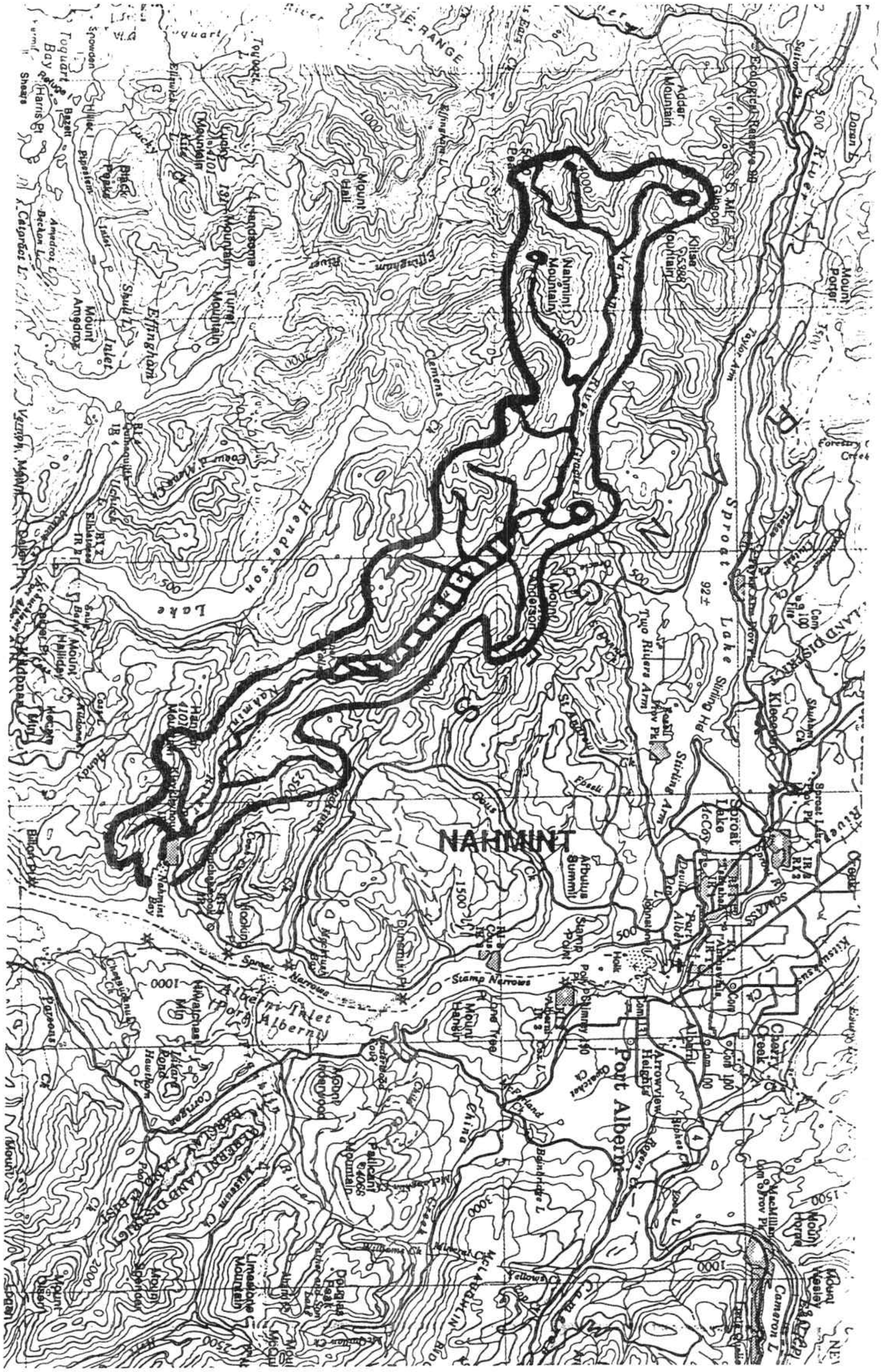

Fig. A3. Catchment for Nahmint River. Figure superimposed on map ASE EDITION 4: SERIES A 502 Port Alberni (92F).

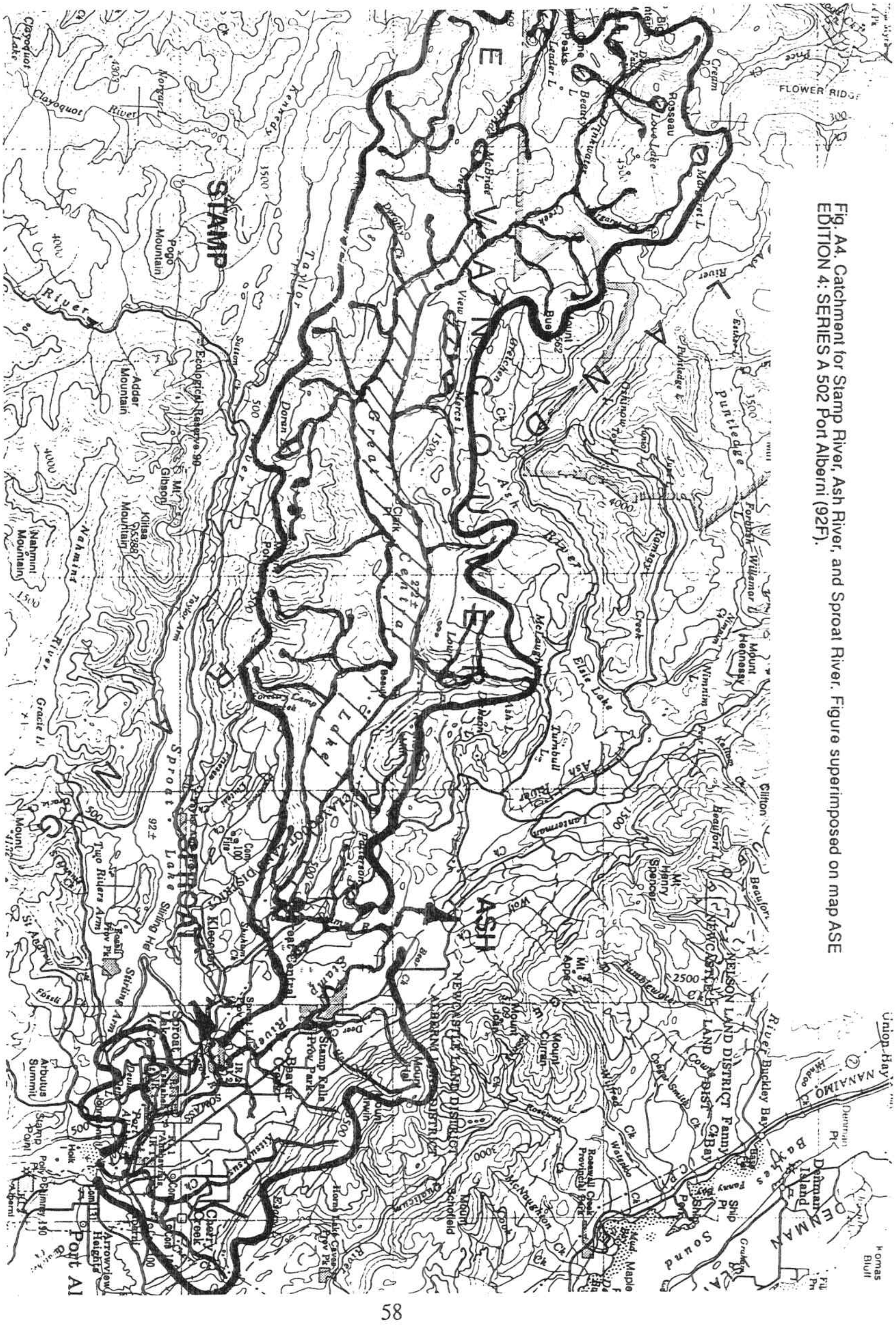

Fig. A4. Catchment for Stamp River, Ash River, and Sproat River. Figure superimposed on map ASE EDITION 4: SERIES A 502 Port Alberni (92F).

