README FILE:

This PDF file consists of the Technical Report and map series that was distributed to Workshop participants. Links to some of the maps are provided where appropriate; but not all maps are referred to in the text. The maps provide details of the regional summary of CFIA 2000 cultured oyster Cadmium residue data [see page 71 (83 OF 492)] as well as providing a comparison with historical Environment Canada and limited results from DFO surveys of wild oysters. Information is also provided on BC coastal geology and stream sediment geochemistry.

In the AGENDA portion, blue box links will take you to the ABSTRACT for that author. In ABSTRACTS, there are red box links that will take you to the slide show of that author. Additional links within the author's abstract will navigate to specific slides. Additional note; when you want to return to your original location from a power point presentation do control and previous view.

Proceedings of a Workshop on Possible Pathways of Cadmium into the Pacific Oyster *Crassostrea gigas* as Cultured on the Coast of British Columbia, Institute of Ocean Sciences, March 6-7, 2001

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PROCEEDINGS OF A WORKSHOP ON POSSIBLE PATHWAYS OF CADMIUM INTO THE PACIFIC OYSTER *CRASSOSTREA GIGAS* AS CULTURED ON THE COAST OF BRITISH COLUMBIA, INSTITUTE OF OCEAN SCIENCES, MARCH 6-7, 2001.

by

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LIST OF ACRONYMS AND ABBREVIATIONS

ADI	Acceptable Daily Intake
AMMA	Active Malaspina Mariculture Association
BCSGA	BC Shellfish Growers Association
CAC	Codex Alimentarius Commission
CCFAC	Codex Committee on Food Additives and Contaminants
CFIA	Canadian Food Inspection Agency
CHS	Canadian Hydrographic Service
CODEX	Codex Alimentarius of the FAO/WHO (International Food Code)
CSSP	Canadian Shellfish Sanitation Program
DFO	Department of Fisheries and Oceans
EC	Environment Canada
FAO	Food and Agriculture Organization of the United Nations
FAU	Florida Atlantic University
FBO	Fanny Bay Oysters
HACCP	Hazard Analysis Critical Control Point
HC	Health Canada
ICPMS	Inductively Coupled Plasma Mass Spectrometry
HEB	Habitat Enhancement Branch, DFO
IOS	Institute of Ocean Sciences, DFO
JECFA	Joint FAO/WHO Expert Committee on Food Additives
MAFF	Ministry of Agriculture Food and Fisheries, BC.
MEHSD	Marine Environment and Habitat Science Division, DFO
NRCAN	Natural Resources Canada
OCAD	Office of the Commissioner of Aquaculture Development
OSAP	Ocean Science and Productivity Division, DFO
PFC	Pacific Forestry Center
PSARC	Pacific Scientific Advice Review Committee, DFO
PTWI	Provisional Tolerable Weekly Intake
RGS	Regional Geochemical Survey
SEOS	School of Earth and Ocean Sciences
SFU	Simon Fraser University
SQCRD	Skeena Queen Charlottes Regional District
UBC	University of British Columbia
UVIC	University of Victoria
WHO	World Health Organization

ABSTRACT

On 6-7 March, 2001 approximately 40 invited participants from Canada, the USA, New Zealand, Australia and Mexico gathered at the Institute of Ocean Sciences in Sidney, BC to exchange information on the possible sources of cadmium in BC cultured oysters. This Report comprises informal Proceedings of this exchange and includes an outline of ideas for discussion, Abstracts provided by the 29 speakers, as well as their presentations on a CD-ROM. A synthesis of the discussions includes the identification of data gaps and contains recommendations on directions for future research.

Keywords: *metals, cadmium, shellfish, bivalve, oyster culture, pathways, oceanography, upwelling, phytoplankton, geochemistry, workshop, British Columbia, IOS.*

RÉSUMÉ

Les 6 et 7 mars 2001, environ 40 experts du Canada, des États-Unis, de la Nouvelle-Zélande, de l'Australie et du Mexique se sont rassemblés, sur invitation, à l'Institut des Sciences de la Mer de Sidney, en Colombie-Britannique, pour échanger des informations sur les sources possibles du cadmium dans les huîtres de culture de cette province. Ce rapport contient les comptes rendus informels des échanges qui eurent lieu, un cenevas d'idées pour discussion, les résumés des exposés de 29 conférenciers, ainsi que leurs présentations sur disque compact. Une synthèse des discussions inclut l'identification des données encore à acquérir et des recommandations sur les orientations futures de la recherche.

Mots clés : métaux, cadmium, bivalve, huître du Pacifique, huître de culture, cheminement, océanographie, remontée d'eau profonde, phytoplancton, géochimie, atelier, Colombie Britannique

INTRODUCTION

In response to a May, 2000 request by the Canadian Food Inspection Agency (CFIA) the Department of Fisheries and Oceans (DFO), Pacific Region undertook to investigate the potential reasons for apparently elevated Cadmium levels in BC cultured Pacific oysters *Crassostrea gigas*. Earlier in the year, CFIA reported that several shipments of BC farmed oysters had been rejected by the Hong Kong Food and Environmental Hygiene Department as being in excess of their 2 µg Cd/g (ppm) wet weight limit. A preliminary literature search was conducted, contacts were made with BC shellfish growers and processors, both government and academic researchers were consulted and the resulting information was synthesized by GMK in the form of a PSARC (Pacific Scientific Advice Review Committee) report: *Cadmium in BC farmed oysters: A review of available data, potential sources, research needs and possible mitigation strategies*

(http://www.pac.dfo-mpo.gc.ca/sci/psarc/ResDocs/Habitat_00.htm)

Among recommendations of the PSARC report was the holding of a Cadmium and Oysters Workshop to exchange information with oceanographers, geologists, geochemists, oyster growers, toxicologists, biochemists and biologists; the objective being to define fruitful avenues of research and possible mitigative strategies. These are the Proceedings from that Workshop.

WORKSHOP OBJECTIVES

1. Disseminate information gathered by Canadian Food Inspection Agency (CFIA) in 2000.
2. Provide status report on what information DFO Science has assembled in relation to CFIA data provided to us in May 2000.
3. Seek clarification of Health Canada and CFIA's role.
4. Provide opportunity for input from BC Shellfish Growers Association (BCSGA), Growers Coops, and individual oyster farmers.
5. Seek advice on logistics of proposed grow-out experiment: common stock of oyster distributed to various sites to be sampled after a year of suspension culture.
6. Provide a forum for exchange of scientific information which might be utilized to clarify and perhaps define potential Cd pathways.
7. Formulate ideas for potential collaborative research projects with the objective of generating an interdisciplinary proposal for FY 2002-2003.

ORGANIZATION

Literature work and discussions led to the formulation of general hypotheses and ideas. These are presented below as *Potential sources and Factors Influencing Cadmium Uptake in Oysters.* Contacts were established with specialists at the University of British Columbia, Simon Fraser University in Vancouver, University of

Victoria and University of Northern British Columbia in Prince George. These researchers as well as federal and provincial government contacts and industry representatives were invited to elaborate on these topics in the context of addressing cadmium pathways into bivalves, regulatory and health aspects, as well as methodologies that could be applied in mounting a research effort to address data gaps.

The workshop was held Tuesday March 6th and Wednesday 7th, 2001, with the Agenda as indicated on page 13. Minor scheduling modifications were necessary to accommodate a few speakers, but in general, presentations were grouped by topic. The first day dealt with the roles of various government departments, BC 's plans for expansion of shellfish culture, and the terrestrial component including remote sensing. The second day was devoted to oceanography, physiology and biochemistry of Cd uptake and storage.

A Wednesday evening session was held to discuss and synthesize information that was exchanged. The objective was to identify data gaps, define what would be useful to collect or assemble from existing knowledge, consider the possible applicability of remote sensing as well as investigate the potential for interdisciplinary proposals for research to gather new information and to identify potential funding sources.

A draft summary was prepared by R. Addison, R. Macdonald, E. Black and G. Kruzynski and circulated to participants after the workshop. Comments received were incorporated and this synthesis is presented in the Summary and Discussion (p. 4) and in Recommendations for Research (p. 8)

Thirty-one presentations were made by 29 speakers. GMK made several short presentations between speakers to facilitate continuity. Dr. Keith Hunter of University of Otago, New Zealand, whose travel was inadvertently cancelled due to severe winter weather, kindly provided a copy of his talk and this is included in the set. Mr. H. Nelson of Environment Canada presented data (Nelson and Goyette 1976) that had already been synthesized by GMK, (Appendix Fig. 2) so is not included separately.

Authors were asked to provide copies of their presentations in Microsoft PowerPoint™ format and these have been reproduced with minimal editing in CD-ROM format in Appendix A which also contains the set of maps distributed by GMK at the workshop. Abstracts provided by authors begin on page 21. A list of the approximately 40 participants is presented in Appendix B and provides contact information.

POTENTIAL SOURCES AND FACTORS INFLUENCING CADMIUM UPTAKE IN OYSTERS

Aquatic

<u>Oceanographic/Food Chain</u>

- Vertical transport by upwelling of phosphate and Cd from deeper waters
- Horizontal transport by currents

- Influence of salinity and temperature
- Preferential uptake by plankton during blooms; possible influence of zinc limitation
- Pathway to oysters via food supply
- Evidence for a latitudinal Cd gradient

Terrestrial
Geology/Geochemistry

- Local mineralogy
- Sequestration by hematite
- Contribution of glacial flour

Agriculture

- Cd contaminated phosphate fertilizers

Forestry Practices

- Wholesale forest canopy removal, soil erosion, exposure of bedrock, increased leaching
- Fertilizer application at reforestation

Other Sources

- Municipal STP's (sewage treatment plants)
- Pulp mills
- Fertilizers applied to golf courses
- Septic sludge
- Plastics with Cd as pigment/UV stabilizer utilized in oyster culture

Biological Factors

- Unnatural feeding regime during suspension culture
- Resuspension and re-ingestion of accumulating waste
- Sequestration by anoxic sediments
- Uptake controlled by salinity

QUESTIONS
General

- Is this new?
- What are the contributing factors?
- Is it a health risk?
- What can be done about it?

Scientific

- What is known about differences in Cd uptake by phytoplankton of importance to the oyster diet?
- What seasonal data do we have on phosphate?
- Utility of BC Regional Geochemical Survey (RGS) stream sediment Cd data?

- Is there a potential application for remote sensing and satellite images?

SUMMARY AND DISCUSSION

General background

The issue of Cadmium (Cd) in Pacific oysters cultured in BC arose in early 2000 after three successive batches were rejected by the Hong Kong Food and Environmental Hygiene Department in December 1999, January and February 2000, as their Cd concentrations exceeded the 2 ppm (2 µg/g) wet weight (ww) standard applied there. The workshop whose proceedings are summarised here was organised to exchange information about the industry, to discuss possible reasons for Cd accumulation by Pacific oysters, and to seek practices or processes which might mitigate the problem. The participants included shellfish growers, scientists and regulators from federal and provincial government departments, and scientists from academia.

The value of the Pacific oyster industry in BC is about $15M annually (1996-1997 data: Carswell 2001) and it provides employment for about 1000 individuals. Approximately 17% of production is consumed domestically, another 17% is exported to the Far-east (half to Hong Kong) and the balance (about 65%) is exported to the USA (the value of the Hong Kong market is therefore about $2M).

Although these figures are not large compared to the value of total landed fishery catch in Canada, they are disproportionately significant to coastal communities where few employment opportunities exist. The shellfish industry has the potential to grow to a value of about $100M. The industry is managed and regulated domestically by many federal and provincial agencies. However, despite the complexity of the regulatory structure, all the key players seem to work well together. The concentration of Cd in BC Pacific oysters, which is usually around or over 2 µg ww, is not at present a domestic issue, as Health Canada has no guidelines for Cd consumption by the Canadian consumer. However, both domestic and international markets would be seriously affected if Canada and export markets were to adopt the Codex rules now being discussed which could lead to a recommended concentration limit of 1 µg/g ww. Currently, the USA recommends that Cd concentrations in Pacific oysters should not exceed 3.7 µg/g ww. However, Canada usually “aligns" itself eventually with the Codex standards.

A "back-of-envelope" calculation illustrates the level of exposure one might expect from the consumption of oysters. A 300 g meal of oysters (6 x 50g) at 2 µg/g ww Cd would provide a dose of 600 µg Cd –about 50% over the WHO recommended adult weekly intake (385 µg) from all including non-food sources. This is probably not an issue for most Canadians consumers given the safety factors incorporated into recommended intakes, but it would be significant to consumers for whom oysters are an important dietary component.

The Codex standard is based on considerations of human health and safety, although economic factors are also taken into account. Codex negotiations are now at Step 3; at Step 6, countries *and organisations* can comment on draft standards.

In summary, *if the Codex standard becomes 1 μg/g (ww) and the US adopts it, Canada's main export market for Pacific oysters would close. It follows that the British Columbia Shellfish Growers Association (BCSGA) and other interested parties should maintain a vigilant watch on Codex negotiations and be prepared to comment at Step 6.*

Distribution of Cd in Pacific oysters — possible sources and pathways

Several participants at the workshop presented data describing Cd concentrations in oysters and other cultured shellfish. The data occasionally appeared contradictory, probably due to factors we presently do not adequately understand, so the following should be recognised as a *general* summary. A limited survey of Cd in BC oysters was undertaken by DFO and BC Fisheries during the summer of 2000 with sites selected to provide insight into variables such as history, growing conditions, age, and size. When completed, the analytical data from this survey may prove helpful in fine tuning some of research directions recommended at this workshop.

Cadmium concentration is usually related to age or size of the animal; *concentrations* may decrease with increasing size ("growth dilution") though *burdens* (total Cd contained in a given oyster) increase with size (Thomson 1982; Kruzynski 2001). Concentrations in oysters appear to be independent of culture method (Schallie 2001), though one study (from Tasmania) suggests that concentrations may be higher in oysters living on bottom sediments (Thompson 2001). However, other studies (McConachie and Lawrance 1991; Thomson 1982; Hayes et al. 1998) revealed no such difference; i.e. sediment Cd was not correlated to that in oysters.

There appears to be a slight trend of increasing Cd concentration from south to north in BC cultured oysters from the Strait of Georgia. Cd concentrations seem not to have declined from the early 1970s to the present, though this conclusion is tentative as it is based on a comparison between wild and cultured oysters. The lack of evidence of any decline in Cd concentrations over this interval contrasts the situation for the southeast US and the Gulf of Mexico, where Cd concentrations in *Crassostrea virginica* (used as a "sentinel" organism in the US "Mussel Watch" – for example see Baliaeff et al.1997) have declined steadily in response to reduced industrial and urban discharges. This suggests that Cd in BC oysters is not related industry but rather derives from natural processes, which is consistent with the absence of industry or urbanisation near the growing areas. This in turn implies that BC oysters could correctly be referred to as “enriched in", but not "contaminated by" Cd; an important point when considering any future action to mitigate such enrichments.

The most probable source of Cd to the oysters is their food: phytoplankton and other filtered particulates (Reinfelder et al. 1997), though direct uptake from water may also contribute. Data from Lares (2001) suggests that in (e.g.) *Mytilus californianus*, Cd concentrations in tissue can fluctuate in concert with water concentration. Eventually Cd in oysters becomes bound to a specific protein (metallothionein, MT: Kohler and Riisgard 1982; Roesijadi 1996) and the Cd-MT complex turns over very slowly (the half life of Cd in Cd-MT in *C. virginica* gills is of the order of 80 d, Roesijadi 2001). There appear to be no data describing Cd concentrations in local phytoplankton; however, Cd concentrations in surface sea water in the NE Pacific have been documented, and are about 3-fold higher than in surface waters of the NW Atlantic (Crispo 2001). The deeper waters of the Pacific that upwell along BC's coast and supply nutrients to support phytoplankton growth, are also relatively enriched in Cd.

Land-based *natural* occurrences of Cd cannot be eliminated as sources, especially since the surfical geological structures of coastal BC are rich in Zn-containing minerals with which Cd is usually associated (Lett and Jackaman 2001). However, no estimates of "loadings" of Cd from streams or rivers to shellfish growing areas have been made. It is also possible that alteration in terrestrial systems by human activities such as occur during mining, road construction, forest clear-cutting or farming could have led to increased surface run-off or altered patterns of runoff, but it is not known whether such alterations are a significant source of Cd in any location. Phosphate fertiliser, which inevitably contains Cd (Elinder and Järup 1996), is widely used (e.g., in agriculture, silviculture (Brown 2001) and for golf courses) and the application of phosphate could, therefore, supply Cd to estuaries through runoff. We have no data for the Fraser Valley or other areas and further work to determine the significance of this as a potential Cd source is clearly warranted.

Taking these points together, we draw the following general conclusions about possible sources and pathways that lead to Cd accumulation by cultured Pacific oysters.

1. Cd is enriched in the North Pacific Ocean relative to the Atlantic simply as part of the natural global ocean nutrient cycle. Cd mimics phosphorus in the ocean because it follows the soft-body parts of plankton during remineralization and therefore becomes elevated in waters exhibiting high nutrients (Bruland and Franks 1983). For BC, nutrient- and Cd-enriched water is upwelled along the coast especially during summer when winds are from the north (Freeland and Denman 1982; Mackas et al. 1987). Upwelled water also provides the source for much of the nutrient supply for the marginal basins of the coast including the Strait of Georgia and coastal inlets (Harrison et al. 1991; Stucchi 2001; Whitney 2001). Due to this higher natural Cd concentration, it seems probable that Cd would be accumulated to a greater degree by phytoplankton, particularly during blooms, and there is some evidence that Cd may partially replace Zn if the latter is depleted in sea-water, both in phytoplankton (Lane and Morel 2000; Price and Morel 1990) and in bivalves (Sunda and Huntsman 2000). In Japan, the highest levels of Cd were found in mussels *Septifer virgatus* that had the lowest levels of Zn and it was suggested (Y. Shibata personal communication 2000) that this bivalve was able to accumulate Cd instead of Zn when Zn depletion occurred. The phytoplankton-associated Cd would then be accumulated by feeding

oysters, and fairly rapidly scavenged by metallothionein and sequestered as a complex with a slow turn-over rate.

Local factors may play an important –or even crucial –role in the uptake of Cd by oysters. For example, runoff in some coastal streams may be enriched in Cd especially in locations exhibiting high mineralization or upland watershed disturbance. If this Cd is labile (available) it could be accumulated in oysters as part of the particulate food they consume provided the oysters do not selectively reject such material. It is also possible that a partitioning onto particles plays a role wherein a mineral such as haematite (Fe_2O_3; red iron ore) can provide an intermediary that acts as an efficient –and re-usable –Cd pathway from water to mineral surface to oysters through filter feeding (McConchie and Lawrance 1991). Since beach sands in BC often contain haematite, this remains a possible, but unevaluated, pathway. Another speciation possibility are iron-oxy-hydroxides formed as floc at the freshwater-marine interface. These provide a very large surface area and are known to sequester other metals, particularly in ionic form and as metallo-organic complexes associated with the dissolved organic carbon (DOC) component of freshwaters. If this is the case, then factors such as the Fe, DOC and Cd content of the freshwater and the Cd content of the marine waters may be critical issues affecting the resulting chemistry of the suspensates that might be ingested by the shellfish. (Garrett, R. personal communication, NRCAN).

2. Other components of the water, for example dissolved organic carbon (Guo et al. 2001) may affect metal uptake. In Australian waters a correlation has been observed between Cd in oysters and Cd in the sediments on which they rest (Thompson 2001). In such a case, there might be a pathway that operates by enriching Cd in sediments through redox chemistry (cf. Pedersen et al. 1989) and then releasing this Cd to oysters via resuspension.

3. Finally, it is possible that there is a complex interaction between some or all of these processes that depends critically on seasonal cycles which vary from location to location. For example, rivers on Vancouver Island tend to peak during autumn whereas coastal (Mainland) rivers which drain large glaciers and snowfields tend to peak in June. Particle loads (e.g. glacial flour perhaps enhanced in Cd) and salinity stratification produced locally by these rivers would interact differently with the oyster's physiology and thereby affect Cd uptake.

The three pathway components delivering Cd to northeastern Pacific oysters about which we are most confident –global ocean cycle, upwelling, and the oyster's proclivity to accumulate Cd –are also the three that we can do little to change. The complex local or regional factors listed above may provide clues to identify poor sites for oyster culture or poor times to harvest oysters, but at present we have few data with which even to test hypotheses.

If the factors listed above turn out to be the major controls for Cd in BC oysters, there are several implications:

1. Cd accumulation should be a feature not just of cultivated oysters, but also wild oysters, and, indeed, any filter-feeding organism (though shellfish are probably the most important commercially). Regardless of the uptake process, Cd is sequestered as a Cd-MT complex which has a slow turn-over rate.

2. The slow turnover of Cd-MT makes it unlikely that high Cd concentrations could be "depurated" by holding the oysters in clean water (assuming reasonably Cd-free sea-water would be available). Mitigation of the problem should therefore be based on other strategies, such as harvesting before the spring plankton blooms, or in the cases where the Cd can be shown to be present in inorganic constituents of the food, e.g. from upland sources, avoidance of such sites may be necessary.

3. The behaviour of Cd tends to mimic that of phosphate in the ocean; since nutrient supply fuels the phytoplankton blooms on which the oysters feed, selection of sites of high biological productivity actually selects for high Cd supply. However, if Cd accumulation by phytoplankton depends to some extent on Zn depletion, this is most likely to occur towards the end of a bloom; thus exposure to Cd might be reduced by monitoring the progress of a bloom.

These points suggest directions for further work focussed mainly on the components of the Cd pathway that we do not understand at present.

RECOMMENDATIONS FOR FURTHER RESEARCH

Among the studies that should be carried out in the short term:

(a) Address the hypothesis that *Cd accumulation by cultured oysters reflects Cd uptake by phytoplankton during a bloom, and specifically the relationship between Cd and Zn uptake by phytoplankton.* Requires frequent (1-2x/week) sampling of phytoplankton and oysters at 2 -3 selected sites during a bloom and analysis for Chl a, Zn and Cd. Some of these data may be available through remote sensing (Borstad 2001).

(b) Define the relative importance of oceanic (via upwelling) and local riverine and run-off sources of Cd by contrasting uptake of Cd in oysters from locations influenced by streams that are Cd enriched with those where nearby streams are not Cd enriched. Gut contents partitioning into organic and inorganic constituents would help define the pathways.

(c) Investigate the relationship between Cd in sediments (both suspended and deposited) and Cd in oysters (evidence presently available suggests that there is no such correlation but further data should be collected as an extension to the recent oyster survey). Additionally, elemental scans available with ICP-MS could be used to seek relationships between Cd and other elements. In the list of hypothetical contributors to Cd enrichment in oysters have been included 1) the food web; both organic and inorganic, 2) surface adsorption and 3) redox enrichment. Each of these processes enriches elements differently depending on their biogeochemistry (e.g., conservative, recycled, scavenged) and the signature of the important process might show up in the oysters themselves (a cheap and uncertain fishing expedition).

(d) In some coastal inlets, e.g. Effingham Inlet (Barkley Sound, Fig.1c) there may well be a lateral salinity gradient from the head seaward at least in the surface waters where oysters are suspended. Grow-out oysters could be deployed along this gradient. Of course, if there are also mineral deposits, and logged areas these could be acting in concert. A desktop exercise could be carried out to define these from LANDSAT (Burt and Snijders 2001) and RGS (Regional Geochemical Survey) data as well as from any salinity data that might exist.

(e) Determine locations on the BC coast where wild oysters can still be collected. Such sampling should coincide with the 1973 Environment Canada sites (Figure 1 Appendix) which generated baseline data on wild oysters. A comparison of current Cd wild oyster residues would serve to determine temporal trends and whether the suggested latitudinal gradient still persists.

For longer term studies

(f) Establish whether there is a relationship between Cd uptake and Zn availability and, if so, attempt to manage the Cd/Zn uptake relationship in phytoplankton by "fertilising" a bloom at an oyster rearing site with Zn. A pilot laboratory culture experiment should precede this effort.

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AGENDA

Oyster and Cadmium Workshop
Agenda for Tuesday, March 6th and Wednesday, March 7th 2001

Titles in bold, topics suggested to authors in italics.

08:30-09:30 **Registration**

09:30-10:00
George M. Kruzynski, IOS. **Cadmium in BC Cultured Oysters: An Overview**
Introduction. Outline of events, Cadmium use, potential cadmium sources, PSARC Workshop plan.

10:00-10:30
Brian Kingzett, Kingzett Professional Services, Duncan, BC. **The Shellfish Culture Industry in British Columbia.**
History, current and future species, economics, general overview and comparison of production methods and materials.

GMK 1 slide* (materials leaching results)

10:35-10:45
William F. Dewey Taylor Shellfish Co., WA. **Cadmium in Taylor Shellfish Company Oysters, Washington USA**

Quick overview of Cd data from longline vs bottom culture in two locations in Puget Sound.

10:45-11:15
William A. Heath and Barron Carswell BC Fisheries, Courtenay and Victoria resp.: **Site Selection Considerations for Shellfish Farming in British Columbia** &
The BC Shellfish Development Initiative Process and the Relevance of Cadmium concentration data in BC cultured oysters to Industry Development (respectively).

Historical background of Industry, Shellfish Development Initiative, site selection protocols, future expansion plans.

GMK 2 slides* (Fish farms/oyster lease interaction)

11:15-11:30 **COFFEE BREAK**

11:30-11.45
Sheila Dobie, SQRCD, Prince Rupert**: Notes on the North Coast Shellfish Industry, April 2001.**
Skeena Queen Charlotte Regional District (Prince Rupert): Northern expansion plans including growing interest by First Nations.

GMK 2 slides* (Comparison of Cadmium and Zinc residues among Species)

12:00-12:15

Ruth Salmon, Executive Director BCSGA **How Industry Sees the Cadmium Issue.**

Perspectives on the issue of the BC Shellfish Growers Association representing some BC oyster growers, relationship to CFIA.

12:15-12:30
Allison Webb, DFO. **Shellfish Monitoring Project.**
Role of the Office of the federal Commissioner of Aquaculture

12:30-13:00 **LUNCH Provided**

13:00-13:30
Sing Liem CFIA Burnaby. **CFIA's Role in Food Safety Matters**
Klaus Schallie, CFIA Burnaby: **Results of the 2000 Survey of Cadmium in BC oysters.**

CFIA mandate in relation to DFO and Health Canada, results of 2000 CFIA processor survey (mapped by GMK)

13:30-13:45
Hal Nelson Environment Canada. **Historical and Present EC Involvement in Shellfish Programs.**

EC historical Cd data mapped by GMK.

13:45-14:00
Wayne Knapp DFO RHQ Vancouver, Habitat Enhancement Branch.
Cadmium in Shellfish, Habitat Management Roles and Responsibilities.

DFO HEB mandates from a habitat protection and human health standpoint. Relationship with Health Canada and CFIA.

14:00-14:30
Kevin Telmer University of Victoria, School of Earth and Ocean Sciences. **Approaches to Source Apportionment-Oyster and Cadmium Workshop.**

Research approaches including geochemistry tools as a potential fingerprint of Cd sources..

14:30-15:00
George Kruzynski, IOS. (see 09:30h).

Comparison of CFIA 2000 and historical data, fate of Cadmium, regulations/consumption/dietary intake comparisons.

15:00-15:30
Carl Alleyne, Health Canada. **Assessment of Risk to Human Health from Contaminants in Foods.**

Risk Assessment protocols, relationship to International Standards, US FDA, WHO/FAO, CODEX

15:30-15:45 **COFFEE**

15:45-16:00
George Kruzynski, (See 09:30h) **<u>Potential Terrestrial Sources, Introduction</u>**.

16:00-16:15
Kevin Brown, BC Ministry of Forests, Research Branch, Victoria. **<u>Forest Fertilization on Vancouver island as a Potential Terrestrial Source of Cadmium to Oysters.</u>**

Fertilizer application as a potential anthropogenic source of Cadmium to watersheds

16:15-16:45
Ray Lett and Wayne Jackaman, BC Geological Survey. **<u>Cadmium in Coast BC Sediments</u>**

BC mining exploration, coastal geology and potential utility of the (RGS) Regional Geochemical Survey to measure Cd inputs

16:45-17:15
Will Burt and Marcella Snijders, University of Victoria, Department of Geography. **<u>How Satellite Imagery Can Help to Understand Cadmium Contamination in Oysters</u>**

Can remote sensing of watershed disturbance be a useful tool to apply to the terrestrial Cd mobility question ?

17:15-17:45
Pal Bhogal , NRCAN Pacific Forestry Center, Victoria. **<u>Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD) - An Overview</u>**
Application of remote sensing technology to mapping watershed coverage, tree physiology, stress and future potential for metals analyses from satellites using hyperspectral sensors.

17:45- 18:15
Gary Borstad, Borstad Associates Ltd., Sidney, BC. **<u>Potential Practical Applications of Remote Sensing for BC Aquaculture.</u>**
Remote sensing as applied to aquaculture impacts, tracking chlorophyll, temperature, suspended sediments, plankton blooms.

*** Useful bits of information.**

Wednesday March 7th
Oceanography and Uptake

08:45-09:15
Sabrina Crispo Earth and Ocean Sciences University of British Columbia. **Marine Geochemistry of Cadmium.**

Information on oceanic Cd pathways, relationships to nutrients eg. phosphate, influence of upwelling and how this cycle may differ in coastal waters. Data on Cd concentrations in BC coastal waters. ~45-75 ng/L however Lares reported up to 278 ng/L during storm events at Amphitrite Point, BC.

09:15-09:45
Frank Whitney Institute of Ocean Sciences. Sidney, BC. **Nutrient Supply Along the Northeast Pacific Margin.**

An outline of upwelling or changes therein over the last couple of decades. Trends in salinity, nutrients, temperature with emphasis on coastal waters where oyster leases are presently and may be in the future up the west Coast of Vancouver Island including the Queen Charlotte Islands. Implications for productivity re-phytoplankton…higher/lower biomass….species differences that may be important to oyster feeding.

O9:45-10:15
Lucila Lares, Departamento de Ecología
Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico.
Mussels as Indicators of Cd in Upwelling Regimes

Responses of California mussels to upwelling events at Amphitrite Point, Ucluelet, West Coast of Vancouver Island. Temporal difference, evidence of regulation of Cd residues. Some discussion of particulate vs dissolved uptake dynamics. Pertinent information from Baja Mexico where apparently there is also some concern about Cd in cultured oysters. Some discussion of differences intra and interspecies Cd dynamics. Ideas why this might be so. Feeding , uptake, binding and depuration differences.

10:15-10:45
Leah Bendell-Young Biological Sciences Simon Fraser University, Burnaby BC.
Cadmium and Oysters

Laboratory and field experiments in uptake dynamics by filter feeding bivalves. Why are oysters different then mussels and clams as far as retention of residues. Why is depuration not feasible. What are the influences if temperature, salinity, geochemistry of Cd, types and sizes of particles filtered, rejected, organic/inorganic, colloidal what is adsorbed, absorbed, differences in plankton uptake of Cd, what determines what is filtered or rejected in pseudofeces. How this changes seasonally, how it is affected by nutrient and food availability. How does uptake in an oyster feeding 24h/day compare with an intertidal one. Are there any physiological or metabolic differences that we know about ?

10:45-11:00 COFFEE

11:00-11:30
Guri Roesijadi Dept. Biological Sciences Florida Atlantic University, Boca Raton Florida, USA**. <u>Mechanisms of Cadmium Sequestration in Oysters</u>**

How bivalves deal with Cd after it is taken up. Effects of salinity and other factors on uptake, metal binding by metallothionein..what it is, why binding is tight and therefore Cd difficult to displace by simple depuration. What is the relationship to zinc, what would happen if zinc were limiting. Are there significant inter and intraspecies biochemical differences if not, why is Cd taken up to higher levels in some and not other bivalve species. Scallops>oysters>mussels>clams. Limitations of laboratory experiments, utility of field transplants. Can these tell us sources or just that one location is better or worse than another? Can this be extrapolated over time or too variable Feasibility of experimental biochemical mitigation by dietary zinc replacement.

11:30-12:00 Keith Hunter, Russel D. Frew, and Barrie M. Peake. Centre for Chemical and Physical Oceanography, Department of Chemistry, University of Otago, NZ.
<u>Cadmium in Dredge Oysters (*Tiostrea chilensis*) and Related Species in New Zealand Coastal Waters.</u>

Keith had to cancel but did provide an extended Abstract which includes images that would have comprised his presentation. Oceanographic factors resulting in extremely high levels of Cd far from any anthropogenic inputs. Implication of phytoplankton as an important pathway. Possibility of substitution of Cd for Zn

11:30-12:00
Dario J. Stucchi, IOS <u>Physical Oceanography of Effingham Inlet</u>

Bottom features, sills, seasonal circulation patterns, temperature/salinity vertical profiles, fresh water lens, horizontal gradients in this watershed of very high rainfall. Sediment geochemistry: are there anoxic zones if so where, could this be a sequestration mechanism for Cd. If so, could Cd be released again with turnover or intrusion of more oxygenated water? One oyster culture site in Effingham had 4.65 µg/g Cd (see Carswell slide # 22; all were > 2 µg/g)

LUNCH 12:15-13:00

13:00-13:30
Robie W. Macdonald, IOS. <u>The General Oceanography of BC's Coast and the Strait of Georgia as it Pertains to Cd Enrichment in Oysters.</u>

Seasonal movement of Fraser River plume, depositional zones, how much might move up the eastern Mainland coastline, would it reach Jervis Inlet, direction of flow. Utility or *lack thereof of core sampling for tracing temporal changes in Cd. How far might very fine particulates, silt, clay, colloidal form of Cd move seasonally. There is a major input of Cd in Vancouver area stormwater..do we know where most of this goes? What is the nearshore seasonal salinity profile heading up the eastern shore of the Strait. Could lowered salinities by facilitating Cd uptake by oysters?*

13:30-14:00
Dario Stucchi, IOS. <u>Some Comments on the General Oceanography of the Northern Strait of Georgia and Inlets.</u>

General oceanography of mid to northern part of Strait of Georgia. Contribution of inlets, inlet oceanography, seasonal circulation patterns, temperature regimes, what is it about Bute, Jervis and Toba (Desolation Sound and Redonda Islands that renders these prime oyster growing areas? nutrients, warm temperatures? If so why so, is circulation/exchange reduced by sills, are certain areas protected from winds eg Pendrell Sound? If Cd were added from terrestrial sources, are there reasons why it may become more available to cultured oysters? Are there known anoxic zones(eg. Teakerne Arm) are these near oyster growing areas. How much water comes down seasonally through the Johnstone Strait to the area around Quadra Island? How does this water mass differ from that feeding up from the southern Strait. Does it carry with it SE Alaskan water? Are these inlets characterized by lower surface salinities, if so for how many months of the year? Does this surface input spread across the Strait to Denman Island?

14:00-14:30
Peter Thompson, University of Tasmania**: <u>Cadmium in Pacific Oysters</u>**

Ideas on trophic transfer of Cd via phytoplankton. Could nutrient dynamics be such that might stimulate blooms of species that could be more efficient at sequestering Cd from seawater and on to oysters? What happens if a bloom reduces Zn sufficiently, would preferential uptake of Cd then occur? Recent information that Cd can be utilized by phytoplankton in enzyme function. Any pertinent information from Tasmania? Do we have any local evidence that oysters grown in high density can deplete nutrients and switch to inorganic or organic particulates as an energy source. D.B. Quayle (Pacific Oyster Culture in British Columbia) indicates that a raft of 10 m x 6 m containing 60-100K oysters deposits 0.6-1.0 tonnes of feces and pseudofeces per year. Could this be a mechanism at magnification whether by ingestion at the time or resuspension from the bottom by turbulence at certain times of year?

14:45-15:00 COFFEE

15:00-15:30 DISCUSSIONS

Growers /BC Fisheries *So what do you think? Additional input and discussion. Any local knowledge/conditions that might be pertinent to the information presented above? What else do we need to know?*

15:30- 16:00
Bill Heath BC MAFF: *Planned grow-out experiment. Oysters and mussels. Any modifications based on information exchanged above?*
16:00-16:30 General Discussion

Dinner at Dunsmuir Lodge

19:00> Think Tank/Synthesis Session at Dunsmuir Lodge.

ABSTRACTS

In order presented:

Kruzynski, George, M. *Fisheries and Oceans Canada, Marine Environment and Habitat Science Division, Institute of Ocean Sciences, Sidney. BC.*

Cadmium in BC cultured oysters: An overview

In response to a May, 2000 request by the Canadian Food Inspection Agency (CFIA) the Department of Fisheries and Oceans (DFO), Pacific Region undertook to investigate the potential reasons for apparently elevated Cadmium levels in BC cultured Pacific oysters *Crassostrea gigas*. Earlier in the year, CFIA reported that several shipments of BC farmed oysters had been rejected by the Hong Kong Food and Environmental Hygiene Department as being in excess of their 2 µg Cd/g (ppm) wet weight limit. A preliminary literature search was conducted, contacts were made with shellfish growers and processors, both government and academic researchers were consulted and the resulting information was synthesized by GMK in the form of a PSARC (Pacific Scientific Advice Review Committee) report (http://www.pac.dfo-mpo.gc.ca/sci/psarc/ResDocs/Habitat_00.htm)

We found that there are no historical baseline data on Cd residues in BC cultured oysters, so Cd residue data on wild intertidal oysters collected over the period 1973-1999 by Environment Canada and DFO were used as a comparison. These were mapped and overlaid on current CFIA 2000 oyster data and indicated that in the northern reaches of the Strait of Georgia, there were already Cd residues approaching 2 ppm 27 years ago. In the absence of any obvious anthropogenic Cd inputs, it is suggested that Cd is naturally available in some surface waters where oysters are reared, whether from mineral deposits local geology or sediment transport from watersheds or the heads of fjords. The bioavailability of dissolved Cd may be enhanced by low salinities. On the West Coast of Vancouver Island, Cd accompanying nutrients such as phosphate upwelling from deep waters, could also be a contributing factor.