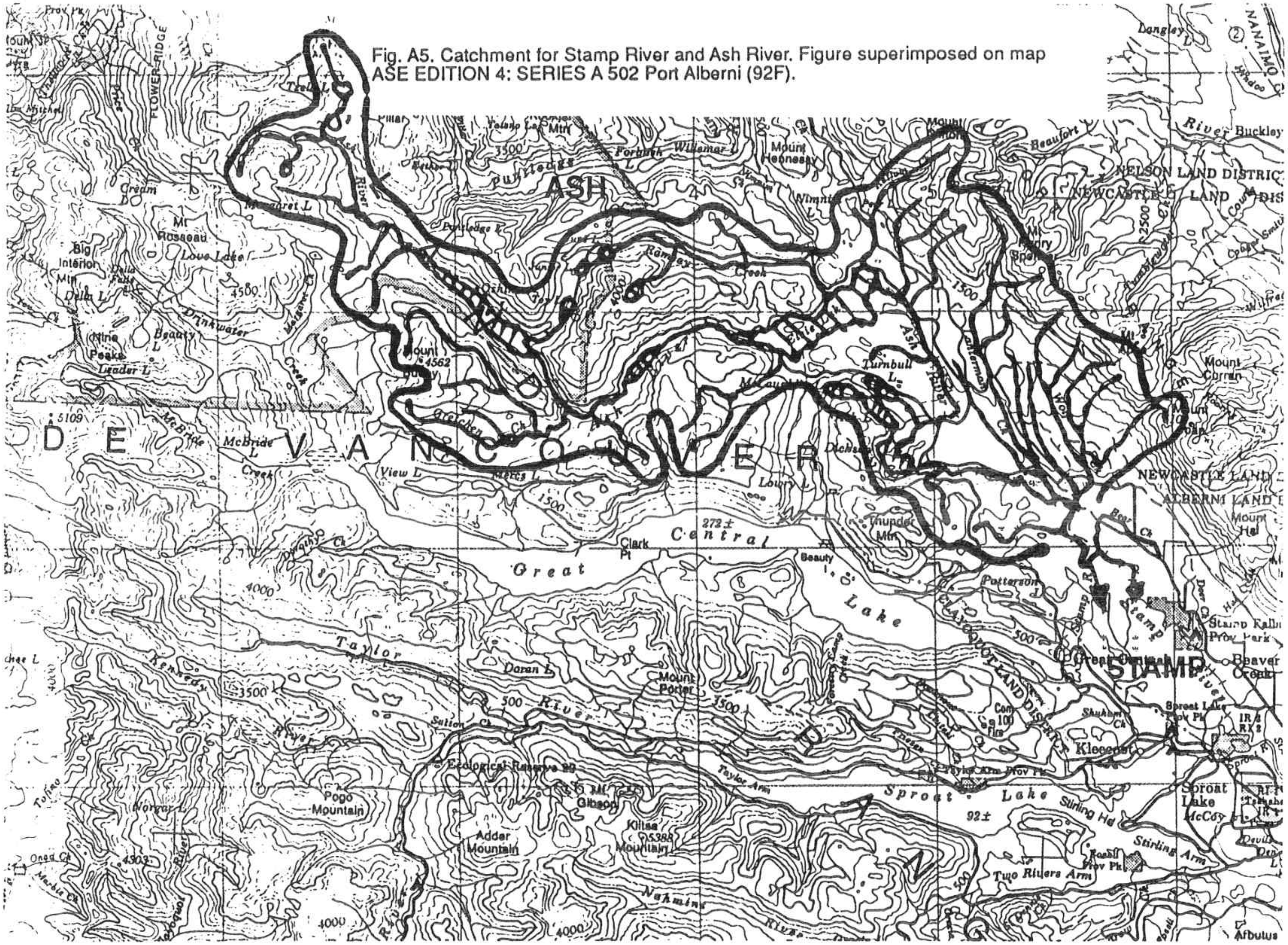

Fig. A5. Catchment for Stamp River and Ash River. Figure superimposed on map ASE EDITION 4: SERIES A 502 Port Alberni (92F).