Among recommendations of the PSARC report was the holding of a Cadmium and Oysters Workshop to exchange information with oceanographers, geologists, geochemists, oyster growers, toxicologists, biochemists and biologists; the objective being to define fruitful avenues of research and possible mitigative strategies.

This paper presents an outline of some of the PSARC information and BC cultured oyster Cd residues are discussed in context of internationally accepted weekly allowable intake levels. The results of a culture materials Cd leaching experiment are also presented.

Maps showing the relationship of BC coastal geology and existing stream sediment Cd data to oyster growing areas are presented and the suggestion is made that BC Fisheries may wish to consider local geochemistry in future oyster lease suitability approvals.

Several hypotheses on Cd pathways from both marine and terrestrial sources as well as potential applications to the BC situation are suggested. This overview is meant to set the stage for subsequent presentations by the 29 invited specialists who elaborate on these ideas.

<u>*References*</u>

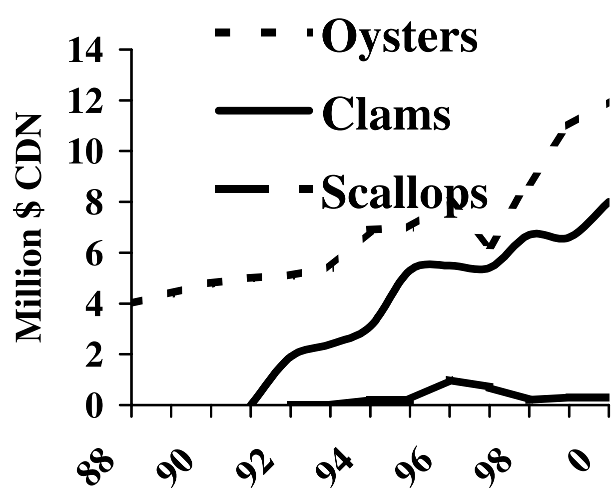
Nelson, H., and D. Goyette. 1976. Heavy metal contamination in shellfish with emphasis on zinc contamination of the Pacific oyster Crassostrea gigas. Environment Canada, Environmental Protection Service, Pacific Region Report EPS-5-PR-76-2. 57 p

Sprague, J.B. 1986. Toxicity and tissue concentrations of lead, zinc and cadmium for marine molluscs and crustaceans. Report prepared for the International Lead Zinc Research Organization Inc., North Carolina, USA. 215 p

Kingzett, Brian. *Kingzett Professional Services Ltd., Duncan, BC*

The shellfish culture industry in British Columbia

Currently the B.C. shellfish culture industry is located in the south coast region that is from the northern tip of Vancouver Island South, in the Strait of Georgia and the West Coast of the Island. The three main species of shellfish cultured in British Columbia are: Pacific Oysters, Manila Clams and Japanese or Pacific Scallops. Of note is that all three species are exotics introduced intentionally or unintentionally from Japan. Also being investigated or developed for culture are blue mussels, geoduck clams and abalone. Current wholesale value of the industry is approximately 20 million dollars.



The Pacific Oyster was introduced from Japan into the Pacific Northwest beginning about the turn of the century and continued up until the Second World War. The Pacific Oyster is barely established in BC with only three small areas where it breeds with any regularity.

The Manila clam was accidentally introduced into British Columbia in the mid 1930s with oyster seed from Japan, it is now established in BC where it has been the subject of a large boom and now almost bust fishery.

The Japanese Weathervane Scallop also marketed as a Pacific Scallop was introduced into BC from Japan by a joint program of the Department of Fisheries and Oceans and the Provincial Government during the 1980s. Broodstock were held in quarantine, bred and successive offspring were used to begin a scallop culture industry in BC.

Shellfish Growers rely primarily on hatchery-produced seed for all three species, clam growers also rely on increasing survival of clam larvae that settle out on culture beds. Of note is that almost all oyster and clam seed is imported from the US.

A very short overview of the main production methods for each species is provided.

OYSTER PRODUCTION

In B.C., generally, oysters are grown for two product forms "shuckers" where oysters are produced for the meats which are shucked in federally inspected processing plants and sold by the volume (typically quarts or gallons). Shucking oysters are usually between 4 and 6 inches and usually shuck out at 100-120 per US gallon. Growers are paid on how their product shucks out and usually receive between 15 and 17 dollars per gallon. Current production is about 100,000 gallons annually.

Oysters are also produced for the single or half shell market. Single oysters are sold "in shell." This product is of higher value and is sold by the dozen in a variety of size grades ranging from 2 inches to greater than 6 inches. Farm gate prices range from about $1.75 to more than $6.00 per dozen. Recently there has been a significant amount of production going to flash-frozen as meats, whole oysters or TVO, which is top valve off.

BC Growers are a diverse lot and there are a variety of methods used for growing out oysters depending on the site, the type of product and the method preferred by the grower:

Seed is acquired as larvae, and it is remote set on site or a central site, onto substrate usually old oyster shells or it is acquired as singles and may be nursed up in Floating upwellers (FLUPSY) to approximately 1 inch.

The oldest and simplest grow-out method is to spread oysters out on the beach and wait for them to grow. Grow-out times for beach product range from two to five years.

Beach Oysters

- Hard shells do not break
- Harder to shuck
- Longer shelf life –more marketable
- Slow growing
- Less fluting little colour

Much of the development of the industry is coming from deep-water or off-bottom culture where oysters remain fully submerged. Grow-out time is usually halved and 4-5 inch oysters large enough for shucking product can be produced in two growing seasons in most areas. Oysters are never grown out on the bottom in deep water.

Deepwater Oysters

- Soft shells often break
- Easier to shuck
- Shorter shelf life –less marketable
- Fast growing

The most common techniques include: mother shell inserted into specially made two strand poly rope (string culture), or with oysters attached to artificial cultch known as "French pipes" (tube culture), which are individually hung vertically from longlines for 2 year grow-out to 4-6 inches.

String Culture –Oyster seed on shell inserted into two-strand rope

- Lower money up-front
- Higher labour costs
- Hard to mechanise harvest

Tube (Pipe) Culture –Oysters attached to PVC tubes

- Higher money up front
- Less Labour
  - Can be mechanically harvested

Or as single oysters contained in plastic culture trays, grown for about one to two years and then placed into the intertidal to harden the shellstock or sold directly.

Two main types of trays are used:

Dark Sea Trays

–Shallow trays 10-15 per stack

–Grow 3/4" seed - X-small/small

High Flow Aqua-tech Trays

–Deep trays in stacks of 7

–Grow small and medium oysters

Aspects of Deep water tray grown oysters include:

- Grow-out times 12-18 months
- Better meat quality
- Softer shells less marketable may require hardening
- Higher labour costs/more equipment

Whatever the method, farmers working deep-water leases may use longlines or rafts to suspend the oysters being cultured.

Characteristics of Longlines are:

- Best for large, more exposed or sites with less current
- Use with trays, pipes or strings
- Surface or subsurface longlines
  Barrels or oyster floats

Rafts made from wood and styrofoam floatation are used to produce Large amounts of production in a small area.

- Best for small or sites with sufficient current
- Use with trays, pipes or strings
- Two and three foam designs

MANILA CLAMS

Clam farming is a relatively new venture in British Columbia. The first permitted clam farms in B.C. were established on existing shellfish culture leases in 1988, and the licensing of clam farming did not become official until 1991.

Hatchery produced clam “seed” are purchased from nurseries in B.C., Washington or California. This seed is spread directly out onto firm, low sloping mud-gravel grow-out beaches.

To protect the significant investment in seed from scoter ducks, flounder and crab all of which consider young clams as prize food, panels of a light-weight plastic net is laid down across grow-out plots and secured. Mature clams are harvested by hand digging after two to three years of grow-out.

Scallop culture

he scallop industry is still in its infancy in British Columbia as growers overcome a variety of production hurdles but it is anticipated that production of this species will increase dramatically in the very near future. Production is hatchery based and with one hatchery in BC producing scallop juveniles. The species is fast growing with marketable product able to be produced within two years of the hatchery.

GMK Note: for additional detail including photographs and diagrams consult: http://www.bcsga.ca

Dewey, William F. *Taylor Shellfish Company, Inc. Shelton, Washington*

Cadmium in Taylor Shellfish Company oysters, Washington, USA

the fall of 1993 and spring of 1994 Taylor Shellfish had elemental analysis performed on samples of oysters from Samish Bay in Northern Puget Sound and Totten Inlet and Pickering Passage in Southern Puget Sound. Cadmium was one of the elements quantified in the analysis.

Taylor Shellfish Company has export markets which include Hong Kong. Taylor Fine Foods, Ltd is a distributorship whichTaylor has established in Hong Kong. Because of this vested interest in the Hong Kong market and Taylor's sampling being some of the only data available on Cadmium in Washington's oysters, Mr. Dewey agreed to participate in DFO's Institute of Ocean Sciences March 6, 2001 workshop on Cadmium.

The initial sampling was undertaken at the request of Dr. Susan Cook, a research scientist who lived in the agricultural area adjacent to Samish Bay. Dr. Cook was hypersensitive to heavy metal contaminants and was aware of elevated levels of arsenic in the region. Dr. Cook was aware of high levels of arsenic and cadmium being present naturally as a result of local geology. Dr. Cook also suspected fertilizers applied by an extensive agricultural industry in the watershed could be a source. She was interested in the oysters potential ability to bioaccumulate these contaminants.

In December 1993 oyster samples were collected from Samish Bay (Northern Puget Sound) and Totten Inlet (Southern Puget Sound) and shipped to Elemental Research in Vancouver B.C. for processing. In April 1994 additional oyster samples as well as bottom substrate were sent from Samish Bay intertidal longlines and oysters from Pickering Pass (southern Puget Sound control) in an effort to explain dramatic growth rate variation between oysters on the bottom and those suspended in ropes 40 cm above the bottom.

It was not known whether Elemental Research in Vancouver followed the same testing protocols as DFO, whether pallial fluid was included or even whether the oysters were shucked prior to processing the samples. The samples were believed to have been a composite of multiple oysters. Of the five oyster samples run, Cadmium levels ranged from 0.65 μg/g to 2.09 μg/g (wet weight).

The Cadmium levels found were well below the U.S. Food and Drug Administrations recommended level of 3.7 μg/g and thus did not represent a concern for the company. Periodic sampling by Hong Kong has not apparently detected levels over their 2.0 μg/g acceptable limit since none of Taylor's shipments have been rejected.

Heath, **William A.** *Shellfish Production Specialist, BC Ministry of Agriculture, Food and Fisheries, Courtenay, BC.*

Site selection considerations for shellfish farming in British Columbia.

BC Fisheries, part of the Ministry of Agriculture, Food and Fisheries, has the mandate to lead the provincial government's efforts to build and sustain healthy fish populations and to develop and diversify the fisheries and aquaculture sectors.

Diversification of the shellfish farming sector will involve producing new products by innovative methods in new locations along the BC coast. The selection of appropriate sites for the farming of shellfish is central to the economic viability of new or expanding shellfish operations. Factors to consider include biophysical attributes (physical and biological conditions) and suitability issues (e.g. risk of conflict with other incompatible resource uses). A convenient way of combining these criteria is through use of a "Site Capability Index" or SCI, with numerical values between 0 (worst) and 1 (ideal), similar to the widely used habitat suitability index approach. Nearly all of the British Columbia coast has been assessed for shellfish capability for culture of the Pacific oyster (*Crassostrea gigas)*, the Manila clam *(Tapes philippinarum)*, and the Japanese scallop *(Patinopecten yessoensis)*.

In addition, socio-economic factors such as the availability of infrastructure, labour and marketing resources will also affect the viability of operations. In the context of low ($\leq$2 ppm wet wt.) current or proposed Cd threshold levels for export markets and relatively high natural Cd concentrations in BC waters, it is also prudent for shellfish agencies and farmers to better understand the process of Cd accumulation in commercial shellfish in the various growing regions of British Columbia. There is a distinct possibility that shellfish Cd levels may become an important suitability factor for shellfish site selection.

Carswell, B. 2001. *Economic Development Officer, A/Manager Resource and Community Planning Unit, Sustainable Economic Development Branch BC Fisheries, Victoria, BC.*

The BC Shellfish Development Initiative process and the relevance of cadmium concentration data in BC cultured oysters to industry development

The Provincial Shellfish Development Initiative announced in November 1998 has as its goal doubling the amount of area under tenure for shellfish aquaculture from 2115 ha to 4230 ha. With this increase in cultivation area, the industry has the potential to increase wholesale values from 13 M to 100 million, and provide 1000 new person years employment in coastal communities. Development of the industry is preceded by consultation with First Nations, other government agencies, communities and industry. The model used for the consultation involves the formation of Regional Shellfish Steering committees, which consist of a wide spectrum of coastal stakeholders. These committees provide advice to government on how best to proceed with shellfish development initiative in local communities. Specific work of the committees includes;

1) Development of shellfish suitability maps showing areas that the community deems that shellfish aquaculture is/is not an appropriate use;
2) Indication of industry growth rate that community deem acceptable/desirable;
3) Developing criteria that could be used to rank competing applications, when industry growth rate above would be exceeded (if all applications received were accepted and approved) or when applications overlap;
4) Ranking the applications when necessary under 3, and provide government with advice on the applications deemed most desirable from a community perspective. (Undertaken as necessary upon receipt of applications).

Steering Committees have been set up for Powell River, Barkley Sound, Clayoquot Sound, Nootka -Kyuquot Sound, Quatsino Sound, Comox Valley, and the North Coast.

By digitising the suitability analysis from the committees and combining with digital capability data we are able to determine the areas of greatest opportunities. As shown, additional data sets such as existing commitment on Crown land, bathymetry and the results of Cadmium sampling can further assist in site selection.

Dobie, Sheila *Seafood Development Office, Skeena Queen Charlotte Regional District Prince Rupert B.C.*

Notes on the North Coast Shellfish Industry, April 2001

The north coast is an important location for any further investigations of cadmium levels in shellfish. Current local investments towards developing new shellfish farming industries make baseline water quality assessments critical. The existing farms on Porcher Island and in Skidegate Inlet have been participating in the biotoxin program and in other piloting initiatives. In addition, First Nations communities have been directly participating in a community based biotoxin monitoring system that gives any additional investigations a structure and coordinating base, as well as links to Northwest Community College and Northern Labs.

Salmon, Ruth. *Executive Director, BC Shellfish Growers Association, Duncan, BC.*

How Industry sees the Cadmium issue

Brief Profile of Shellfish Aquaculture In BC
Small, growing industry (approximately 12 million farmgate in 1999)
250 companies; 400 culture sites
Shellfish Farmed:

- Pacific Oysters

- Manila Clams
- Pacific Scallops
- Mussels & Geoduck

Who is the BCSGA?
The B.C. Shellfish Growers Association (BCSGA) is the voice of the shellfish farming industry in BC and has been in existence since 1948.

In the last few years, the BCSGA has been steadily increasing its membership that currently stands at approximately 150 members. The association represents the majority of shellfish growers in BC and over 85% of the farmed shellfish production.

Cadmium – the issue
The issue of Cadmium in oysters is not confined to Canada as is demonstrated today by the presence of workshop participants from Australia, New Zealand and Mexico. However, we are pleased that Canada is taking a leading role in assessing the issue & initiating a forum for the exchange of information. Our association is also pleased to be a part of that discussion –because of course, it is a priority of our industry to continue to market safe product.

The importance of food safety is reflected in the program initiatives of our association. In addition to the development of an industry Environmental Management System, food safety and quality assurance programs take up a large percentage of both Board and staff resources. To give you some examples…

1. The SGA, together with CFIA & provincial health authorities, is an active participant on the provincial *Vibrio parahaemolyticus* committee. To assist growers supply a safe product during the summer months when the risk of elevated Vp levels are higher, the BCSGA helped to develop harvesting guidelines for growers. Following this, we provided all growers with a harvesting kit, which included a pocket thermometer for determining accurate meat temperatures and a Bill of Lading for tracking key harvest information.

Every effort was made on the part of industry to help reduce the risk of illness & the combined efforts of producers & processors resulted in almost negligible illnesses last summer.

2. We are also currently participating in a national program to develop a farm based HACCP system for improved quality assurance at the farm level. This program involves a series of pilot projects to test and incorporate HACCP methodologies and techniques for grower involvement in water quality monitoring programs. The use of a HACCP framework will provide a mechanism for grower participation and funding, micromanagement of growing areas and increased quality assurance *without* compromising the roles of federal regulatory agencies or the Canadian Shellfish Sanitation Program. The project will also assess the cost-benefit and technical issues surrounding the use of site-specific classification of growing waters.

I've shared these examples only to illustrate the kind of emphasis our association puts on the issues of food safety and quality assurance. The same philosophy also applies to Cadmium. Industry views continued research into the Cadmium issue positively. However, the only caution we would bring forward is that since all issues of food safety are both complex and sensitive, they must be handled extremely carefully in the public arena.

Clearly the issue of Cadmium is receiving heightened interest internationally. Cadmium in ALL foods is undergoing a review in the Codex Alimentarius, but any decision by this body is not expected in the near future. While we all collectively research the issue & continue to explore ways of reducing naturally occurring cadmium levels in shellfish, we must remember the current facts:

- All evidence to date suggests that Cadmium is a naturally occurring phenomenon unrelated to pollution and occurs in all areas of the oceans with high mineralization.
- Our industry is highly regulated and rigorous government controls are in place to assure the safety of oysters for consumption.
- Canadian oysters fully comply with existing international standards and those of its major markets, particularly it's most important market, the US.

Webb, Allison. *West Coast Advisor, Office of the Commissioner for Aquaculture Development, DFO*

Shellfish Monitoring Project

Budget reductions in the federal government have resulted in declines in services for water quality and marine biotoxin testing for the shellfish aquaculture industry in British Columbia. This was of concern for current growers as well as prospective entrants to the sector. This same situation was expected in other areas of Canada as well. As a result of a proactive approach to this situation, the shellfish industry approached the Office of the Commissioner for Aquaculture Development and garnered support for the development of a national Shellfish Monitoring Project which aims to increase industry participation in water quality and marine biotoxin monitoring programs

This project has the support and participation of all 3 departments/agencies that administer the Canadian Shellfish Sanitation Program (CSSP), Environment Canada, the Canadian Food Inspection Agency and Fisheries and Oceans. As well, there is representation from the shellfish industry from across Canada.

The main initiatives of the project are: the development of a farm based quality assurance program in the form of the well accepted Hazard Analysis Critical Control Point (HACCP) program; the commercial species project which aims to test the use of commercial species as sentinel species as opposed to the California mussel with the expectation that uptake and depuration levels/rates will be different and may allow a longer growing season; and a communications initiative to foster better information two way information flow between industry and government regulators. Information on heavy metals and contaminants are being discussed within the parameters of this study.

The project began in the Spring of 1999 and is expected to be completed in the Winter of 2001. Recommendations on possible changes to the delivery of the CSSP will be forthcoming at that time

Liem, Sing. *Chief, Fish Program Network, Western Area, Canadian Food Inspection Agency, Burnaby, B.C.*

CFIA's Role in Food Safety Mandate

The Federal Government's Food Safety Mandate is delivered through a shared responsibility between Health Canada and the Canadian Food Inspection Agency (CFIA).

Health Canada, who has the food safety mandate for Canadian consumers, develops food safety policies, set standards, conduct risk assessments and audit the delivery of the Food Safety Programs. The Canadian Food Inspection Agency is responsible for the delivery and enforcement of the Food Safety Mandate and enforces all federal legislation on food inspection, agricultural inputs, animal health and plant protection.

The Fish, Seafood and Production Division within CFIA is responsible for the delivery of an inspection program to provide reasonable assurances that fish are safe, wholesome, of acceptable quality and are fairly traded. The Fish Inspection Act and Regulations provides the regulatory framework for controlling all aspect of preparing fish for market, including the transportation, unloading, handling, processing, labelling and certification of fish products.

The Canadian Shellfish Sanitation Program provides the policies and controls for the safety of molluscan shellfish. As part of this program, CFIA monitors product for marine toxin, pathogens and contaminants, including Cadmium.

Schallie, Klaus. *Aquaculture & Molluscan Shellfish Specialist, Canadian Food Inspection Agency, Burnaby, B. C.*

Results of the 2000 Survey of Cadmium in B.C. Oysters.

In 2000 the Canadian Food Inspection Agency embarked on a survey of cadmium levels in the major oyster growing areas of British Columbia. This was in response to information from the Hong Kong Food and Environmental Hygiene Department that several shipments of oysters from British Columbia were found to have cadmium levels that exceeded their action level of 2 ppm (wet weight).

CFIA staff began by reviewing historical data from the CFIA's own Environmental Contaminants Program. It was noted that Cadmium levels in approx. 39% of the samples of oysters and scallops exceeded 2ppm but that levels were < 2 ppm in other species of shellfish, marine invertebrates and finfish. Environment Canada also provided some analysis results from their monitoring surveys and these cadmium levels were consistent with the CFIA's data following conversion from dry weight.

Oysters for our survey represented all of the major growing areas and also different sizes and culture methods. More than 60% of our samples taken in 2000 had levels of cadmium over 2 ppm and the mean for 81 samples was 2.63 ppm. All of the major volume growing areas were found to have means over 2 ppm. Only two areas show results that are consistently under 2 ppm. These are the southern portions of DFO Statistical Areas 17 (southeast Vancouver Island near Ladysmith) and 24 (southern Clayoquot Sound.)

No relationship between size/age of oysters and cadmium levels was apparent, likewise for intertidal vs off bottom (long line or tray) culture. Consequently, no shipments of oysters from B. C. are being certified for the Hong Kong market at this time.

Regulatory limits for cadmium in shellfish vary widely from country to country and there is currently a review being conducted by the WHO/FAO. The data from the 2000 cadmium survey was forwarded to Health Canada with a request for an updated risk assessment. Also, CFIA is reviewing the data to identify other samples which could be taken to fill gaps in our knowledge.

Knapp, Wayne. *Fisheries and Oceans Canada, Habitat and Enhancement Branch, RHQ, Vancouver, BC.*

Cadmium in Shellfish: Habitat Management Roles and Responsibilities

There are three general aspects to the cadmium in shellfish issue: problem identification (i.e. scope and significance), human health implications of consuming cadmium contaminated shellfish and potential need for restrictions on harvesting of seafood products. The Department of Fisheries and Oceans (DFO), Habitat and Enhancement Branch (HEB) is concerned about cadmium contaminated shellfish in light of the Department's responsibilities for fish and fish habitat protection, because the contamination could affect both wild and culture shellfish species and because of the broad responsibilities for ensuring product quality in the commercial, recreational and 1st Nations harvesting of these resources.

HEB supports DFO Science staff in the scientific assessment of the issue, provides supporting information (e.g. resource distribution and harvesting information) and may assist in the collection and analysis of samples. The Branch co-ordinates information to and Regional DFO requests to health agencies (e.g. Health Canada) for health hazard assessments.

Based upon the advice of health agencies HEB, in consultation with other agencies and user groups as appropriate, determines the need for, and extent of, fish harvest restrictions with an emphasis on the commercial, recreational and 1st Nations fisheries. These actions may be taken pursuant to the *Management of Contaminated Fisheries Regulations* or the *General Fisheries Regulations* (Variation Order). Where contaminants originate from anthropogenic sources HEB may, in conjunction with Environment Canada, investigate contaminant reduction pursuant to Section 36(3) of the *Fisheries Act* (prohibition of the discharge of deleterious substances).

Telmer, **Kevin.** *School of Earth and Ocean Sciences, University of Victoria, Victoria, BC.*

Approaches to Source Apportionment - Oyster and Cadmium Workshop, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia.

The source of Cadmium (Cd) found in Canadian West Coast oysters is currently unknown. The use of stable and radiogenic isotopes and major and trace elements to fingerprint the source of chemicals to naturally occurring processes or anthropogenic impacts – methods of "source apportionment" – may be a fruitful approach to improving our understanding of the source of Cd in oysters. It can broadly be accomplished in 5 ways:

1. Chemical Fingerprinting – "Environmental Forensic Science". This can accomplished by identifying a chemical constituent unique to a plausible source of that constituent. In the case of synthetic chemicals such a PCBs, the source is unquestionably unatural and the precise structure of the compound may be unique to a manufacturing process or distributor and so can be readily identified. Chemical fingerprinting can be more difficult for naturally occurring materials such as metals. In this case, the most reliable link to source are unique isotope ratios. The power of this approach has recently been illustrated for sources of Pb in the southern hemisphere by Bollhofer and Rosman (2000; Geochim. Cosmochim. Acta. Vol. 64). They are able to uniquely isolate multiple sources of Pb by measuring 206/207 and 208/207 ratios. Elemental associations (does elevated Pb occur along with elevated levels of other substances) also represent a method of chemically fingerprinting source but for natural materials, only isotopic ratios can provide indisputable evidence of the source of elements – the so called "smoking gun."

2. Spatial Analysis – anomalies in space and their associations. Statistically, or qualitatively correlating elevated metal concentrations with landscape features such as geology, water type, plankton, forestry, landuse, industry, agriculture, urbanity and point sources has been a “pathfinding” strategy employed by scientists for many years. This approach is often informative and can greatly assist in formulating ideas and testing hypothesis but rarely provides irrefutable evidence for source. The robustness of this approach, however, is improving with innovations in remote sensing making many more spatial data products available. Combining this approach with the others described here also offers the potential for greater insight.

3. Temporal Evidence – comparing past to present. By observing enrichments or depletions in elements in a single media through time – in ice cores or sediments – inferences can be made about recent rates of environmental dispersal versus historical rates. This approach works well if the media used to extract the historical record is relatively inert both chemically and structurally. Unfortunately these criteria rarely occur in nature – with ice cores perhaps representing close to ideal behaviour. The ability to extracting an irrefutable historical record of element deposition from subaqueous sediments is however hotly debated. It may be possible by carefully choosing a location and analysing the right material but it is no easy task and so this approach is also rarely attains irrefutable source apportionment evidence.

4. Speciation / Partitioning - Which phase? Solid, aqueous, gaseous? Crystalline or amorphous? Mineralogical or adsorbed? The “chemical location” of elements in the environment tells us much about pathways and bioavailability and also provides information about source. For example the Pb contained in highly resistant silicate minerals in sediment cores is unlikely of anthropogenic origin and is unlikely a source of toxicity whereas the Pb bound to amorphous iron oxyhydroxide coatings on mineral grains could be. The distribution of elements in the sample matrix therefore is useful information in constraining source (as well as behaviour) but rarely provides the “smoking gun” for source.

5. Mass Balances – Mass distribution and at what flux rate? The mass of an element that passes through or is contained within a system is often a strong constraint on source apportionment hypotheses. For example, an up-core enrichment of Hg in lake sediment cores may seem to provide evidence of a recent increase in Hg deposition due to anthropogenic emissions (perhaps from coal burning). However when coupled with direct measurements of Hg deposition to the lake system, the mass of Hg bound in the uppermost layers is simply too high to be explained by atmospheric deposition. In such a case, new hypotheses invoking other fluxes must be formed to explain the mass distribution in the environment.

Only the first and last methods, isotopic evidence and mass balances, offer irrefutable evidence about source. The others provide useful information for constraining ideas about source but rarely are able to quantitatively apportion it. With this in mind, Cd isotope systematics are being investigated as a possible source apportionment tool for Cd in oysters. Currently, six samples have been submitted to Micromass, UK, for determination of the eight naturally occurring Cd isotopes. The samples are two sequential extractions (weakly bound / strongly bound) of lake sediments from three depths. The results of these analysis may provide a starting point for applying isotopic evidence to sources of Cd.

Alleyne, Carl. *Health Products and Food Branch, Health Canada, Burnaby, BC.*

Assessment of Risk to Human Health from Contaminants in Foods

Health Canada shares its responsibility for a safe food supply with other partners, including the Canadian Food Inspection Agency (CFIA), and other levels of government, *viz.,* Provincial, Territorial, and Municipal. The specific activities which it undertakes on foods, include policy development, standard-setting, risk/benefit assessments, research, pre-market reviews, and surveillance of the food supply.

The health risks from consumption of foods containing toxic contaminants entails are assessed by comparing the probable daily dietary intake (PDI) of the contaminant with the tolerable daily intake (TDI). PDI depends on the amount of the food consumed and the contaminant level, while the TDI is based on the inherent toxicity of the contaminant and also includes a safety factor. For example, the provisional TDI recommended by the World Health Organization and the Food and Agriculture Organization (WHO/FAO) for cadmium is 7 micrograms per kilogram body-weight per week. The WHO/FAO TDI is not universally accepted since some countries set their own guidelines. Health Canada has not set a national guideline for maximum contamination levels of cadmium in foods. For risk assessment purposes, Canada generally aligns its national food standards with those of the Codex Alimentarius Commission (Codex), an international body which has a mandate to establish and harmonize international food safety standards.

Codex recently proposed a draft standard for maximum levels of cadmium in molluscs and other foods, *viz*., 1 milligram cadmium per kilogram (mg/kg or parts-per-million) for molluscs. At the time of writing (May 2001), this proposal has not been adopted and is at Stage 4 of an 8-step approval process. The Codex Committee on Food Additives and Contaminants (CCFAC), the body which is responsible for the cadmium standard, is accepting comments from committee member countries for consideration and possible amendment of the proposed standard. As an interim measure, while the draft standard for cadmium in molluscs is being discussed, Health Canada is using the proposed maximum level of 1 mg Cd/kg molluscs for risk assessment purposes.

Brown, **Kevin.** *British Columbia Ministry of Forests Research Branch, Victoria*

Forest fertilization on Vancouver Island as a potential terrestrial source of cadmium to oysters[1]

Cadmium (Cd) occurs in fertilizers containing phosphates and some trace elements. In coastal forests of B.C., such fertilizers are often applied to individual seedlings at the time of planting. Established stands are generally fertilized only with N, primarily as urea (46-0-0). Aerial fertilization of some young western hemlock stands on northern Vancouver Island with N and P has also been initiated during the past 12 years. While fertilization at planting occurs only once during the lifetime of a stand, established hemlock stands could conceivably be fertilized an additional 1 to 3 times prior to harvest (anticipated at age 80-150). The fertilizers applied at planting, along with the N+P fertilizer applied to some hemlock stands, could conceivably be a terrestrial source of Cd to oysters farmed along the coast of Vancouver Island.

Estimates of Cd loading from forest fertilization are complicated by several factors: (1) data on Cd concentrations are not readily available for the specific fertilizers applied; (2) reported concentrations for a specific formulation vary with the sources of the primary fertilizers and the sampling and analytical procedures used; (3) rates and formulations applied vary over time. For fertilizers applied at planting, the most comprehensive data available are for the Greater Nanaimo watershed (Table 1; www.city.nanaimo.bc.ca/speed/gnwd/src/fertilizer.pdf). From 1998-2000, four fertilizers were applied at the time of planting. Rates ranged from 30-50 g seedling^{-1} and planting densities ranged from 978 – 1150 seedlings ha^{-1}. Cadmium concentrations reported for the Dawson Seed 25-9-9 fertilizer applied in 1998-1999 ranged from 0.5 – 42 µg g^{-1}. This compares with a typical background concentration in soil of 0.35 µg g^{-1}. In total, approximately 0.485 kg Cd was applied via fertilization at planting in the Nanaimo watershed from 1998-2000, equivalent to 0.46 g Cd ha^{-1}.

The young western hemlock stands on northern Vancouver Island which are aerially fertilized with N+P receive 75 kg P ha^{-1}, i.e., ~ 385 kg ha^{-1} of triple super phosphate (0-45-0). Cadmium concentrations in triple super phosphate may be as low as 15 µg g^{-1} (Brown, unpubl. data), but were as high as 115 µg g^{-1} (Washington Dept. of Agriculture; www.wa.gov/agr/pmd/fertilizers/index.htm#database), which would translate to a range of ~ 6 - 44 g Cd ha^{-1} per application. The average area fertilized on northern Vancouver Island from 1989-2001 was 971 ha year^{-1} (range of 0-3416). Approximately 75 % of the area fertilized with N+P drains into Quatsino Sound. Forest fertilization with P could then result in a potential Cd loading of 4 – 32 kg year^{-1} to watersheds draining into Quatsino Sound. A summary of potential Cd loadings from fertilization at planting and from N+P fertilization later in stand development is shown in Table 2.

[1] The assistance of John McClarnon and Rob Brockley (British Columbia Ministry of Forests Forest Practices and Research Branches, respectively) and Annette van Niejenhuis (Western Forest Products) in preparing this submission is gratefully acknowledged.

Potential loadings of Cd from forest fertilization at planting appear low, compared with loadings from other known sources. Potential loadings of Cd from aerial fertilization are higher, but vary greatly with the concentration of Cd in the applied fertilizer. Over time, Cd loading from fertilization is minimized by the infrequency of applications over the lifespan of a stand. Migration to surface waters of Cd applied in P fertilizers will be further minimized by 10 metre-wide streamside (no fertilization) buffer zones specified in the Forest Fertilization Guidebook (www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm), by the adsorption of Cd by soil, and by the uptake and accumulation of Cd in above- and below-ground biomass. However, assessments of the fate of Cd applied in fertilizers are hampered by difficulties in quantifying the amounts added, and by a limited understanding of the behavior of applied Cd in forest soils.

Lett, Ray and Wayne Jackaman, *B.C Geological Survey, Victoria, BC.*

Cadmium in Coast BC Sediments

Elevated cadmium levels have been detected in shellfish tissues at several locations along the British Columbia coast. Among the common geological sources for cadmium are zinc sulphide (sphalerite), secondary zinc minerals (smithsonite) and sedimentary rocks. Rock-forming silicate minerals typically have less than 1 ppm cadmium. Coastal B.C. and Alaska geology represents periodic collision of island arc chains, carried by continental drift across the Paleo-Pacific ocean, with ancestral north America over the past 200 million years. Distinct geological terranes (e.g. Stikina, Wrangellia, Alexandra) were formed by these collisions. Massive lead-zinc-copper sulphide deposits hosted by the volcanic, sedimentary and intrusive rocks forming these terrains are a likely primary source for the cadmium. Weathering of minerals releases cadmium and other metals into streams where they may concentrate in bottom sediment. Ultimately, metals can be discharged into the sea from coastal streams either bound to suspended sediment in stream water or in solution.

Cadmium levels in coastal stream sediment have been determined as part of a regional geochemical survey (RGS) carried out by the British Columbia Ministry of Energy and Mines Geological Survey Branch. These surveys are aimed at stimulating mineral exploration. The < 0.177 mm size fraction of active stream and moss mat sediment, collected at a average density of 1 sample/10 to 13 square kilometers, is routinely analysed for up to 50 elements including cadmium by a combination of instrumental neutron activation (INAA) and aqua regia-atomic absorption spectrometry (AAS). Stream water samples are analysed for uranium, fluoride, sulphate and pH. Since 1977 over 45,000 samples have been collected covering 70 per cent of the province. RGS data has revealed that cadmium levels up to 1.9 ppm occur in sediment from the Bamfield area, 7.5 ppm in sediment from the Cortes Island area and up to 2.2 ppm in streams draining into Jervis Inlet. There is no clear link between the source and the presence of elevated cadmium in sediment or shellfish although there are potentially cadmium-bearing mineral occurrences in the watersheds of some coastal streams.

Burt, Will and Marcella Snijders. *Department of Geography, University of Victoria, Victoria, BC.*

How satellite imagery can help to understand cadmium contamination in oysters.

This presentation introduces the fundamentals of satellite remote sensing and displays Landsat Thematic Mapper 7 (TM) images of some oyster license regions to provide a qualitative review of possible anthropogenic activities on land cover in these regions that may contribute to elevated cadmium concentrations in the oyster population.

Images of Effingham Inlet, Baynes Sound, Desolation Sound and Clayoquot Sound were produced using TM bands five, four, and three that were acquired in 1999. This band combination highlighted differences in vegetative cover in the study areas and thus allowed the identification various stages of forest growth, forest denudation, roads and agricultural land uses.

In all four regions, anthropogenic activities such as logging, road building and agriculture can to be seen to have a dominant effect on the landscape. No obvious visual correlation between oyster sites with elevated cadmium concentrations and land use could be made due to the wide extent of anthropogenic activities throughout all the areas of interest.

To conclude the presentation, another application of remote sensing in relation to the oyster cadmium concentration problem was suggested. This application would use either satellite or airborne remote sensing in conjunction with ground based sampling to detect the mode and extent of cadmium transportation within the suspended load of coastal river plumes.