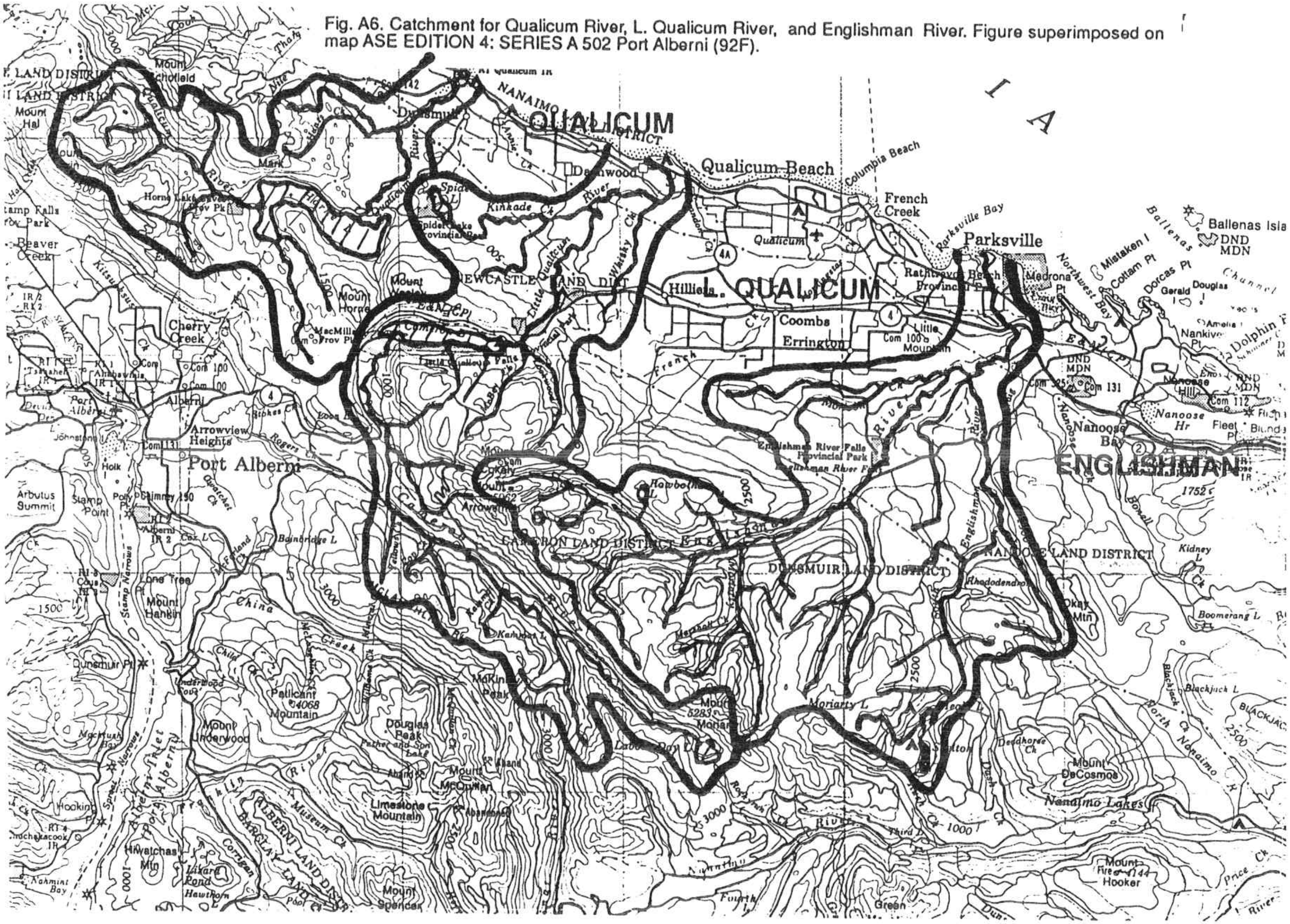

Fig. A6. Catchment for Qualicum River, L. Qualicum River, and Englishman River. Figure superimposed on map ASE EDITION 4: SERIES A 502 Port Alberni (92F).

TABLE B1. Annual precipitation chemistry summary. All parameters in mg.L-1 except precipitation (mm.d-1). Detection limit for all parameters except Ca and Mg was 0.01 mg.L-1. Detection limit for Ca and Mg was 0.02 mg.L-1.

	MEAN										STDEV										COUNT									
	Ca	Cl	K	Mg	NH4	NO3	Na	SO4	pH	Prcptin	Ca	Cl	K	Mg	NH4	NO3	Na	SO4	pH	Prcptin	Ca	Cl	K	Mg	NH4	NO3	Na	SO4	pH	Prcptin
Nanoose																														
86	0.14	0.99	0.14	0.06	0.14	1.02	0.58	1.15	4.89	3.2	0.10	1.12	0.17	0.09	0.40	1.30	0.64	0.96	0.32	3.1	32	33	33	32	33	33	33	33	32	33
87	0.25	1.25	0.28	0.07	0.13	1.02	0.76	1.57	4.88	2.2	0.29	0.90	0.29	0.05	0.15	0.87	0.58	1.16	0.47	2.6	37	38	38	37	37	38	38	38	37	39
88	0.11	0.90	0.17	0.04	0.08	1.03	0.50	1.20	4.77	2.3	0.10	0.58	0.17	0.03	0.11	1.29	0.30	1.11	0.40	2.5	40	42	41	40	41	42	41	42	41	43
89	0.11	0.75	0.20	0.03	0.06	0.88	0.47	1.04	4.94	1.9	0.12	0.63	0.19	0.02	0.09	1.13	0.56	0.89	0.45	1.6	42	43	43	41	43	43	43	43	42	44
90	0.12	0.65	0.14	0.04	0.09	1.61	0.30	0.94	4.77	2.9	0.10	0.52	0.09	0.02	0.14	3.34	0.19	0.85	0.40	2.9	34	36	33	34	34	36	33	36	36	37
91	0.14	0.67	0.17	0.04	0.09	1.03	0.33	0.94	4.80	2.7	0.12	0.63	0.13	0.02	0.09	0.71	0.22	0.50	0.30	4.0	38	39	38	38	38	39	38	39	41	41
92	0.13	0.72	0.13	0.05	0.07	0.72	0.40	0.73	4.97	3.1	0.08	0.63	0.05	0.04	0.06	0.51	0.35	0.23	0.27	4.4	13	13	13	13	13	13	13	13	13	13
Victoria																														
86	1.05	3.26	0.19	0.22	0.28	1.52	1.85	4.28	4.82	3.4	1.81	2.23	0.28	0.16	0.26	1.61	1.28	5.17	0.46	4.0	25	26	26	25	26	26	26	26	26	26
87	0.41	4.73	0.18	0.31	0.17	0.86	2.59	2.82	4.77	2.6	0.28	3.91	0.11	0.26	0.12	0.95	1.95	1.60	0.29	2.3	12	12	12	12	12	12	12	12	12	12
88	0.27	3.22	0.15	0.22	0.13	1.04	1.72	2.59	4.65	2.7	0.34	4.03	0.10	0.32	0.17	1.30	2.15	2.83	0.26	2.0	23	24	23	23	23	24	23	24	24	24
89	0.24	1.80	0.26	0.11	0.18	1.64	1.05	2.37	4.65	2.3	0.21	1.45	0.28	0.08	0.17	1.20	0.86	1.11	0.41	1.8	40	42	42	40	38	42	42	42	42	42
90	0.24	1.74	0.16	0.13	0.21	1.28	1.03	2.00	4.68	2.0	0.25	1.45	0.09	0.10	0.16	0.90	0.81	1.03	0.36	1.7	34	35	35	34	35	35	35	35	35	35
91	0.21	1.30	0.18	0.08	0.21	1.25	0.78	1.77	4.74	2.3	0.24	0.74	0.11	0.05	0.18	1.00	0.44	1.04	0.36	3.3	24	25	25	24	25	25	25	25	26	28
Port Hardy																														
86	0.15	4.29	0.19	0.29	0.13	0.26	2.46	1.09	5.53	12.7	0.10	3.34	0.16	0.27	0.25	0.21	1.92	0.53	0.35	11.8	12	12	12	12	12	12	12	12	12	12
87	0.18	2.61	0.10	0.18	0.13	0.26	1.41	0.82	5.57	5.1	0.15	2.27	0.08	0.16	0.15	0.15	1.19	0.46	0.33	4.7	41	41	42	41	42	41	42	41	42	42
88	0.10	1.94	0.11	0.11	0.09	0.31	1.13	0.74	5.40	4.3	0.07	1.75	0.08	0.12	0.08	0.18	1.00	0.30	0.47	5.0	41	41	41	41	41	41	41	41	41	41
89	0.08	1.65	0.12	0.11	0.12	0.42	0.93	0.75	5.53	4.2	0.05	1.61	0.07	0.10	0.16	0.51	0.88	0.38	0.59	4.7	32	32	32	32	32	32	32	32	32	32
90	0.11	2.63	0.28	0.14	0.13	0.26	1.55	0.95	5.48	5.1	0.07	2.26	0.43	0.12	0.23	0.21	1.35	0.75	0.41	6.3	40	43	43	40	43	43	43	43	44	44
91	0.10	2.53	0.26	0.13	0.09	0.22	1.35	0.77	5.57	4.3	0.06	2.72	0.40	0.14	0.14	0.23	1.35	0.58	0.55	4.8	36	40	38	36	38	40	38	40	40	40
92	0.09	2.41	0.14	0.15	0.02	0.18	1.46	0.57	5.46	9.9	0.06	1.69	0.11	0.10	0.01	0.08	1.05	0.25	0.24	7.7	7	7	7	7	7	7	7	7	7	7

TABLE B2. Annual precipitation chemistry summary. Maximum and minimum annual values. Sample numbers based on data in Table B1. All parameters in mg.L-1 except precipitation (mm.d-1). Detection limit for all parameters except Ca and Mg was 0.01 mg.L-1. Detection limit for Ca and Mg was 0.02 mg.L-1.

	MAX										MIN									
	Ca	Cl	K	Mg	NH4	NO3	Na	SO4	pH	Prcpttn	Ca	Cl	K	Mg	NH4	NO3	Na	SO4	pH	Prcpttn
Nanoose																				
86	0.44	6.5	0.74	0.50	2.25	5.5	3.48	4.3	5.47	16.0	0.02	0.29	0.01	0.02	0.01	0.16	0.16	0.29	4.07	0.07
87	1.35	3.9	1.23	0.22	0.64	3.9	2.95	6.4	6.11	10.1	0.02	0.35	0.02	0.01	0.01	0.01	0.17	0.43	3.99	0.09
88	0.44	2.8	0.87	0.13	0.49	6.3	1.33	5.8	5.82	10.7	0.01	0.14	0.02	0.01	0.01	0.01	0.09	0.41	3.87	0.01
89	0.63	3.1	0.90	0.13	0.36	7.0	3.40	5.7	6.83	6.1	0.02	0.18	0.01	0.01	0.01	0.01	0.10	0.23	3.89	0.01
90	0.48	2.4	0.50	0.13	0.75	20.3	0.70	5.0	5.52	12.8	0.02	0.16	0.10	0.02	0.01	0.06	0.10	0.21	3.50	0.04
91	0.62	3.8	0.60	0.12	0.38	3.3	0.90	2.3	5.48	18.9	0.02	0.13	0.10	0.02	0.01	0.21	0.10	0.25	4.25	0.01
92	0.28	2.6	0.20	0.16	0.20	2.2	1.40	1.2	5.70	17.1	0.04	0.26	0.10	0.02	0.01	0.16	0.10	0.42	4.59	0.41
Victoria																				
86	6.85	8.8	1.13	0.67	0.88	5.8	4.74	21.4	6.49	16.6	0.02	0.30	0.01	0.04	0.01	0.21	0.20	0.99	4.11	0.27
87	0.95	15.3	0.42	1.02	0.41	3.6	7.84	7.3	5.10	9.4	0.11	0.40	0.07	0.03	0.01	0.09	0.30	1.55	4.19	0.43
88	1.26	14.3	0.46	1.26	0.65	6.7	7.70	13.5	5.32	7.9	0.01	0.08	0.02	0.01	0.01	0.17	0.04	0.79	4.27	0.21
89	1.06	6.3	1.35	0.39	0.71	4.4	3.61	4.5	6.40	9.9	0.02	0.03	0.08	0.02	0.01	0.21	0.10	0.75	4.03	0.23
90	1.21	6.9	0.40	0.44	0.56	3.7	3.90	4.9	5.64	7.5	0.04	0.20	0.10	0.02	0.01	0.18	0.10	0.82	4.12	0.00
91	1.12	2.8	0.60	0.19	0.72	4.0	1.70	4.9	5.62	11.3	0.04	0.35	0.10	0.02	0.03	0.28	0.20	0.79	4.15	0.04
Port Hardy																				
86	0.37	12.6	0.56	0.92	0.88	0.8	7.13	2.3	6.48	44.0	0.02	0.93	0.02	0.02	0.01	0.06	0.51	0.33	5.10	0.49
87	0.66	8.4	0.40	0.58	0.58	0.7	4.30	2.3	6.38	16.7	0.02	0.29	0.01	0.03	0.01	0.07	0.17	0.24	5.02	0.21
88	0.28	7.5	0.42	0.50	0.36	0.8	4.29	1.7	6.52	16.4	0.01	0.15	0.02	0.01	0.01	0.01	0.10	0.32	4.68	0.00
89	0.16	5.1	0.31	0.32	0.76	2.9	2.85	1.8	7.19	19.3	0.02	0.20	0.03	0.01	0.01	0.01	0.13	0.29	4.42	0.00
90	0.40	8.0	1.80	0.50	1.15	0.9	4.90	2.9	6.37	27.9	0.02	0.11	0.10	0.02	0.01	0.06	0.10	0.15	4.71	0.00
91	0.36	13.0	2.50	0.80	0.58	1.2	7.40	3.5	7.15	20.1	0.02	0.27	0.10	0.02	0.01	0.01	0.20	0.27	4.59	0.03
92	0.18	5.2	0.40	0.29	0.05	0.3	3.20	1.0	5.89	22.4	0.03	0.49	0.10	0.03	0.01	0.09	0.30	0.24	5.14	2.21

TABLE C1. River chemisty summary. (T) Total, (D) dissolved, and (S) soluble. All units in mg.L-1 except for pH and temperature (°C). Minimum detection limits for each parameter represent detection limits for the majority of the data. Total forms are listed for metals if dissolved data were below minimum detection limits. Dissolved forms are listed for metals if there was no significant difference between dissolved and total data. Mean, standard deviation, and count listed for each river chemistry station for the duration of the record (~1986-1990 for most sites). Data grouped into low (April-September) and high (October-March) flow periods. Data from rivers in the same catchment are pooled following lists for individual rivers. Sampling station name and site code listed for each station.