Bhogal A.S. (Pal) [1], D.G. Goodenough[1,2], A. Dyk[1], R. Hall[3], J. Iisaka[2], D. Leckie[1], A. Hollinger[4], J. Pearlman[5], J. Miller[6], Olaf Niemann[2], Karl Staenz[6], Harold Zwick[7]

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[7]*MDA, Richmond, B.C.*

Evaluation and validation of EO-1 for sustainable development of National Forests (EVEOSD) - An overview

Hyperspectral sensors provide measurements of targets at high spectral resolution. In the forest, canopy chemistry can be used to estimate new and old foliage, detect damage, identify trees under stress, and map chemical distributions in the forests.

At this time, our hyperspectral work involves a new project entitled "Evaluation and Validation of Earth Observer-1 (EO-1) for Sustainable Development of forests (EVEOSD)". NASA's EO-1 satellite was successfully launched on November 21, 2000. Data collection over the Greater Victoria Watershed District (GVWD) will commence in July 2001. In September 2000, in preparation for airborne and spaceborne data collection and calibration, we collected foliar canopy and ground cover chemistry samples from 54 plots distributed across the GVWD test site. Treetop samples were collected from helicopters, and concentration of both organic and inorganic constituents was determined. One of these inorganic compounds was Cadmium. We are continuing our analysis of organic and inorganic constituents in the foliage in our test site, with further data collection scheduled for the summer of 2001.

In this paper, we provide an overview on the application of hyperspectral sensors to the extraction of forest attribute information, both directly and indirectly. We also discuss the value of multi-temporal and multi-sensor data fusion with GIS for calibrating spectral measurements and validating observations of forest stands under stress.

Borstad, Gary. *G.A. Borstad Associates Ltd, Sidney, BC.*

Potential practical applications of remote sensing for BC Aquaculture

The most practical applications of remote sensing to BC aquaculture currently are:

- upland use (logging, agriculture other land use);
- suspended inorganic sediment concentration, turbidity, water clarity ;
- sea surface temperature;
- phytoplankton chlorophyll concentration, red tide mapping.

All of these parameters can be mapped quantitatively from one or more satellite sensors and from aircraft, but it is important to realize that the more detail one wants, the more it costs, and the less often it is available. Satellite sensors cover large areas repeatedly, but for these parameters are blocked by cloud. Aircraft can carry sensors to make measurements under cloud of smaller areas and provide the platform to make visual observations, and to take in situ samples.

There is a "family" of satellite sensors aimed at global coverage that provides free or low cost data at about 1 km spatial resolution, and nearly daily coverage. A series of American weather satellites operating at these scales provides sea surface temperature imagery. Water colour sensors from several countries are now providing semi-quantitative imagery of phytoplankton blooms. Although more work is required to improve the accuracy of their measurements, these sensors provide useful description of large blooms and upwellings on the outer coast, but will be of limited use in inlets or near the coast.

At present, the area very near the coast and in fjords can be imaged with several sensors having spatial resolution in the range 15 to 30 m. However these sensors generally have fewer spectral bands [they are capable of only crude colour measurements] and have long repeat cycles [they only return over a particular site about every two weeks]. Because they image any particular area less, the chances of imaging on cloud-free days is less. Generally these sensors are commercial and there is a charge for the data.

Later this year, the European Space Agency (ESA) will launch MERIS, a sensor with 300 m resolution designed for detailed quantitative water colour measurements in the coastal zone. It should be capable of quantifying pigment content in plankton blooms even into the fjords, as well as perhaps monitoring the physiology of the blooms.

Suggestions:

1. Use the UVic Landsat Archive (of which Jim Gower has a copy) to make 'snapshot' images of relative sediment concentration [as % Reflectance] and Surface Temperature in BC inlets. (30 m resolution).
2. Use Landsat Archive to map land-use above present and past aquaculture sites. (30 m).
3. Use ASTER data freely available on-line to map land use (15 m resolution), and water temperature - (infrequently).
4. Use Coastal Zone Colour Scanner (CZCS) archive (1978-1986: recently assembled by Borstad for Parks Canada) to study seasonal and inter-annual changes of phytoplankton on the coast (this has only begun and there is no funding to continue).
5. Use SeaWiFS archive (1997 – present) created by Jim Gower to study seasonal and inter-annual changes of phytoplankton on the coast.
6. Use MODIS (2000 – present) data freely available on the web to map phytoplankton (Borstad is beginning a project in May with a view to improving chlorophyll retrievals close to the coast).
7. Make an Atlas of phytoplankton concentration and sea surface temperature 'snapshots' and time series, for the areas with many aquaculture sites, but also of areas of the north coast where the BC government is considering expanding licencing.
8. Images of turbidity, sediment, chlorophyll and temperature also provide snapshots of circulation patterns.

Crispo, Sabrina*. Department of Earth and Ocean Sciences, University of British Columbia, Vancouver BC.*

Marine geochemistry of cadmium

The depth profile of dissolved cadmium in the open ocean is similar to a nutrient profile in that the concentration in the surface waters is low ($1.1x10^{-4}$-$1.1x10^{-3}$ ppb) and increases with depth (up to 0.11 ppb). The maximum concentration of particulate cadmium occurs at the chlorophyll maximum (depth ~ 100m) but is only 35% of the total cadmium in the surface waters so most of the cadmium is in the dissolved phase (<0.45µm fraction). Speciation of dissolved cadmium affects cadmium's bioavailability to phytoplankton. In surface waters, 70% of the dissolved cadmium is bound to organic ligand(s) thought to originate from phytoplankton. The remaining 30% is mostly bound to chloride, with ~0.9% free (Cd^{2+}). For certain toxic metals, such as copper, some species of phytoplankton have been shown to extrude organic ligands to bind the metal, making the metal biologically unavailable. Since cadmium is considered toxic, the organically bound cadmium may also be biologically unavailable. The concentration of the organic ligand(s) decreases with depth, and in water deeper than 200m, 97% of the dissolved cadmium is bound to chloride, and 3% is in free form.

Since dissolved cadmium increases with depth, cadmium-rich water is brought to the surface during upwelling. Upwelled water comes from depths of 200-400m where the cadmium concentration is 85-250 times higher than surface concentrations. Also, this upwelled cadmium has different speciation than the cadmium in the surface. If the cadmium-binding organic ligand(s) in the surface occur to decrease its bioavailability to phytoplankton, upwelled water is not only enriched in cadmium but is enriched in more toxic cadmium.

The fractionation of cadmium, in deep waters, between the North Altantic and the North Pacific oceans is due to the long residence time of cadmium (60,000 years) compared to the time scale of deep ocean circulation (1000 years) and the assimilation-regeneration cycling of cadmium in the ocean. Deep water formed in the North Atlantic travels south, through the Indian Ocean and ends up in the North Pacific Ocean, making the deep water of the North Pacific the "oldest" deep water. This old water has accumulated cadmium from sinking particles for ~1000 years so the cadmium concentration at depth in the North Pacific is 2-5 times greater than the concentration of the fairly "young" deep water of the North Atlantic.

This oceanic fractionation also affects the amount of cadmium brought up to the surface during upwelling. Upwelled waters in the Pacific have 2-5 times the cadmium concentration of upwelled water from the same depth in the Atlantic.

There is a linear correlation between dissolved cadmium and phosphate (Cd/PO_4• 0.2-$0.3x10^{-3}$ mol/mol) that holds true for deep-water profiles. When comparing ratios of different oceans, the trend is the older the water, the higher the ratio.This could be due to preferential uptake of cadmium or faster remineralization of phosphate. Both result in sinking particles have a higher Cd/PO_4 ratio, resulting in higher ratio at depth when remineralization occurs. Other areas the Cd/PO_4 relationship doesn't always hold is in surface water, estuaries and old upwelled water.

In surface water, the ratio is lower (~ $0.1x10^{-3}$) due to preferential uptake of cadmium or faster regeneration of phosphate. In surface water, it has been found that cadmium uptake is dependent on the available Zn, Mn and pressure of CO_2, which does not control phosphate uptake, thus a decoupling of this relationship in surface water occurs.

In estuaries, cadmium does not have a specific behavior. Considering just speciation, estuaries should be a source of dissolved cadmium from the particulate phase (cadmium should be released from particles when binding to chloride). This release is found in some estuaries, but removal and conservative mixing behavior is also found. Since the behavior of cadmium in estuaries is unpredictable, the relationship with phosphate is decoupled due to other physical and chemical considerations.

In upwelling areas, the Cd/PO_4 ratio of the source water holds true until a plankton bloom occurs. Since coastal waters also have a supply of zinc and manganese, plankton do not require cadmium and thus phosphate is depleted before cadmium and higher ratios result. In areas of low zinc and manganese, the opposite is true; cadmium is depleted before phosphate.

Values of cadmium in the surrounding areas range from 0.045-0.07 ng/g; getting as high as 0.10 ng/g during upwelling and 0.278 ng/g during a storm at Amphitrite Point, British Columbia.

Whitney, Frank. *Fisheries and Oceans Canada, Ocean Science and Productivity Division, Institute of Ocean Sciences, Sidney, BC.*

Nutrient supply along the Northeast Pacific margin

Nutrient supply to the southern B.C. coast is governed largely by winter mixing which fuels the spring bloom, summer upwelling which enriches the exposed coast, and other processes such as tidal mixing, river discharge and katabatic winds which dominate fjords and inland basins. My data shows that ocean stratification has altered nutrient supply to outer coastal waters in recent decades. The 1990s was an abnormally warm decade. Upper ocean warming was observed throughout the region, causing an increase in the stratification of the upper ocean. Strong stratification reduces nutrient supply from the deep ocean to the surface where it can support phytoplankton growth. Since the chemistry of phosphate and cadmium are closely affiliated in open ocean, nutrient dynamics can be used to infer cadmium sources. Upwelled waters will be relatively rich in Cd, as they are in nutrients.

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Mussels as indicators of Cd in upwelling regimes

The oceanic distribution of dissolved Cd is highly correlated with that of nutrients. Thus, upwelled nutrient-rich waters are also rich in Cd. The west coast of Vancouver Island is a recognized upwelling region where strong upwelling events occur in the summer. There is evidence that mussels reflect these Cd-rich upwelled waters since high concentrations of Cd in mussels have been detected on exposed rocky shores during upwelling season.

A study on the Pacific coast of Baja California, México, with samples taken on a monthly basis, clearly showed that the high Cd concentrations detected in the mussel *Mytilus californanus* (up to 17 µg Cd g^{-1}, dry wt) were due to the Cd input from upwelled waters. A Principal Component Analysis (PCA) performed on these data showed the relation of the concentrations of Cd in the mussels with those in brown seaweed (indicators of dissolved Cd) and to upwelling indicators (upwelling index, phosphate, seawater temperature). Other metals (Hg, Al, Mn) did not show any relationship with upwelling. A short-term variability study (samples taken every other day) during the upwelling season showed that this species has the capacity (contrary to other *Mytilus* species) to decrease its Cd concentrations in just few days.

Based on the results from the upwelling region of México, a study on the west coast of Vancouver Island (Amphitrite Point) was carried out to further investigate the capacity of this species to decrease its Cd levels at short periods of time in these regimes. Daily samples of mussels, together with seawater (for dissolved Cd determination, phosphate and salinity) and temperature measurements, were taken during a period of 4 weeks in the summer of 1991. Two upwelling events were detected including a period of high mixing after a strong storm that hit the coast.

Mussels reach up to 9.5 µg Cd g^{-1} (dry wt) during an upwelling event and also increased their concentrations during the period of high mixing. The mussels decreased their concentrations very rapidly after these increases. A PCA on these data showed the relationship of mussel Cd concentrations with the condition index (high loads on Factor 3). However, after accounting for the variability due to the condition index through the use of the Cd/shell wt index, this index showed a very strong relation with dissolved Cd inputs from upwelling (high loads on Factor 1). The capacity of *Mytilus californianus* to release Cd very rapidly appears to be a capacity showed only by this species and at low levels of exposure. This was demonstrated through an experiment in which *Mytilus trossulus* and *Mytilus californianus* were contaminated at two Cd levels and depurated afterwards for few days. At the high Cd level tested, both species increased their Cd concentrations and did not decrease them after being in “clean” seawater for few days. However, at the low level of exposure, while *M. trossulus* did not increase its concentrations at all, *M. californianus* increase its concentrations significantly, to decrease them again to the background levels in just two days.

Higher levels of Cd in *Mytilus californianus* than the one previously mentioned have also been detected on the Baja California coast and have been related to strong upwelling. Levels up to 28 µg Cd g^{-1} (dry wt) have been measured in *Mytilus californianus* during the upwelling season. Cadmium in Baja California oysters (*Crassotrea gigas*) has also been measured from a culture carried out in a coastal lagoon adjacent to an area where upwelling is strong. The oysters exhibited similar Cd levels as the mussels from the adjacent area. The maximum levels detected (up to 16 µg g^{-1}, dry wt) in these oysters occurred in July; a month after the highest mussel Cd level was detected. A short-term variability (samples taken every other day) study on these oysters, carried out over a period of 4 weeks during upwelling season, showed high intrasample variability and only one significant decrease (from 16 to 11 µg g^{-1} dry wt) after four days.

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Cadmium and oysters

Exposure and subsequent accumulation of cadmium by filter feeding bivalves will be dependent on the complex interplay between bivalve pre-selective feeding strategy and seston geochemistry. Bivalves are capable of highly dynamic pre-selective feeding bahavior that will select organic rich particles over inorganic rich particles thus increasing carbon intake. However, at low particle concentrations, bivalves will incorporate both inorganic and organic material as diet. Both laboratory and field based studies have demonstrated that bivalves actively assimilate cadmium from organic matter, and passively from inorganic matter. Under conditions of low seston quantity, bivalves will filter both components from the water column, hence, both components of the seston need to be considered as cadmium exposure routes. Studies on identifying routes of cadmium exposure to suspension feeding organisms should focus on first quantifying the sediment geochemistry of seston from the region the bivalves are actively filtering and then determine field based seston ingestion rates and subsequent assimilation of cadmium from the geochemically characterized seston. Finally, field based elimination rate constants are required to allow for predictions of where and when bivalves such as oysters are at most risk to cadmium exposure through their diet.

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Mechanisms of cadmium sequestration in oysters

Oysters accumulate cadmium through two primary pathways. One is direct uptake by the gill for the dissolved forms of cadmium in the external medium and the other is uptake of ingested material in the digestive glands. Subsequent interorgan transport results in a tissue level distribution that involves the above organs, the hemolyph, and other internal organs.

The kidney plays an important role in release of cadmium. The concentration of cadmium in the various tissues is determined by the net uptake or loss by each, the integration of which results in the whole body concentration at any point in time. Once taken up by cells in the various organs, cadmium is bound to or sequestered in structures that serve to protect cells from the toxicity of the metal. The most studied systems are the metal-binding protein metallothionein and vesicle-bound granules and concretions. Metallothioneins considered to be metallothionein were first reported in oysters in the species *Crassostrea virginic*a (1). The subsequent purification and characterization of these proteins (2) confirmed their identity as metallothionein that had been previously identified in higher animals. This and subsequent work (3), which resulted in deducing the complete amino acid sequence of the cDNA, provided tools in this laboratory for detailed studies on responses of both the protein and its responsible mRNA. Metallothionein is expressed in both adult (see above) and larval (4) oysters. Its expression spares, but does not prevent, binding of cadmium to other structures and related toxicity. Use of antisense oligonucleotides to inhibit metallothionein synthesis has shown that metallothionein in oysters functions to protect against cadmium toxicity (5).

Examination of oysters in natural populations shows that metallothionein-bound cadmium is elevated in individuals exposed to cadmium in the field (6). Cadmium is also reported to occur as granules in granular amoebocytes of Crassostrea gigas (7). Cadmium bound in cellular compartments such as metallothionein and granules are potential sources for uptake by consumers of oysters and also contribute to fluctuations in cadmium concentrations in oyster tissues. The latter is highlighted in studies of *Crassostrea virginica* in which cadmium concentrations can fluctuate over a three-fold range over a two-month period (8). Changes in cadmium levels in the above structure likely account for a significant portion of changes in the whole body cadmium.

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Cadmium in dredge oysters (Tiostrea chilensis) and related species in New Zealand coastal waters

High concentrations of Cd in the dredge oyster (*Tiostrea chilensis*) in the area of Foveaux Strait, at the bottom of New Zealand's South island, have been known for some years (Neilsen, 1975; Frew *et al*., 1989). Figure 1 tabulates oyster Cd concentrations in New Zealand from the latter two studies and compares them with some results form elsewhere in the world. The very high values in Foveaux Strait (> 5 ppm wt weight) are very puzzling, because this is an almost pristine marine region largely devoid of heavy industries. In particular, there is no Zn or Cd mining or refinement here (or anywhere else in New Zealand).

Recent work in our laboratory (Peake, unpublished data) shows that this anomaly extends to other shellfish species. Figure 2 shows Cd levels in New Zealand scallops (*Pecten novazealandiae*). Note the high values in Paterson Inlet (in Stewart Island, adjacent to Foveaux Strait) and at the Chatham Islands, east of New Zealand.

Figure 3 shows the geography of southern New Zealand in relation to ocean currents. High shellfish Cd levels are observed in all waters affected by the subtropical convergence, which is the oceanographic boundary between warm subtropical waters (e.g. Tasman Current) and cold, nutrient-rich subantarctic waters. Cd concentrations in the ocean are often highly correlated with those of the nutrients nitrate and phosphate (e.g. Frew and Hunter, 1992, 1995) However, although the convergence waters are rich in nutrients, this does not imply high Cd here; indeed, the waters of Foveaux Strait have extremely low Cd concentrations (Frew and Hunter, 1995). This probably indicates very efficient scavenging of Cd from the water column by phytoplankton, and may perhaps be the key to the unusual bioaccumulation of Cd seen in the bivalves.

Figure 4 shows a map of sampling stations used by Frew *at al*. (1997) for an extensive survey of Cd in the Foveaux Strait system. Figure 5 shows more detail of stations occupied around Stewart Island. Oysters were sampled wherever possible, but were generally not found at southern sites around Stewart Island.

Figure 6 shows the histogram of Cd concentrations for all 431 oysters sampled, centred on about 5 ppm wet weight. Figure 7 shows that a major fraction of the Cd is found in the viscera, with least in the muscle tissue.

Figure 8 shows a map of Cd concentrations in the oysters, with the symbol size used to indicate the magnitude of the concentration. The geographic pattern is not especially clear. However, as argued by Frew *et al*. (1992), concentration of Cd in the oyster tissue is not a useful biogeochemical measure because changes take place in the mass of oyster tissue independently of Cd through nutritional state, spawning etc. It is better to use the Cd uptake rate, calculated by using growth rings in the shell, or the mass per unit area of the shell, to determine the age of each oyster specimen (Frew *et al*., 1992, 97).