			Alkalinity: T	Aluminum: D	Ammonia: T	Arsenic: T	Boron: T	Cadmium: T	Calcium: T	Chloride: D	Chromium: T	Copper: D	DO	Hardness: T	Iron: D	Iron: T	Lead: T	Magnesium: D	Manganese: D	Molybdenum: D	Nickel: T	Nitrite: D	NO2NO3: D	pH	PO4 3-: D	Phosphate: D	Phosphate: T	Potassium: S	Silica: D	Sodium: D	Sulphate: D	Temp	Vanadium: D	Zinc: D
	MINIMUM DETECTION		0.1	0.050	0.005	0.050	0.01	0.00	0.100	0.100	0.001	0.001	0.10	0.10	0.010	0.010	0.010	0.010	0.010	0.010	0.01	0.005	0.002		0.003	0.003	0.003	0.1	0.100	0.100	0.10	0.10	0.01	0.001
PUNTLEDGE R. AT CONDENSORY	MEAN	HIGH	18.4	0.055	0.006	0.001		0.01	5.518	1.567	0.001	0.001		17.90		0.270	0.002	0.890	1.018	0.010	0.01		0.042	7.425		0.003	0.008	0.1	4.650	1.100	1.90		0.01	0.017
0125981		LOW	17.2	0.040	0.005	0.001		0.01	5.173	1.200	0.001	0.005	11.70	16.18		0.137	0.001	0.913	0.970	0.009	0.01		0.032	7.217	0.003	0.004	0.007	0.1	4.325		0.80	9.00	0.01	0.009
	COUNT	HIGH	3	2	5	4		5	4	3	5	5		1		5	5	1	4	3	3		5	4		1	5	1	2	2	3.00		3	5
		LOW	5	3	6	6		6	6	1	6	6	1.00	5		6	6	3	5	4	4		6	6	1	4	6	1	4		5.00	3	3	6
	STDEV	HIGH	1.4	0.021	0.001				0.573	0.551		0.001				0.391	0.001		0.141	0.000	0.00		0.018	0.222			0.003		0.919	0.141	0.69		0.00	0.035
		LOW	1.9	0.010					0.390			0.007		1.79		0.131		0.117	0.086	0.003			0.008	0.248		0.002	0.003		0.263		0.96	1.00	0.00	0.013
PUNTLEDGE R. AT CF BRIDGE	MEAN	HIGH		0.037	0.006	0.001		0.01	6.795	0.900	0.001	0.002	10.78	24.31		0.075	0.002	2.004	1.193	0.010	0.01		0.023	7.306	0.003	0.005	0.006		4.900	0.700	8.00	8.10	0.01	0.003
0125980		LOW		0.050	0.006	0.001		0.01	6.412	0.600	0.002	0.001	20.43	20.41		0.107	0.001	1.241	1.980	0.015	0.01		0.042	7.295	0.003	0.004	0.005	0.1	5.983	0.900	5.93	12.36	0.01	0.002
	COUNT	HIGH		3	5	5		5	8	1	5	10	4.00	8		10	10	5	4	3	3		6	9	2	3	9		3	1	7.00	5	3	10
		LOW		1	9	4		4	15	1	4	18	9.00	19		17	17	14	5	2	2		14	19	9	4	18	1	6	3	13.00	14	1	19
	STDEV	HIGH		0.021	0.001				3.910			0.003	1.91	15.94		0.084	0.004	1.953	0.749	0.000	0.00		0.010	0.430		0.001	0.002		1.212		17.86	4.53	0.00	0.004
		LOW			0.003				4.494		0.003	0.000	31.37	15.09		0.144	0.001	1.458	2.416	0.007			0.045	0.327	0.000	0.001	0.003		3.685	0.173	17.77	3.34		0.003
PUNLEDGE CATCHMENT	MEAN	HIGH	18.4	0.044	0.006	0.001		0.01	6.369	1.400	0.001	0.002	10.78	23.60		0.140	0.002	1.818	1.105	0.010	0.01		0.032	7.342	0.003	0.004	0.007	0.1	4.800	0.967	6.17	8.10	0.01	0.007
		LOW	17.2	0.036	0.006	0.001		0.01	6.040	0.900	0.001	0.002	19.56	19.53		0.115	0.001	1.183	1.435	0.011	0.01		0.039	7.276	0.003	0.004	0.006	0.1	5.320	0.900	4.51	11.76	0.01	0.004
	COUNT	HIGH	3	5	10	9		10	12	4	10	15	4.00	9		15	15	6	8	6	6		11	13	2	4	14	1	5	3	10.00	5	6	15
		LOW	5	5	15	10		11	22	2	11	25	10.00	24		24	24	17	11	7	7		20	25	10	8	24	2	10	3	18.00	17	5	26
	STDEV	HIGH	1.4	0.021	0.001			0.00	3.196	0.560		0.002	1.91	15.06		0.239	0.004	1.805	0.507				0.017	0.373		0.001	0.002		0.982	0.252	14.88	4.53		0.020
		LOW	1.9	0.017	0.003			0.00	3.717	0.424	0.002	0.004	29.71	13.49		0.136	0.001	1.321	1.616	0.004			0.037	0.307	0.000	0.001	0.003		2.881	0.173	15.13	3.31		0.007
GOLD R. AT HIGHWAY	MEAN	HIGH			0.006																	0.006	0.023	7.367	0.003	0.003								
E207792		LOW	165.0		0.006		0.01	0.01	5.090	1.160	0.013	0.004	8.45			0.046	0.002	0.574	0.010	0.010	0.02	0.003	0.050	7.500	0.003	0.003	0.003	0.1	4.367	0.900	1.01	16.40	0.01	0.010
	COUNT	HIGH			3																	2	3	3	1	1								
		LOW	1		12		3	4	4	1	4	4	2.00			4	4	5	4	4	4	10	12	12	7	9	2	1	3	1	1.00	2	4	4
	STDEV	HIGH			0.001																	0.006	0.006	0.153										
		LOW			0.002		0.00		0.385		0.025	0.004	0.21			0.071	0.001	0.107			0.02	0.004	0.016	0.230	0.000	0.000			0.723			0.99		
HEBER R. UPSTREAM OF GOLD R.	MEAN	HIGH			0.005																		0.033	7.500	0.003	0.004								
E207793		LOW	322.5		0.005		0.01	0.01	7.510	1.620	0.001	0.002	8.80			0.018	0.001	0.824	0.010	0.010	0.01		0.058	7.711	0.003	0.003	0.003	0.1	4.867	1.100	1.10	11.07	0.01	0.010
	COUNT	HIGH			4																		4	4	3	3								
		LOW	1		10		3	5	6	1	4	4	2.00			4	4	5	4	4	4		10	9	6	7	2	1	3	1	1.00	3	4	4
	STDEV	HIGH																					0.013	0.183		0.001								
		LOW			0.001		0.00		0.706		0.005	0.001	0.85			0.023	0.001	0.144					0.027	0.215	0.000	0.000			0.551			5.37		
GOLD/HEBER CATCHMENT	MEAN	HIGH			0.006																	0.006	0.029	7.443	0.003	0.004								
		LOW	243.8		0.006		0.01	0.01	6.542	1.390	0.008	0.003	8.63			0.032	0.001	0.699	0.010	0.010	0.02	0.003	0.054	7.590	0.003	0.003	0.003	0.1	4.617	1.000	1.06	13.20	0.01	0.010
	COUNT	HIGH			7																	2	7	7	4	4								
		LOW	2		22		6	9	10	2	8	8	4.00			8	8	10	8	8	8	10	22	21	13	16	4	2	6	2	2.00	5	8	8
	STDEV	HIGH			0.001																	0.006	0.011	0.172		0.001								
		LOW	111.4		0.001			0.00	1.374	0.325	0.017	0.003	0.54			0.051	0.001	0.178	0.000	0.000	0.01	0.004	0.022	0.243	0.000	0.000			0.637	0.141	0.06	4.82	0.00	0.000

TABLE C2. River chemisty summary. (T) Total, (D) dissolved, and (S) soluble. All units in mg.L-1 except for pH and temperature (°C). Minimum detection limits for each parameter represent detection limits for the majority of the data. Total forms are listed for metals if dissolved data were below minimum detection limits. Dissolved forms are listed for metals if there was no significant difference between dissolved and total data. Mean, standard deviation, and count listed for each river chemistry station for the duration of the record (~1986-1990 for most sites). Data grouped into low (April-September) and high (October-March) flow periods. Data from rivers in the same catchment are pooled following lists for individual rivers. Sampling station name and site code listed for each station.