Figure 9 shows the corresponding geographic distribution of the Cd uptake rate. Now it becomes clearer that the greatest uptake rates occur closest to the north of Stewart Island, and generally in deeper waters. Finally, Figure 10 shows the corresponding Cd concentrations in the fine fraction of the bottom sediments. This shows a clear link between high Cd in the sediments and high Cd uptake rate in the oysters.

The origin of the high Cd levels in these oysters remains a puzzle. The “smoking gun” is that water column Cd levels are unusually low, suggesting enhanced Cd uptake by the phytoplankton. If this is true, the rest of the picture, including high Cd in filter-feeding shellfish, would follow naturally. However, it is not at all obvious why Cd should undergo enhanced uptake. Perhaps Cd is substituting for another biologically essential element, e.g. Zn? We need further research to find out.

Are the oysters from Foveaux Strait dangerous to eat? Some years ago, the Department of Human Nutrition at the University of Otago carried out a major study which failed to find evidence of Cd toxicity in individuals eating as many as 4 dozen per day, which corresponds to the daily Cd dose well above that recommended by most health authorities. The answer may lie on the recent finding from our research that a large fraction of the Cd in these oysters appears to be strongly bound to a metallothionein protein that is very stable to degradation, even with heating (Butcher and Frew, unpublished results).

It is clear that while many questions remain, the example of the Foveaux Strait oysters shows:

1. natural populations of oysters, and other shellfish, can, in certain oceanographic regimes, accumulate Cd levels much higher than that normally recommended for human consumption;
2. these oysters seem to be able to sequester Cd in a form that is probably not biologically available.

Clearly we need better information on the types of oceanographic conditions that lead to these anomalous Cd levels, and a more refined way of setting maximum permissible Cd levels that takes account of possible sequestering in non-biologically available forms such as metallothioneins.

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Physical Oceanography of Effingham Inlet

Effingham Inlet located off the Northwest corner of Barkley Sound is a small (~16km long) and narrow (<2km wide) inlet. The inlet has two main basins: a deep (200m) outer basin with a 60m sill and a smaller, and a shallower (120m) inner basin defined by a 40m sill. Tidal currents are generally weak except at the constrictions. Several small rivers discharge into the inlet and the freshwater discharge is assumed to be closely follow the precipitation pattern i.e. high runoff in winter and minimum runoff in late summer and early fall. The often anoxic deep waters of this west coast Vancouver Island inlet have made it the locale for a collaborative multi-disciplinary paleoceanographic study of long-term fish stock abundance and coastal upwelling intensity (Burd and Thomson 2001). Prior to this collaborative study which started in 1995 there were no known publications or data reports for Effingham Inlet oceanography.

An extensive set of water property profiles (temperature, salinity, dissolved oxygen, fluorescence, nutrients and light transmission) from about a dozen oceanographic surveys of the inlet now exist. In the summer, the inlet has strong thermal stratification near the surface, and at times there is no evidence of a freshwater layer. During the winter, the salinity stratification is strongest and the seasonally high runoff produces a thin (0-2m) surface freshwater layer. In 9 of the 12 surveys, anoxic conditions were present in the bottom waters of the inner and outer basins, but anoxia occurred most often in the inner basin. The replacement or flushing of the deep anoxic waters by intrusions of dense oxygenated waters from Barkley Sound are episodic in nature and appear to be related to coastal upwelling events. Renewal events typically occur in summer to late fall and winter is a time of stagnation.

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The general oceanography of BC's coast and the Strait of Georgia as it pertains to Cd enrichment in oysters

The observed enrichment of Cd in oysters from the Northeast Pacific Ocean could potentially be caused by several factors involving either natural cycling of Cd in the earth-ocean system or contamination from human activities or both. To take action aimed at reducing Cd levels in oysters, therefore, requires a clear understanding of the complete Cd cycle as it pertains to a given location. Here, I provide a brief overview of Cd in the ocean, starting at the global scale and focussing down to processes in coastal BC and the Strait of Georgia. Budgets suggest that at the large scale Cd in the oceans is predominantly controlled by natural cycling which includes supply from land by rivers, entry into the productivity-regeneration cycle and, eventually, sequestering into sediments in authigenic sulphide phases (Macdonald et al., 2000). Cd follows soft-body parts in the nutrient cycle and, therefore, mirrors phosphorus in the upper ocean exhibiting depletion near the surface and enrichment below the mixed layer (Figure 1; Bruland and Franks, 1983; Moore, 1981; de Baar et al., 1994). The biocycling of Cd, its relatively long residence time in the ocean (Boyle et al., 1976) and the global ocean conveyor result in the Pacific Ocean being enriched in Cd by a factor of perhaps 5 compared to the Atlantic Ocean (Figure 1). A direct consequence of the global cycle is that Cd will be more of a problem for the North Pacific Ocean than for the Atlantic Ocean and we have no ability to control or change this fundamental fact.

The coast of BC receives Cd enriched water in the same way it receives phosphorus – through coastal upwelling. This process, which places nutrient rich water from the California undercurrent onto the shelf (eg see Mackas et al., 1987; Denman et al., 1981; Figure 2), supplies not only the outer coast but also the inlets and the Strait of Georgia. Tidal mixing in the passages helps to supply nutrient to the surface water of the Strait (cf Harrison et al., 1994) and therefore also Cd.

Numerous rivers along the coast of BC have the potential to supply terrestrial Cd especially where mineralized rocks outcrop. Additionally, contaminant Cd from human activities (industry, agriculture, mining) can enter freshwater systems and thereby transport to the coast. Of note, the largest rivers tend to have large drainage basins that include the coast mountains and BC interior (e.g., the Fraser River). These coastal/interior rivers exhibit freshet during springtime (June; Figure 3) because they are strongly supplied by snow melt. This contrasts the hydrological cycle for rivers on the outer coast of Vancouver Island which are more strongly forced by autumn and winter precipitation (Figure 3) and we can accordingly expect coupling between riverine input of Cd (particulate and dissolved) and the oyster growth cycle to vary depending on location. This may be an important factor in Cd enrichment especially if particulates provide a pathway to concentrate Cd and deliver it to oysters during feeding (see, for example, McConchie and Lawrance, 1991).

Within the Strait of Georgia, the Fraser River dominates the runoff and particulate supply (Milliman, 1980). Observations show that the Fraser River has generally lower Cd concentrations than the salt water of the Strait (about 20 ng/L vs 70 ng/L; Figure 4; Fletcher et al., 1983) and, although we do not know the availability of this Cd to biota, there is no reason to suspect the Fraser River as a major source of Cd enrichment. Many of the oyster harvesting regions – especially those exhibiting high Cd concentrations – are located toward the north end of the Strait of Georgia. Depending on winds, the Fraser Plume can travel to the north (Figure 5; Stronach et al.,1988; Thomson, 1981) but it is often seen spreading to the south (Figure 6; Gower, pers. comm) and most of the Fraser River water eventually escapes the Strait of Georgia into the Strait of Juan de Fuca via the southern passages (LeBlond, 1983; Thomson, 1981). Sediment traps moored during a two year period at three sites in the Strait of Georgia (Figure 7) show that particulates from the Fraser Plume tend to be deposited off the Fraser River or to the south; northern transport seems to be very much smaller (Figure 8; Macdonald et al., unpublished).

Municipal outfalls are another potential source of Cd to the Strait of Georgia. Based on Ag (Gordon, 1997) and nonylphenol ethoxylates (Shang et al., 1999), the sedimentary footprint for the Iona outfall (Figure 9) is confined to a 40 km^2 area off the Fraser delta. Other outfalls, particularly those discharging near the surface, might have an opportunity to spread contaminants in surface waters over a greater distance, but it seems unlikely that the regions exhibiting high Cd in oysters (north end of the Strait of Georgia) would be vulnerable to these sources which are distributed predominantly near the south end of the Straits.

Cd profiles in dated sediment cores from the Strait of Georgia and Juan de Fuca show little evidence that could be interpreted as contaminant Cd input (Macdonald and Crecelius, 1994; Macdonald et al., 1991; Matsumoto and Wong, 1977; Pedersen et al., 1989). Macdonald et al. (1991) estimated the residence time for Cd in the Strait of Georgia to be greater than 10 years (Figure 10) which is much longer than the 0.5 to 2 years taken to exchange the water (Waldichuk, 1957). This implies that Cd entering the Strait of Georgia either from ocean exchange or from land-based sources tends to mix and transport through the system rather than accumulate in the water or become captured on particles or in sediments. Sediments, therefore, appear not to be suitable recorders of "dissolved" Cd and therefore would poorly reflect contamination should it have occurred. Where Cd enters the system as a particulate (e.g., sulphide mineral phase in mining), burial in sediments may be recorded and once sediments become sulphidic, the strong affinity of Cd for sulphide phases will tend to lock it in place. However, uptake of particulate Cd is possible if animals are foraging on the contaminated sediment (Burd et al., 2000). Curiously, Cd sediment enrichments of up to 8 μg/g have been observed in Ucluelet Harbour sediments (Figure 11; Pederesen et al., 1989) – far from any obvious contaminating sources. Geochemical evidence supports a natural enrichment mechanism that includes upwelling of Cd-rich water, organic carbon fluxes to sediments sufficient to produce anoxic and sulphidic conditions very close to the sediment surface, and diffusion of Cd into the sediments followed by precipitation within sulphide phases. This mechanism of sequestering Cd is widely distributed in marine sediments and controlled by redox conditions which themselves are controlled by sedimentation rate and organic carbon flux (see Gobeil et al., 1997). Although this process of Cd enrichment is natural, it could lead to enhanced amounts of Cd in oysters if, for example, beach sediments were to go anoxic just below the surface (which is often evident from sulphide smell of tidal flats and the black appearance of buried sediment). Cd-rich particles, produced in these anoxic environments, could later be resuspended by wave action, filtered out by oysters, and the Cd released during digestion. Particles have been shown in certain cases to act as a transport medium for Cd (McConchie and Lawrance, 1991), and correlations between sediment and oyster Cd concentrations (cf. Peter Thompson, these proceedings) support such a mechanism under the right circumstances.

Enrichments of elements or compounds in biota usually occur not because of a single factor but, rather, because several factors act together. For the Cd enrichments observed in wild and cultured oysters of the Northeast Pacific Ocean we understand only a couple of the conspiring factors. In particular, the Pacific Ocean contains relatively high baseline concentrations of Cd and upwelled water that feeds the primary production of the coast supplies Cd at the same time. Furthermore, oysters have a physiology that makes them particularly susceptible to concentrate and retain Cd (Engle, 1999). The first factor we cannot change and the second factor would require the development of oyster stocks that are less susceptible to Cd uptake or more able to depurate Cd. Other factors that are presently poorly understood or not understood at all include: 1) Coupling between particles, Cd and oysters; 2) The interaction of runoff and oyster feeding (timing, particle supply, stratification); 3) The interaction between other elements (Zn specifically) and Cd in the biogeochemical cycle (e.g., see Rouhi, 2000; Loscher et al., 1998); 4) The seasonal cycle of Cd uptake by oysters; 5) Natural enrichment of Cd due to drainage basin geochemistry; 6) Enhanced Cd cycling due to basin disturbance (logging, construction); and 7) Contamination from human activities (municipal outfalls, pulpmills, street runoff; mining (acid mine drainage); industry (paint, electroplating); agriculture and silviculture (phosphate fertilizer in particular). Given the locations of oysters exhibiting high Cd concentrations, contaminant sources such as industry, street runoff, and municipal outfalls seem unlikely.

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Some Comments on the General Oceanography of the Northern Strait of Georgia and Inlets

Many investigators (Waldichuk 1957, Thomson 1994) have studied the Strait of Georgia, however most of the studies and sampling have focused on the southern portion of the strait and the influence of the Fraser River. In fact, only about 15% of all samples from the Strait of Georgia have been collected from the northern half.
The observations from the northern strait show that it is also affected by the highly seasonal discharge of the Fraser River. Near surface salinities are low in summer but not as low as in the southern strait, though the Fraser River plume, given appropriate wind and tides, may be driven northward. Most of the freshwater that enters the strait exits through the southern passages because in terms of cross-sectional area, the

northern passages (Discovery Passage, Yuculta and Arran Rapids) are quite small (only 7%) compared to the southern passages through the Gulf and San Juan Islands.

Little is known about the detailed circulation of the northern strait. In general terms, tidal currents are weak (<10 cm/s) except near the constricted tidal passages at the northern boundary of the strait, and there is a rumoured counter-clockwise circulation. South of Discovery Passage waters move southward along the east coast of Vancouver Island and northward along the mainland coast.

Several large inlets adjoin the northern strait, and of these Bute and Jervis Inlets are the largest and best sampled. Jervis and Bute inlets have some similarity in physical attributes but have quite different watersheds and hydrologic cycles. Bute Inlet's water shed area is much larger and drains interior snow fields and glaciers. Bute Inlet's largest river, the Homathko, discharges at the head of the inlet and has a flow pattern similar to that of the Fraser River, though its peak discharge is about one month later. Jervis Inlet has a smaller watershed and freshwater flow. The streams entering Jervis Inlet are distributed along the length of the inlet, and their runoff more closely follows the coastal precipitation pattern and snowmelt in the local mountains. This difference in the amount and timing of the freshwater discharge is reflected in the near surface temperature and salinity cycles of these two fjords. During the summer, Bute Inlet near surface salinity is much fresher (5 to 15 PSU) and temperature much colder (10 to 12°C) than in Jervis Inlet where salinities of about 20 PSU and temperatures of 17 to 20°C are observed. The Desolation Sound area and Pendrell Sound are in close proximity to Bute Inlet and the energetic tidally mixed northern passages, yet some of the warmest waters of the coast occur in this region. The combination of weak tidal currents, very small local freshwater flow and weak winds allow solar insolation to heat the surface water of Pendrell Sound without much mixing and flushing.

<u>*References*</u>

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Cadmium in Pacific oysters

The cadmium that is found in Pacific oysters (*Crassostrea gigas*) from British Columbia (Canada) must come from some source. In this Abstract I argue that this source is mostly likely natural and that the vector is phytoplankton.

Dissolved inorganic Cd appears to behave like a nutrient in oceanic waters. In general it is depleted in surface waters in pattern to similar to [PO_4] (Bruland 1983). Recent research has provided strong evidence that Cd is indeed a nutrient used by phytoplankton (Cullen et al 1999, Lee and Roberts 1995, Payne and Price 1999).

There are several methods that can be used to estimate the possible content of Cd in phytoplankton: 1) from empirical ratio data (e.g. Redfield 1958), 2) from laboratory experiments on Cd content (e.g. Lee and Roberts 1995), 3) from field and laboratory data on the factors that may influence the amount of Cd incorporation (e.g. Sunda and Huntsman 1998, Payne and Price 1999).

From empirical data we can estimate the possible Cd incorporation as from observed water chemistry for the Northeast Pacific (relatively high PO_4 in upwelled water) and Redfield ratios for phytoplankton composition we can estimate the molar C:N:P:Cd rations which should be approximately 318000:48000:3000:1. Given a dry weight (dw) to carbon ratio of about 2:1 and converting to weights (from molar ratios) the expected dw:Cd content of phytoplankton in the NE Pacific could be as high as 15 ppm. Assuming 1:1 incorporation by oysters then phytoplankton at 15 ppm could be expected to yield oysters at about 2 ppm Cd on a wet weight basis.

From laboratory research on the diatom *Thalassiosira weisflogii* the Cd quota of cells varied. Making the assumptions that C:P was 106:1 and dw:C was 2:1 then the range of dw:Cd ratios observed in culture was 0.4 to 14 ppm depending upon culture conditions (Lee and Morel 1995, Lee and Roberts 1995). The Cd was clearly bound in association with carbonic anhydrase.

Factors that could increase Cd content of phytoplankton cells include:

1. Concentration of Cd in water (Payne and Price 1999). For some species Cd quota was a strong positive function of [Cd].
2. Low Mn, low Zn and low CO_2. Because of the physiological uses of Cd within cells low concentrations of any of Mn, Zn, and CO_2 have been shown to result in an increase in Cd quota in a number of phytoplankton species. The details of how and, to a certain extent why, these influence the Cd quota of phytoplankton cells are given in Sunda and Huntsman (1998) and Cullen et al. (1999). For the purpose of this forum the fact that the Cd cell quota can vary significantly and that this variation is related to variability in other environmental factors is important. It provides another mechanism to explain spatial and temporal patchiness of Cd in oysters.
3. Association of Cd with Ca. Due to similar size and charge Cd replaces Ca in Foraminifera (van Geen and Luoma 1999). It seems quite likely that this would also happen in Coccolithophorids. Indeed over a range of phytoplankton Classes the greatest quota of Cd was observed in coccolithophorids by Payne and Price (1999).
4. Based on its distribution in the water column it seems reasonable to assume that Cd recycles on a similar time scale to PO_4. Given the seasonal dynamics of PO_4 concentrations in temperate coastal ecosystems there is likely to be a strong

seasonal component to the concentration of Cd in phytoplankton (in the particulate phase).

In conclusion, phytoplankton are a likely vector for Cd in filter feeding bivalves (including commercially harvested oysters). High nutrient (possibly upwelled) waters are likely to contain sufficient Cd to result in phytoplankton containing relatively high Cd concentrations sufficient to explain Cd concentrations in oysters in excess of 2 ppm (wt weight). Factors such as different phytoplankton species and growth conditions can change the Cd concentrations in phytoplankton cells by a factor of ~10.

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APPENDIX B LIST OF PARTICIPANTS

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INSTITUTE OF OCEAN SCIENCES, SIDNEY B.C.

MARCH 6-7, 2001
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APPENDIX C: CADMIUM RESIDUE WEIGHTS

Comparison of Cadmium residue dry vs wet weight basis based on ~85% moisture. Bold represents at or over the 2 ppm (Hong Kong limit)

µg Cd/g dry weight	µg Cd/g wet weight
35	**5.25**
34	**5.1**
33	**4.95**
32	**4.8**
31	**4.65**
30	**4.5**
29	**4.35**
28	**4.2**
27	**4.05**
26	**3.9**
25	**3.75**
24	**3.6**
23	**3.45**
22	**3.3**
21	**3.15**
20	**3**
19	**2.85**
18	**2.7**
17	**2.55**
16	**2.4**
15	**2.25**
14	**2.1**
13	**1.95**
12	1.8
11	1.65
10	1.5
9	1.35
8	1.2
7	1.05
6	0.9
5	0.75
4	0.6
3	0.45
2	0.3

Oysters and Cadmium Workshop IOS, March 6-7 2001

Credits:

BC Fisheries: Bill Heath, Barron Carswell, Rick Deegan.

CFIA :Klaus Schallie, Gordon Greig

EC: Chris Garrett, Hal Nelson

DFO RHQ Wayne Knapp, Steve Samis

MEHSD: Robie Macdonald, Richard Addison, Shirley Lyons

OSAP: Lisa Miller, Frank Whitney, Dario Stucchi

CHS: Brian Watt, Fred Stephenson, Terry Curran

NRCAN: Colin Dunn , Vaughan Barrie

BC Energy and Mines: Ray Lett & Wayne Jackaman

BCSGA: Ruth Salmon, Brian Kingzett and Growers

Cadmium in BC Cultured Oysters

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HK

CFIA

DFO **HEB**

SCIENCE

literature

contacts > NRCAN; BC Geol. Survey, MOF ; Universities ; IOS International

mapping > BC Fisheries

sampling > BC Fisheries

PSARC Summary Report

PSARC

Literature Review

Contacts

Potential Sources

- Oceanographic
- Geology/Geochemistry
- Anthropogenic
- Culture Techniques

Recommendations:

Additional Sampling

Materials Leaching

Limits/Regulation/Health Issues

Workshop

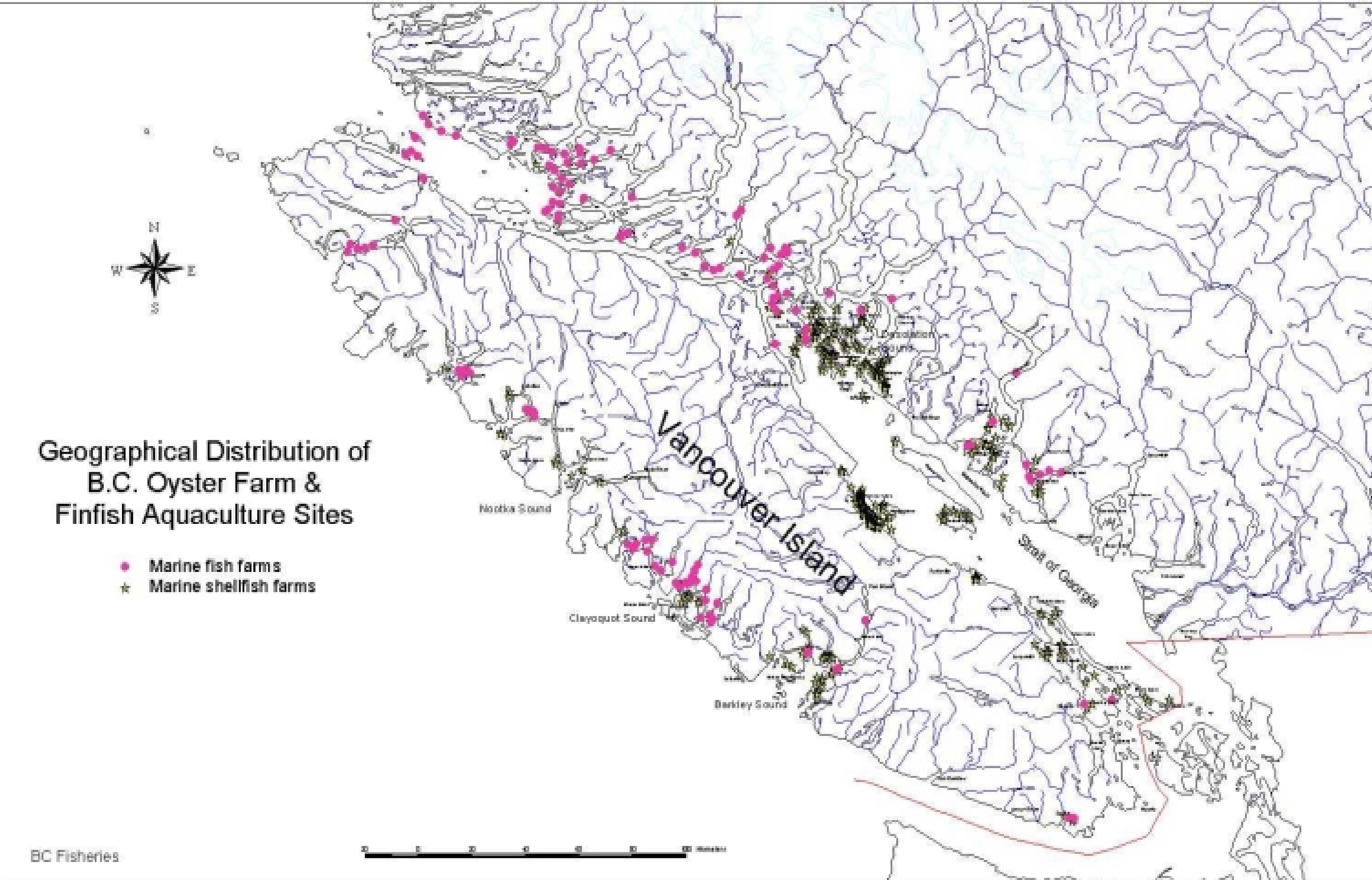
- Exchange Information
- Seek Input from Experts
- Identify Available Data
- Define Best Approach, Mitigation ?
- Explore Opportunities for Collaboration
- Formulate Research Plan
- Identify Potential Funding Sources

Results of 24h Materials leaching test (2%HNO_3)

0.47 ng/sq cm/day

Sample Number	Sample Description	Mass 2% HNO3/g	Cd/ppb	Surface Area/cm2
1	Poly Tray- High Flow Tray Odyssey Shellfish BC	82.9	<0.06	
2	PVC Oyster Tube/Made in France	62	0.29	37.7
3	Oyster Tube (brownish colour)	61.3	2.6	37.7
4	Galvanized Mesh	70.4	2000	
5	Coated Screen (1cm)	65.4	4500	
6	Coated Screen (2cm)	157.8	230	
7	Poly Mesh (Black 0.75 inches)	63.7	<0.06	
8	Poly Mesh (Black 0.25 inches)	59.5	0.43	
9	Predator Netting, Black	87	0.15	
10	Clam/Shellfish Plastic Mesh, Green	64.7	<0.06	
11	Clam/Shellfish Plastic Mesh Net Bag, Blue	64.3	<0.06	
12	Plastic Mesh Brown	82.7	0.12	
13	Rope-Oyster Tray Bridles DSO (green 0.25 inch Dia)	62.8	0.30	
14	Rope- Oyster Blue Culture Rope	53.9	0.18	
15	Rope-Yellow polypro/Made in Korea/Hoyle Ind.	82.6	<0.06	
16	Rope-Blue polypro/Made in Korea/Hoyle Ind.	102.6	0.44	
17	Rope-Yellow polypro/Made in Phillippines	86.5	0.07	
18	Rope-Yellow polypro 1.5inch dia/Made in Canada	66.4	0.67	
19	Rope-Pale Blue Polysteel 1.5inch dia/Made in Ont. Canada	50.7	<0.06	
20	Method Blank (Teflon beaker filled with 2%, no sample)	66.4	<0.06	

Geographical Distribution of BC Oyster Farm and Finfish Aquaculture Sites



Estimate of Cd Loading from Farmed Salmon Diet

~100 farms @ 400 Tonnes/year (x 1.35 conv.)

~ 0.5 ug Cd/g dry feed

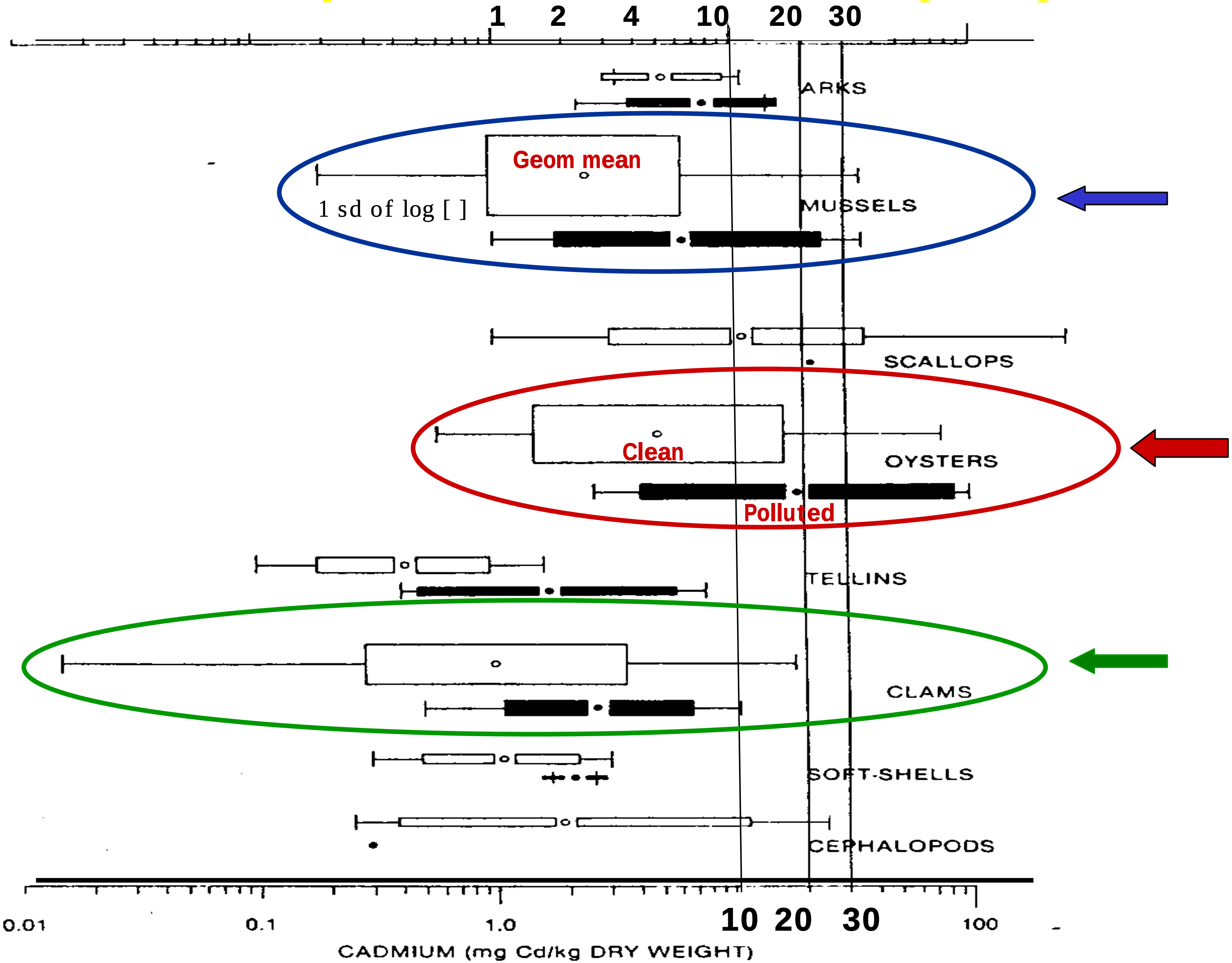
Added: 0.3 kg/y x ~100 farms = 30 kg/y

How much assimilated ?
How much feed lost ? (< 1%)
How much excreted in feces ?

Might it be available to filter-feeding molluscs ?

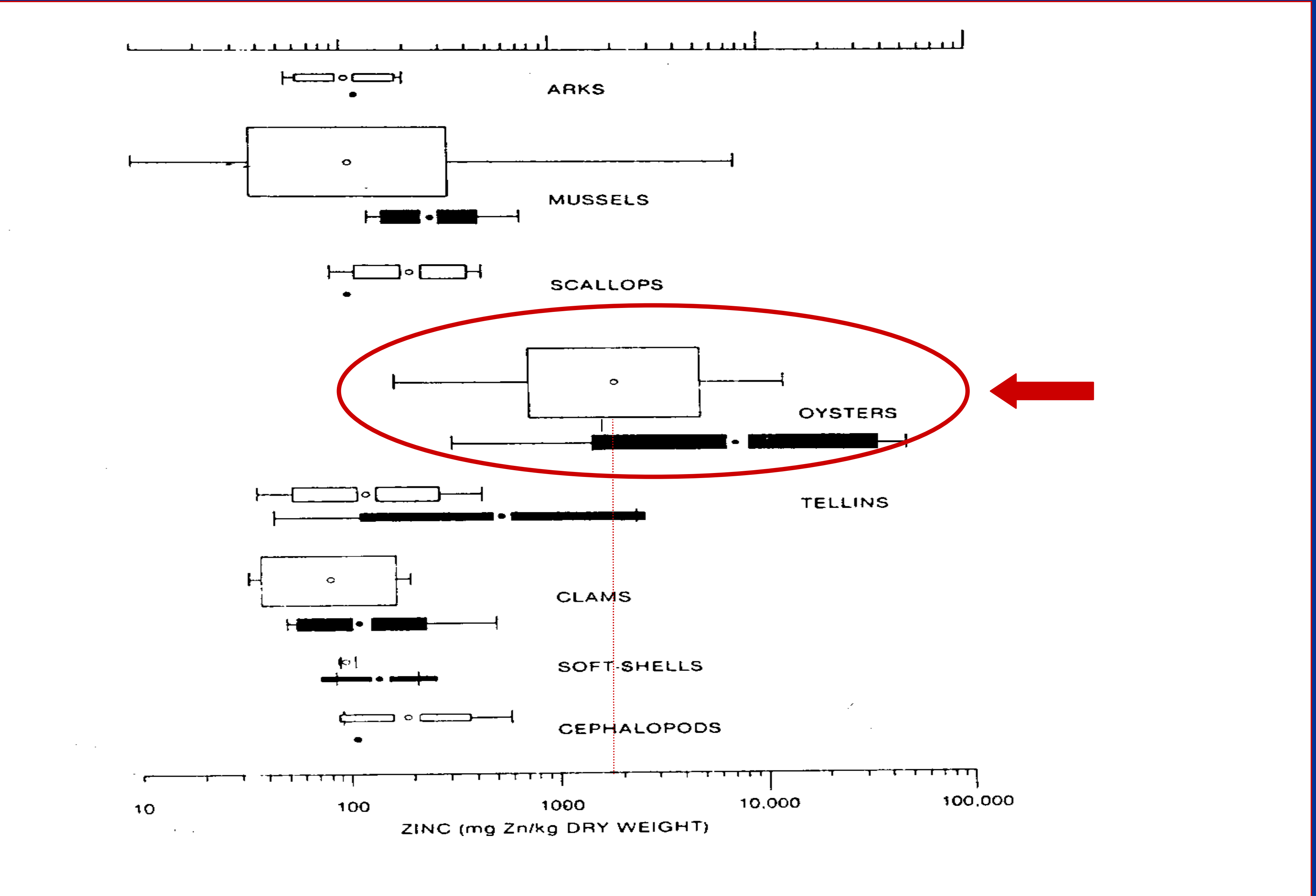
A non issue ?

Cd in Soft Body Parts of Molluscs and Cephalopods

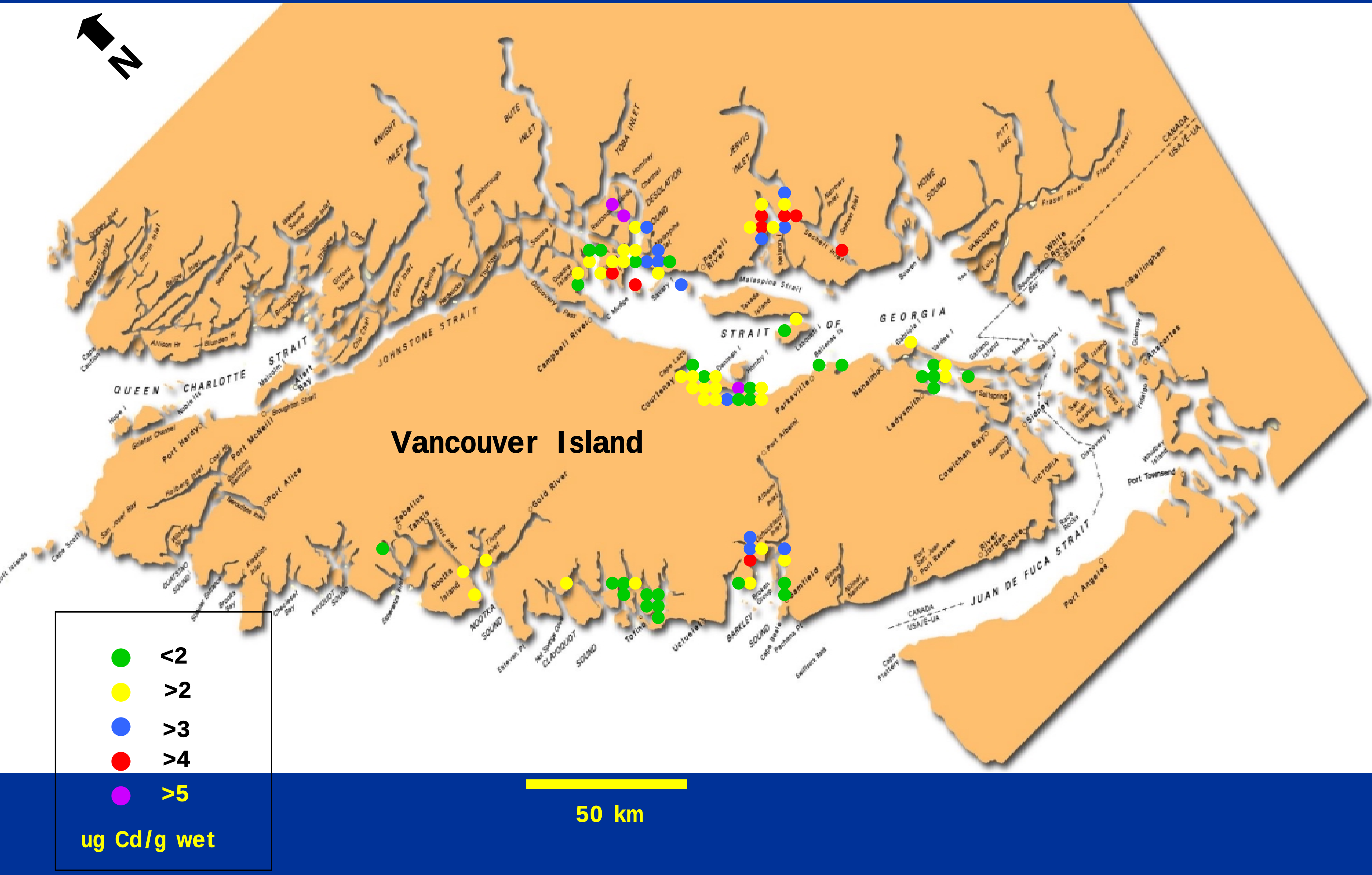


Sprague, J.B., 1986. Toxicity and tissue concentrations of lead, zinc and cadmium for marine molluscs and crustaceans