			Alkalinity: T	Aluminum: D	Ammonia: T	Arsenic: T	Boron: T	Cadmium: T	Calcium: T	Chloride: D	Chromium: T	Copper: D	DO	Hardness: T	Iron: D	Iron: T	Lead: T	Magnesium: D	Manganese: D	Molybdenum: D	Nickel: T	Nitrite: D	NO2NO3: D	pH	PO4 3-: D	Phosphate: D	Phosphate: T	Potassium: S	Silica: D	Sodium: D	Sulphate: D	Temp	Vanadium: D	Zinc: D
MINIMUM	DETECTION		0.1	0.050	0.005	0.050	0.01	0.00	0.100	0.100	0.001	0.001	0.10	0.10	0.010	0.010	0.010	0.010	0.010	0.010	0.01	0.005	0.002		0.003	0.003	0.003	0.1	0.100	0.100	0.10	0.10	0.01	0.001
OYSTER RIVER AT HIGHWAY	MEAN	HIGH	16.9	0.541	0.006	0.001	0.01	0.01	5.051	1.500	0.002	0.005		16.00	0.108	1.072	0.001	1.259	0.025	0.010	0.01	0.010	0.138	7.193	0.003	0.004	0.020		6.220		1.76		0.01	0.004
0125580		LOW	14.6	0.595	0.006	0.001	0.01	0.01	4.318	0.700	0.001	0.006	12.20	13.70	0.048	0.281	0.001	0.901	0.014	0.010	0.01	0.010	0.029	7.303	0.003	0.003	0.005	0.1	5.475	1.100	1.21	7.00	0.01	0.011
	COUNT	HIGH	20	19	18	13	16	32	32	1	32	32		2	16	32	32	30	31	30	31	3	25	30	18	19	20		5		30.00		30	32
		LOW	12	14	13	9	17	27	32	1	32	32	1.00	4	17	32	32	31	32	31	32	3	18	30	15	18	14	1	4	1	27.00	2	30	32
	STDEV	HIGH	3.9	1.383	0.002		0.00		0.876		0.003	0.007		3.68	0.099	2.924	0.001	0.382	0.054		0.01	0.000	0.189	0.350		0.002	0.039		1.314		0.44		0.01	0.005
		LOW	5.8	1.763	0.001		0.00		1.024		0.002	0.024		1.94	0.023	0.853	0.001	0.445	0.023		0.00	0.000	0.038	0.299		0.001	0.002		0.150		0.38	1.41		0.051
OYSTER R. AT LOGGING BRIDGE	MEAN	HIGH	16.8	0.316	0.005	0.001	0.01	0.01	4.884		0.001	0.004			0.059	0.359	0.001	1.008	0.014	0.010	0.01		0.047	7.187	0.003	0.003	0.006		4.800		1.43		0.01	0.003
0125582		LOW	15.0	0.138	0.005	0.001	0.01	0.01	3.919		0.001	0.002			0.033	0.100	0.004	0.709	0.010	0.010	0.01		0.019	7.236	0.003	0.003	0.004		5.300		1.17		0.01	0.004
	COUNT	HIGH	13	14	12	8	13	24	24		24	24			13	24	24	24	24	24	24		24	23	16	16	19		1		24.00		24	24
		LOW	9	6	8	5	12	22	22		22	22			12	22	22	22	22	22	22		22	22	14	14	17		1		22.00		22	22
	STDEV	HIGH	3.7	0.807	0.001		0.00		0.937			0.006			0.071	0.845	0.000	0.242	0.018				0.030	0.216		0.001	0.004				0.25		0.01	0.005
		LOW	4.3	0.053	0.001		0.00		0.751		0.002	0.001			0.019	0.057	0.012	0.192			0.01		0.011	0.284		0.001	0.002				0.31			0.008
OYSTER CATCHMENT	MEAN	HIGH	16.9	0.445	0.006	0.001	0.01	0.01	4.979	1.500	0.001	0.005		16.00	0.086	0.766	0.001	1.148	0.020	0.010	0.01	0.010	0.093	7.191	0.003	0.004	0.013		5.983		1.61		0.01	0.003
		LOW	14.8	0.458	0.006	0.001	0.01	0.01	4.155	0.700	0.001	0.004	12.20	13.70	0.042	0.207	0.002	0.821	0.012	0.010	0.01	0.010	0.024	7.275	0.003	0.003	0.004	0.1	5.440	1.100	1.19	7.00	0.01	0.008
	COUNT	HIGH	33	33	30	21	29	56	56	1	56	56		2	29	56	56	54	55	54	55	3	49	53	34	35	39		6		54.00		54	56
		LOW	21	20	21	14	29	49	54	1	54	54	1.00	4	29	54	54	53	54	53	54	3	40	52	29	32	31	1	5	1	49.00	2	52	54
	STDEV	HIGH	3.8	1.163	0.002				0.898		0.002	0.007		3.68	0.090	2.290	0.001	0.348	0.042		0.01	0.000	0.143	0.297		0.002	0.029		1.311		0.40		0.01	0.005
		LOW	5.1	1.474	0.001				0.936		0.002	0.019		1.94	0.022	0.659	0.007	0.372	0.018		0.01	0.000	0.027	0.292		0.001	0.002		0.152		0.35	1.41		0.040

TABLE C3. River chemisty summary. (T) Total, (D) dissolved, and (S) soluble. All units in mg.L-1 except for pH and temperature (°C). Minimum detection limits for each parameter represent detection limits for the majority of the data. Total forms are listed for metals if dissolved data were below minimum detection limits. Dissolved forms are listed for metals if there was no significant difference between dissolved and total data. Mean, standard deviation, and count listed for each river chemistry station for the duration of the record (~1986-1990 for most sites). Data grouped into low (April-September) and high (October-March) flow periods. Data from rivers in the same catchment are pooled following lists for individual rivers. Sampling station name and site code listed for each station.

			Alkalinity: T	Aluminum: D	Ammonia: T	Arsenic: T	Boron: T	Cadmium: T	Calcium: T	Chloride: D	Chromium: T	Copper: D	DO	Hardness: T	Iron: D	Iron: T	Lead: T	Magnesium: D	Manganese: D	Molybdenum: D	Nickel: T	Nitrite: D	NO2NO3: D	pH	PO4 3-: D	Phosphate: D	Phosphate: T	Potassium: S	Silica: D	Sodium: D	Sulphate: D	Temp	Vanadium: D	Zinc: D
MINIMUM DETECTION			0.1	0.050	0.005	0.050	0.01	0.00	0.100	0.100	0.001	0.001	0.10	0.10	0.010	0.010	0.010	0.010	0.010	0.010	0.01	0.005	0.002		0.003	0.003	0.003	0.1	0.100	0.100	0.10	0.10	0.01	0.001
COWICHAN RIVER U/S PE-247	MEAN	HIGH	20.7	0.025	0.005	0.250		0.01	6.490	1.850	0.010	0.002	9.80			0.050	0.051	0.630	0.010	0.010	0.05	0.005	0.042	7.394	0.003	0.003	0.006	0.2			1.63	6.63	0.01	0.008
120808		LOW	24.0	0.020	0.007	0.250	0.01	0.01	7.550	1.700	0.010	0.003	8.34		0.036	0.038	0.018	0.647	0.010	0.010	0.05	0.005	0.031	7.587	0.002	0.003	0.005	0.2	2.600		1.50	19.05	0.01	0.006
	COUNT	HIGH	3	2	11	2		2	2	2	2	2	1.00			2	2	2	2	2	2	5	16	17	15	12	11	3			3.00	4	2	2
		LOW	5	1	20	1	5	6	6	4	6	6	12.00		5	6	6	6	6	6	6	16	36	38	28	27	24	8	1		3.00	15	6	6
	STDEV	HIGH	0.5	0.007	0.000			0.01	0.962	0.071		0.001					0.070	0.028					0.030	0.195	0.001	0.001	0.002	0.1			0.15	2.10		0.004
		LOW	4.4		0.002				0.238	0.141		0.004	0.81		0.015	0.015	0.040	0.019			0.00	0.000	0.019	0.266	0.001	0.001	0.002	0.1			0.10	3.18		0.002
COWICHAN RIVER D/S PE-247	MEAN	HIGH	21.2	0.020	0.008	0.250		0.01	6.525	1.900	0.010	0.002				0.045	0.051	0.625	0.010	0.010	0.05	0.005	0.049	7.370	0.003	0.004	0.008	0.2			1.55	5.93	0.01	0.017
E206107		LOW	24.1		0.017		0.01	0.01	7.658	1.688	0.010	0.001	8.65		0.033	0.033	0.001	0.652	0.010	0.010	0.05	0.005	0.029	7.661	0.004	0.005	0.010	0.2	2.500		1.50	19.87	0.01	0.005
	COUNT	HIGH	4	2	14	2		2	2	1	2	3				2	2	2	2	2	2	3	14	10	14	12	8	2			2.00	3	2	3
		LOW	5		34		6	6	6	8	6	6	11.00		6	6	6	6	6	6	6	12	28	28	27	25	17	8	1		3.00	12	6	6
	STDEV	HIGH	0.8		0.004			0.01	1.039			0.001				0.007	0.070	0.007				0.000	0.031	0.134	0.000	0.001	0.003	0.1			0.07	1.90		0.020
		LOW	4.3		0.014				0.327	0.181		0.000	0.75		0.018	0.018		0.015			0.00	0.000	0.013	0.253	0.001	0.002	0.003	0.1				2.19		
COWICHAN RIVER @ WEIR	MEAN	HIGH	20.8	0.050	0.006	0.250	0.01	0.01	7.153	1.950	0.010	0.003			0.066	0.085	0.021	0.672	0.010	0.010	0.05	0.005	0.064	7.228	0.003	0.003	0.005	0.2			1.58	5.10	0.01	0.006
E206108		LOW	22.3	0.060	0.007	0.261	0.01	0.01	7.582	1.650	0.010	0.002	8.62		0.049	0.093	0.018	0.690	0.010	0.011	0.05	0.005	0.035	7.478	0.003	0.004	0.007	0.2	2.450		1.45	19.62	0.01	0.006
	COUNT	HIGH	11	18	30	14	5	24	24	2	24	25			5	24	25	24	24	24	24	6	33	29	34	32	27	2			4.00	2	24	25
		LOW	11	16	31	14	13	34	34	4	34	35	9.00		13	34	36	34	34	34	34	8	35	37	33	34	24	4	2		4.00	10	34	36
	STDEV	HIGH	0.9	0.026	0.001			0.00	1.061	0.354		0.006			0.022	0.048	0.040	0.070	0.002				0.040	0.200	0.000	0.001	0.002	0.1			0.13	1.56		0.002
		LOW	3.2	0.053	0.005	0.021	0.00	0.00	0.816	0.058	0.001	0.002	0.60		0.036	0.116	0.037	0.109	0.003	0.007	0.01	0.000	0.027	0.286	0.001	0.001	0.003	0.1	0.071		0.21	2.35		0.002
COWICHAN CATCHMENT	MEAN	HIGH	20.9	0.045	0.006	0.250	0.01	0.01	7.061	1.900	0.010	0.003	9.80		0.066	0.079	0.025	0.666	0.010	0.010	0.05	0.005	0.055	7.304	0.003	0.003	0.006	0.2			1.59	6.06	0.01	0.007
		LOW	22.3	0.060	0.007	0.261	0.01	0.01	7.582	1.650	0.010	0.002	8.62		0.049	0.093	0.018	0.690	0.010	0.011	0.05	0.005	0.035	7.478	0.003	0.004	0.007	0.2	2.450		1.45	19.62	0.01	0.006
	COUNT	HIGH	18	22	55	18	5	28	28	5	28	30	1.00		5	28	29	28	28	28	28	14	63	56	63	56	46	7			9.00	9	28	30
		LOW	11	16	31	14	13	34	34	4	34	35	9.00		13	34	36	34	34	34	34	8	35	37	33	34	24	4	2		4.00	10	34	36
	STDEV	HIGH	0.8	0.026	0.003			0.00	1.042	0.187		0.005			0.022	0.047	0.043	0.067	0.002			0.000	0.036	0.202	0.000	0.001	0.002	0.1			0.12	1.80		0.006
		LOW	3.2	0.053	0.005	0.021	0.00	0.00	0.816	0.058	0.001	0.002	0.60		0.036	0.116	0.037	0.109	0.003	0.007	0.01	0.000	0.027	0.286	0.001	0.001	0.003	0.1	0.071		0.21	2.35		0.002

TABLE C4. River chemisty summary. (T) Total, (D) dissolved, and (S) soluble. All units in mg.L-1 except for pH and temperature (°C). Minimum detection limits for each parameter represent detection limits for the majority of the data. Total forms are listed for metals if dissolved data were below minimum detection limits. Dissolved forms are listed for metals if there was no significant difference between dissolved and total data. Mean, standard deviation, and count listed for each river chemistry station for the duration of the record (~1986-1990 for most sites). Data grouped into low (April-September) and high (October-March) flow periods. Data from rivers in the same catchment are pooled following lists for individual rivers. Sampling station name and site code listed for each station.

			Alkalinity: T	Aluminum: D	Ammonia: T	Arsenic: T	Boron: T	Cadmium: T	Calcium: T	Chloride: D	Chromium: T	Copper: D	DO	Hardness: T	Iron: D	Iron: T	Lead: T	Magnesium: D	Manganese: D	Molybdenum: D	Nickel: T	Nitrite: D	NO2NO3: D	pH	PO4 3-: D	Phosphate: D	Phosphate: T	Potassium: S	Silica: D	Sodium: D	Sulphate: D	Temp	Vanadium: D	Zinc: D
MINIMUM DETECTION			0.1	0.050	0.005	0.050	0.01	0.00	0.100	0.100	0.001	0.001	0.10	0.10	0.010	0.010	0.010	0.010	0.010	0.010	0.01	0.005	0.002		0.003	0.003	0.003	0.1	0.100	0.100	0.10	0.10	0.01	0.001
NANAIMO RIVER @ HIGHWAY # 1	MEAN	HIGH	14.4	0.138	0.007	0.040	0.05	0.00	4.967	2.600	0.005	0.001			0.086	0.170	0.001	0.565	0.014	0.005	0.03		0.036	7.246	0.003	0.015	0.029	0.4	4.300	1.945	1.40	7.00	0.01	0.003
125180		LOW	16.3	0.037	0.007	0.040	0.07	0.01	5.913		0.010	0.002	8.97	12.75	0.040	0.067	0.006	0.614	0.009	0.009	0.04		0.025	7.200	0.003	0.031	0.031	0.4		3.987	1.60	13.44	0.01	0.020
	COUNT	HIGH	7	12	13	5	6	3	12	1	12	12			11	12	12	12	12	12	12		13	13	12	3	3	2	1	2	1.00	5	12	12
		LOW	18	22	17	3	3	4	23		23	23	3.00	2	24	23	23	23	23	23	23		20	23	19	4	4	3		3	1.00	5	23	23
	STDEV	HIGH	1.8	0.109	0.004		0.02	0.01	0.971		0.005	0.001			0.082	0.121	0.001	0.082	0.010	0.005	0.02		0.014	0.416	0.000	0.021	0.019			0.601		0.28	0.01	0.003
		LOW	2.4	0.028	0.004	0.000	0.03	0.01	1.183		0.007	0.002	0.93	0.49	0.014	0.020	0.021	0.093	0.003	0.003	0.01		0.006	0.239		0.019	0.019			0.345		5.26	0.00	0.047
NANAIMO RIVER @ CAMP	MEAN	HIGH	15.2	0.236	0.009	0.040	0.08	0.00	4.526		0.007	0.002	10.20		0.080	0.260	0.001	0.539	0.026	0.007	0.04		0.036	7.177	0.003	0.022	0.040	0.4		1.255		6.88	0.01	0.007
E208103		LOW	15.5	0.044	0.007				5.299		0.010	0.002	9.95		0.045	0.079	0.001	0.533	0.012	0.010	0.05		0.021	7.130	0.003							13.08	0.01	0.005
	COUNT	HIGH	6	7	12	2	2	1	7		7	7	2.00		7	7	7	7	7	7	7		12	13	12	2	2	2		2		6	7	7
		LOW	20	13	16				13		13	13	2.00		13	13	13	13	13	13	13		20	23	20							5	13	13
	STDEV	HIGH	2.6	0.167	0.010		0.01		0.688		0.005	0.001	0.57		0.028	0.162		0.043	0.017	0.005	0.02		0.016	0.359	0.000	0.026				0.233		0.71	0.00	0.002
		LOW	1.5	0.027	0.004				0.600		0.000	0.001	0.35		0.011	0.014	0.001	0.030	0.004	0.000	0.00		0.003	0.203								5.69	0.00	0.001
NANAIMO RIVER @ SOUTH FORK	MEAN	HIGH	13.1	0.236	0.009	0.040	0.08	0.00	4.526		0.007	0.002	10.20		0.080	0.260	0.001	0.539	0.026	0.007	0.04		0.036	7.177	0.003	0.022	0.040	0.4		1.255		6.88	0.01	0.007
E208104		LOW	14.2	0.044	0.007				5.299		0.010	0.002	9.95		0.045	0.079	0.001	0.533	0.012	0.010	0.05		0.021	7.130	0.003							13.08	0.01	0.005
	COUNT	HIGH	5	7	12	2	2	1	7		7	7	2.00		7	7	7	7	7	7	7		12	13	12	2	2	2		2		6	7	7
		LOW	19	13	16				13		13	13	2.00		13	13	13	13	13	13	13		20	23	20							5	13	13
	STDEV	HIGH	2.9	0.167	0.010		0.01		0.688		0.005	0.001	0.57		0.028	0.162		0.043	0.017	0.005	0.02		0.016	0.359	0.000	0.026				0.233		0.71	0.00	0.002
		LOW	2.7	0.027	0.004				0.600		0.000	0.001	0.35		0.011	0.014	0.001	0.030	0.004	0.000	0.00		0.003	0.203								5.69	0.00	0.001
NANAIMO RIVER @ TEEPEE BRIDGE	MEAN	HIGH	16.5	0.085	0.005	0.040	0.05	0.00	5.239		0.005	0.001			0.033	0.075	0.001	0.486	0.006	0.005	0.03		0.032	7.192	0.003	0.022	0.040	0.4		1.120		5.70	0.00	0.005
E208105		LOW	16.2	0.041	0.006	0.040	0.06	0.01	5.760		0.009	0.002	9.63		0.029	0.051	0.001	0.489	0.010	0.009	0.04		0.026	7.173	0.003	0.040	0.040	0.5		1.240		11.88	0.01	0.007
	COUNT	HIGH	6	11	12	5	6	2	11		11	11			10	11	11	11	11	11	11		12	12	12	2	2	2		2		4	11	11
		LOW	19	20	16	3	3	4	20		20	20	3.00		19	20	20	20	20	20	20		19	22	19	3	3	3		3		5	20	20
	STDEV	HIGH	1.8	0.059	0.000		0.03	0.00	0.627		0.005	0.001			0.029	0.052	0.001	0.086	0.005	0.005	0.02		0.010	0.365	0.000	0.026				0.198		0.98	0.01	0.004
		LOW	3.9	0.032	0.002	0.000	0.04		2.270		0.004	0.001	0.47		0.031	0.039	0.000	0.161	0.002	0.004	0.01		0.011	0.216		0.000	0.000	0.2		0.128		4.69	0.00	0.009
NANAIMO RIVER @ CEDAR BRIDGE	MEAN	HIGH	16.2	0.247	0.024	0.040	0.09	0.00	4.644		0.007	0.001			0.069	0.243	0.001	0.633	0.014	0.007	0.04		0.038	7.160	0.005	0.022	0.040	0.4		2.215		7.38	0.01	0.006
E215789		LOW	18.4	0.040	0.006				6.184		0.010	0.002		15.70	0.030	0.074	0.002	0.831	0.010	0.010	0.05		0.024	7.157	0.003							19.50	0.01	0.009
	COUNT	HIGH	4	7	10	2	2	2	7		7	7			7	7	7	7	7	7	7		10	10	10	2	2	2		2		5	7	7
		LOW	10	9	9				9		9	9		1	9	9	9	9	9	9	9		10	14	9							1	9	9
	STDEV	HIGH	1.2	0.197	0.048		0.02	0.00	0.677		0.005	0.001			0.013	0.182		0.054	0.013	0.005	0.02		0.016	0.392	0.006	0.026				0.445		0.48	0.00	0.002
		LOW	2.0	0.015	0.003				0.957		0.000	0.001			0.011	0.032	0.001	0.365	0.000	0.000	0.00		0.007	0.256	0.000								0.00	0.006
NANAIMO CATCHMENT	MEAN	HIGH	15.0	0.158	0.010	0.040	0.06	0.00	4.686	2.600	0.006	0.001	11.13		0.061	0.161	0.001	0.527	0.013	0.006	0.03		0.034	7.193	0.003	0.020	0.037	0.4	4.300	1.530	1.40	6.62	0.01	0.005
		LOW	15.9	0.099	0.007	0.040	0.06	0.01	5.216	2.600	0.008	0.001	10.38	15.70	0.049	0.114	0.001	0.558	0.013	0.008	0.04		0.030	7.185	0.003	0.025	0.037	0.4	4.300	1.372	1.40	8.39	0.01	0.006
	COUNT	HIGH	28	44	58	16	18	10	44	1	44	44	3.00		42	44	44	44	44	44	44		58	60	57	11	11	10	1	10	1.00	25	44	44
		LOW	47	55	61	12	13	10	55	1	55	55	6.00	1	53	55	55	55	55	55	55		65	74	63	10	10	9	1	9	1.00	22	55	55
	STDEV	HIGH	2.3	0.137	0.021	0.000	0.03	0.00	0.966		0.005	0.001	1.67		0.050	0.137	0.001	0.097	0.012	0.005	0.02		0.014	0.376	0.002	0.019	0.010	0.0		0.559		0.87	0.00	0.003
		LOW	3.3	0.111	0.005	0.000	0.03	0.01	1.738		0.004	0.001	1.37		0.049	0.112	0.001	0.219	0.009	0.004	0.02		0.013	0.317		0.019	0.010	0.1		0.412		3.97	0.00	0.006

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