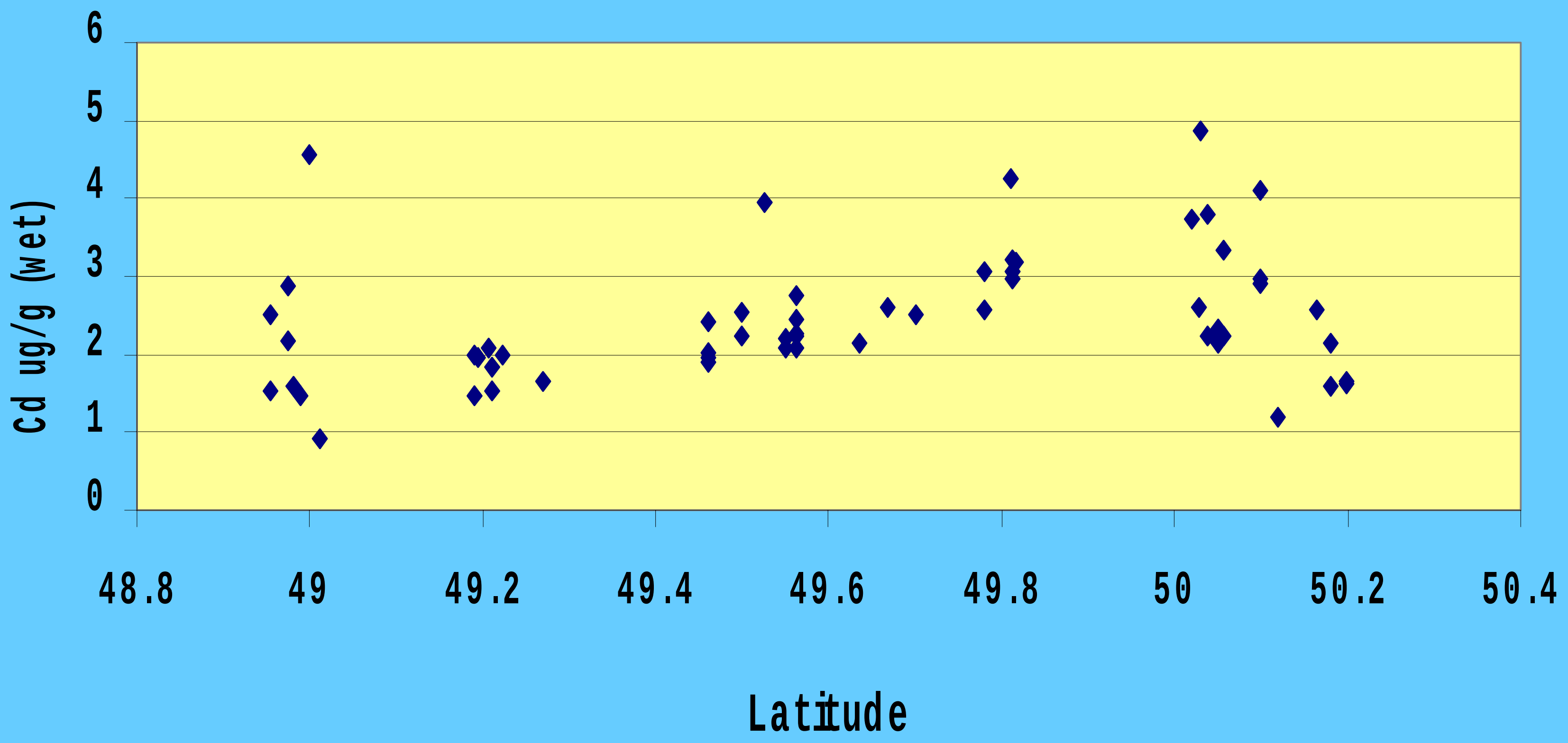
Zn Residues in Soft Body Parts of Molluscs and Cephalopods



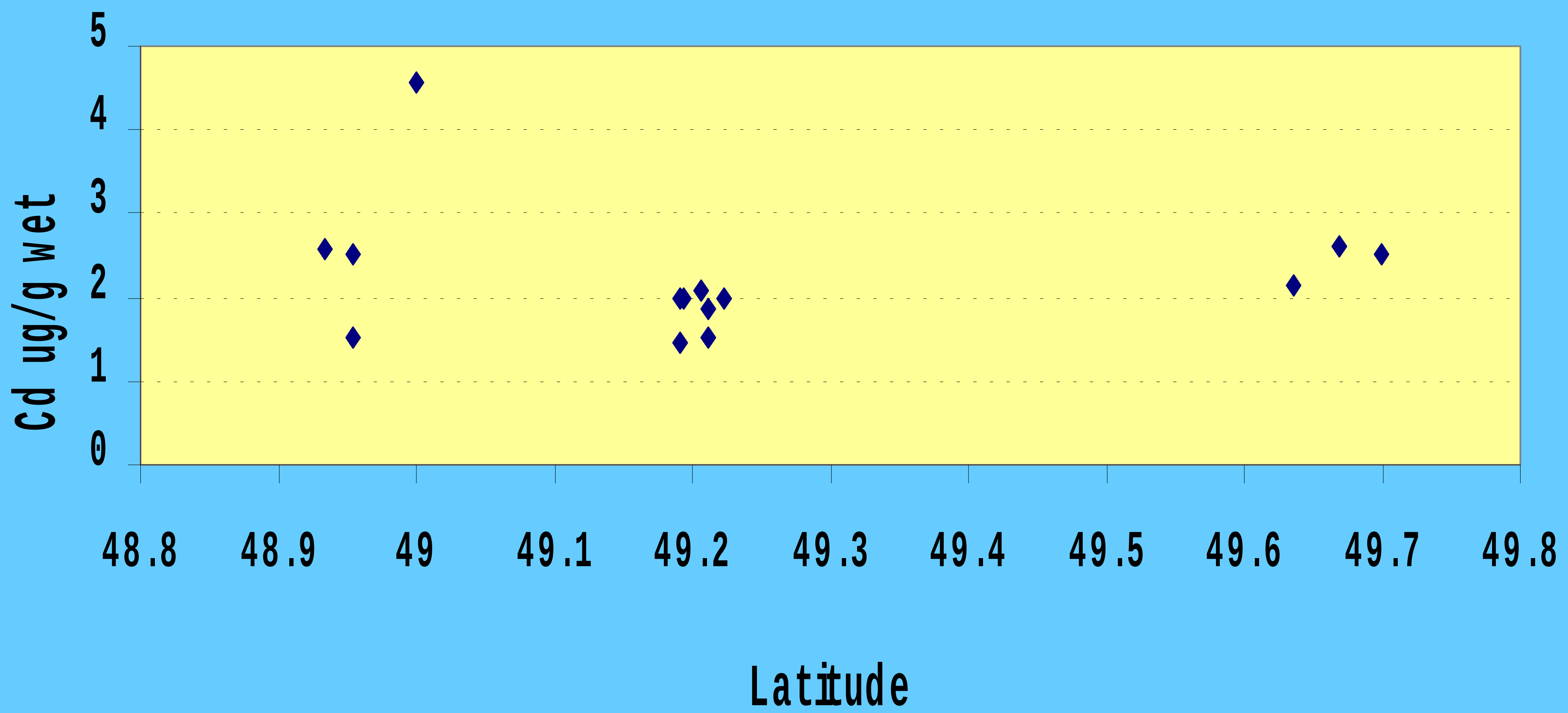
Geographic Distribution of CFIA 2000 Cd in Cultured Oysters



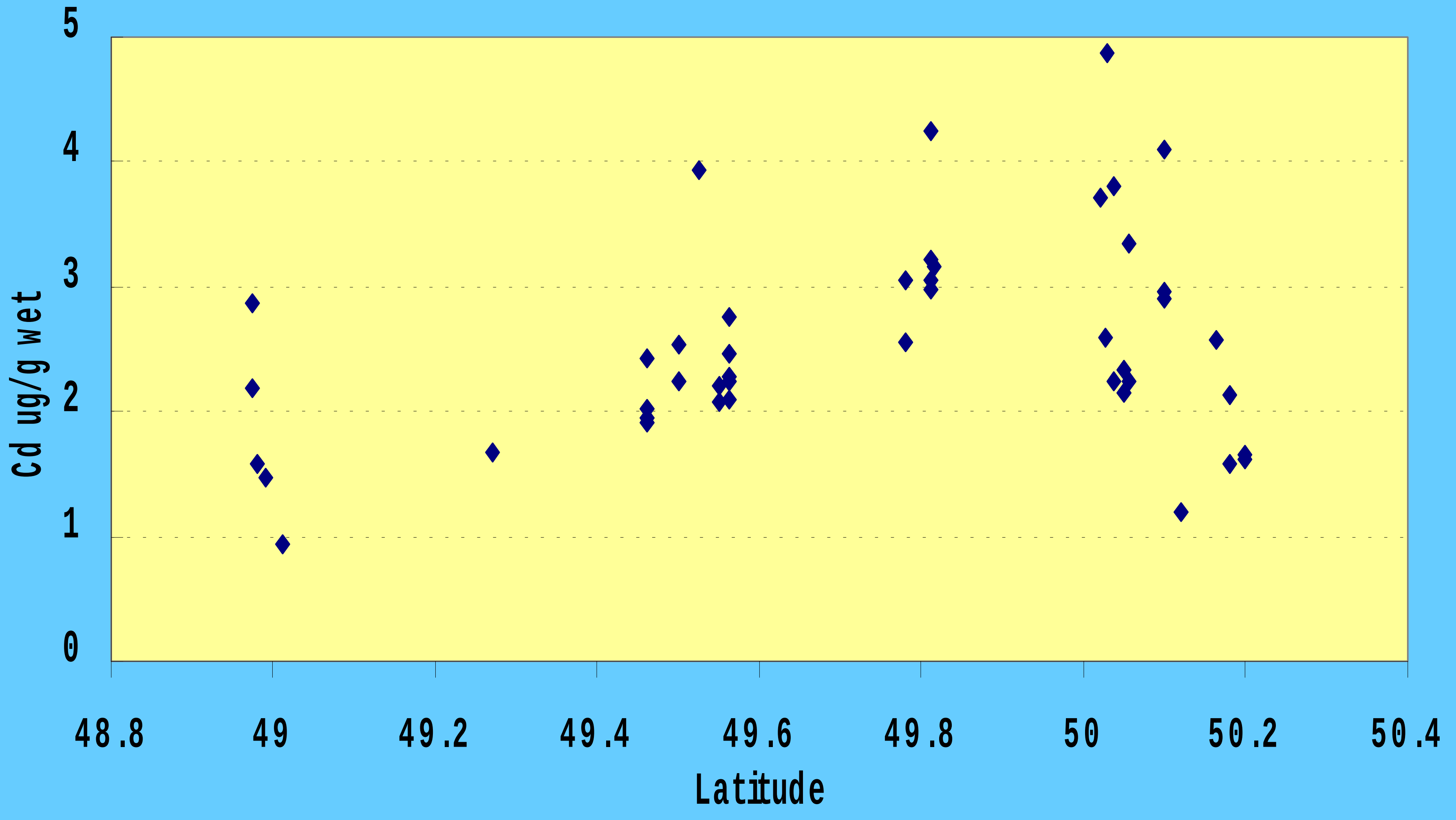
CFIA 2000: All Data, Cadmium in Oysters in Relation to Latitude



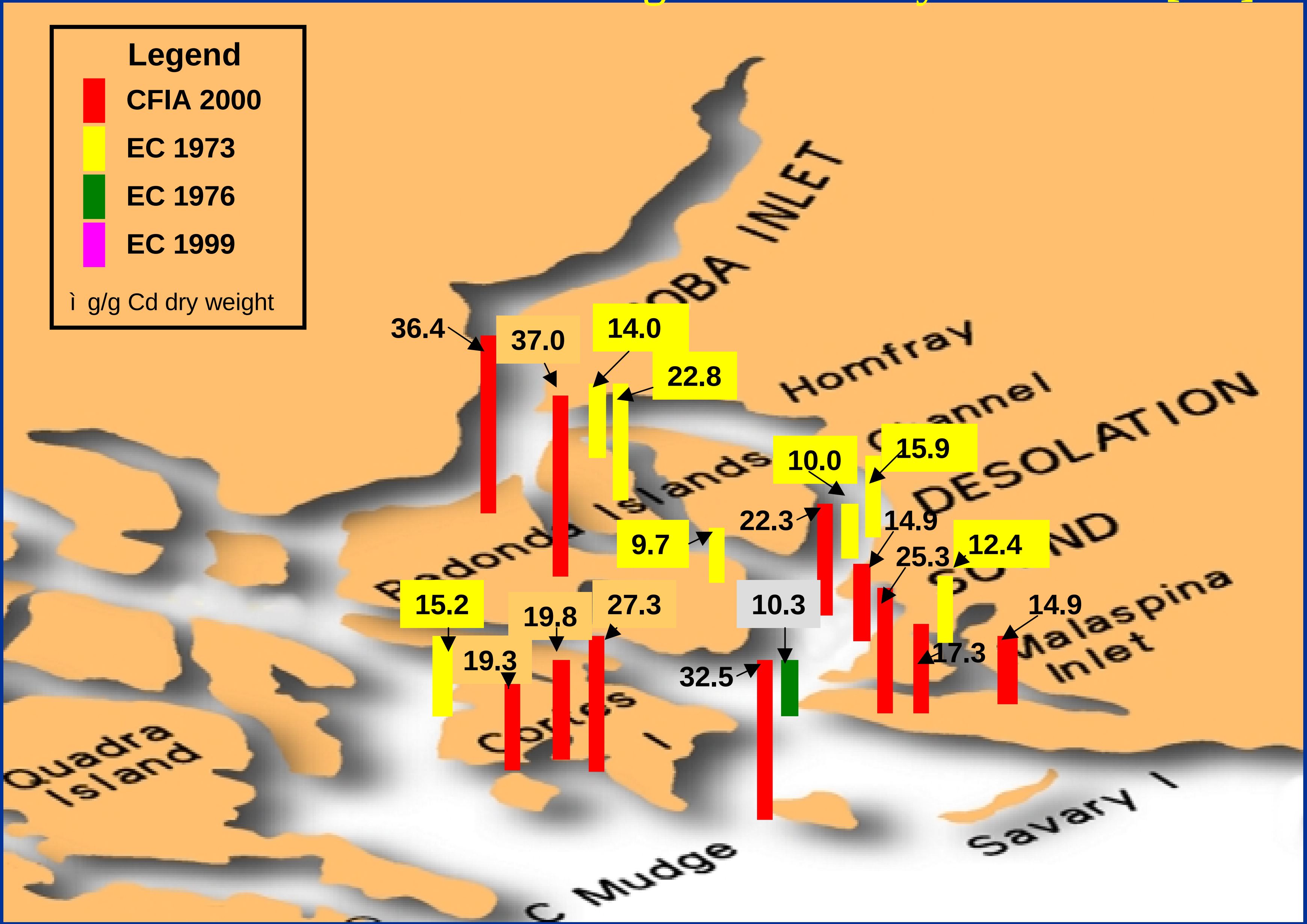
CFIA 2000 Data: Cadmium in Oysters, West Coast of Vancouver Island, Variation with Latitude



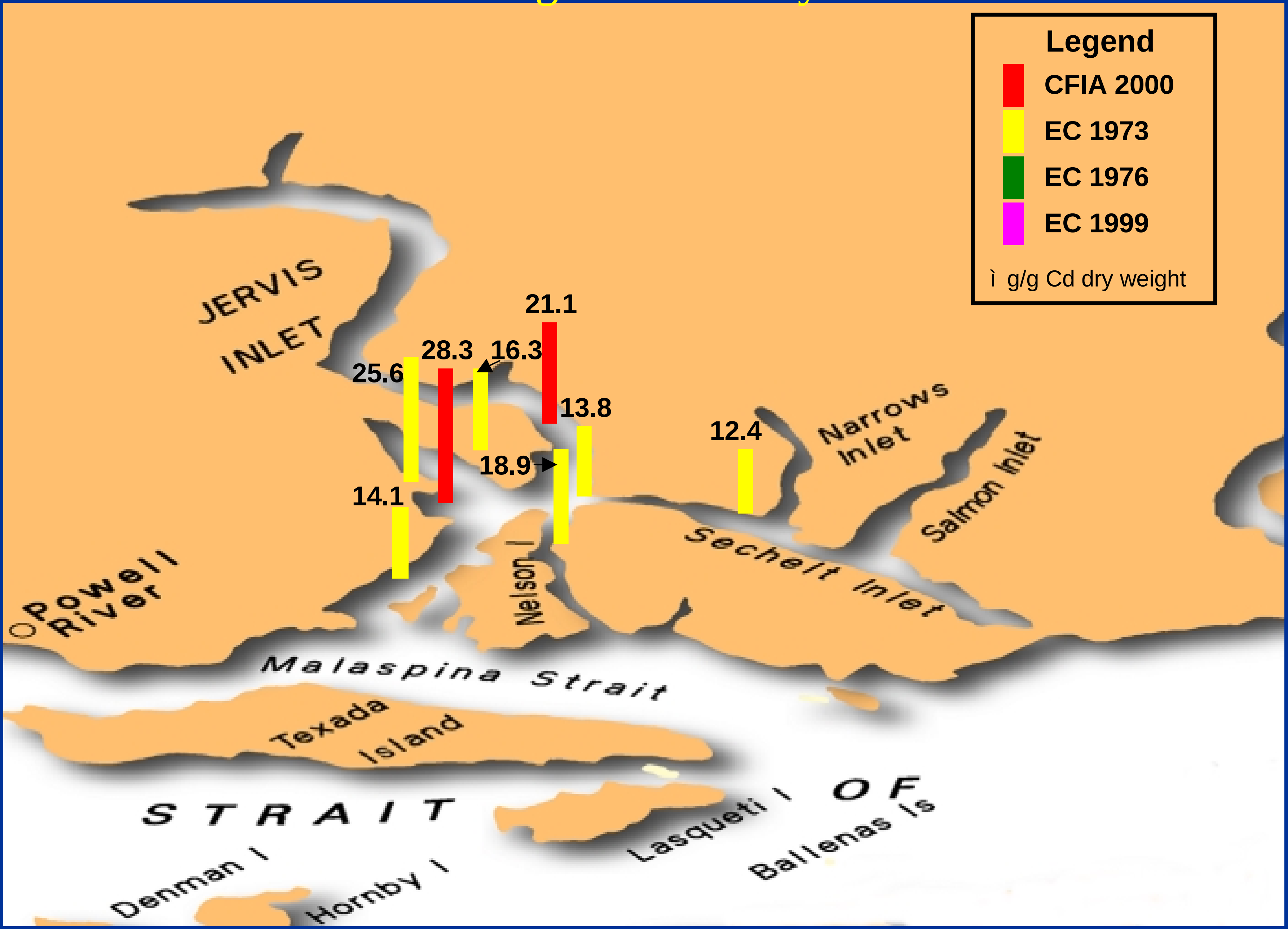
CFIA 2000: Cadmium in Oysters Strait of Georgia, Variation with Latitude



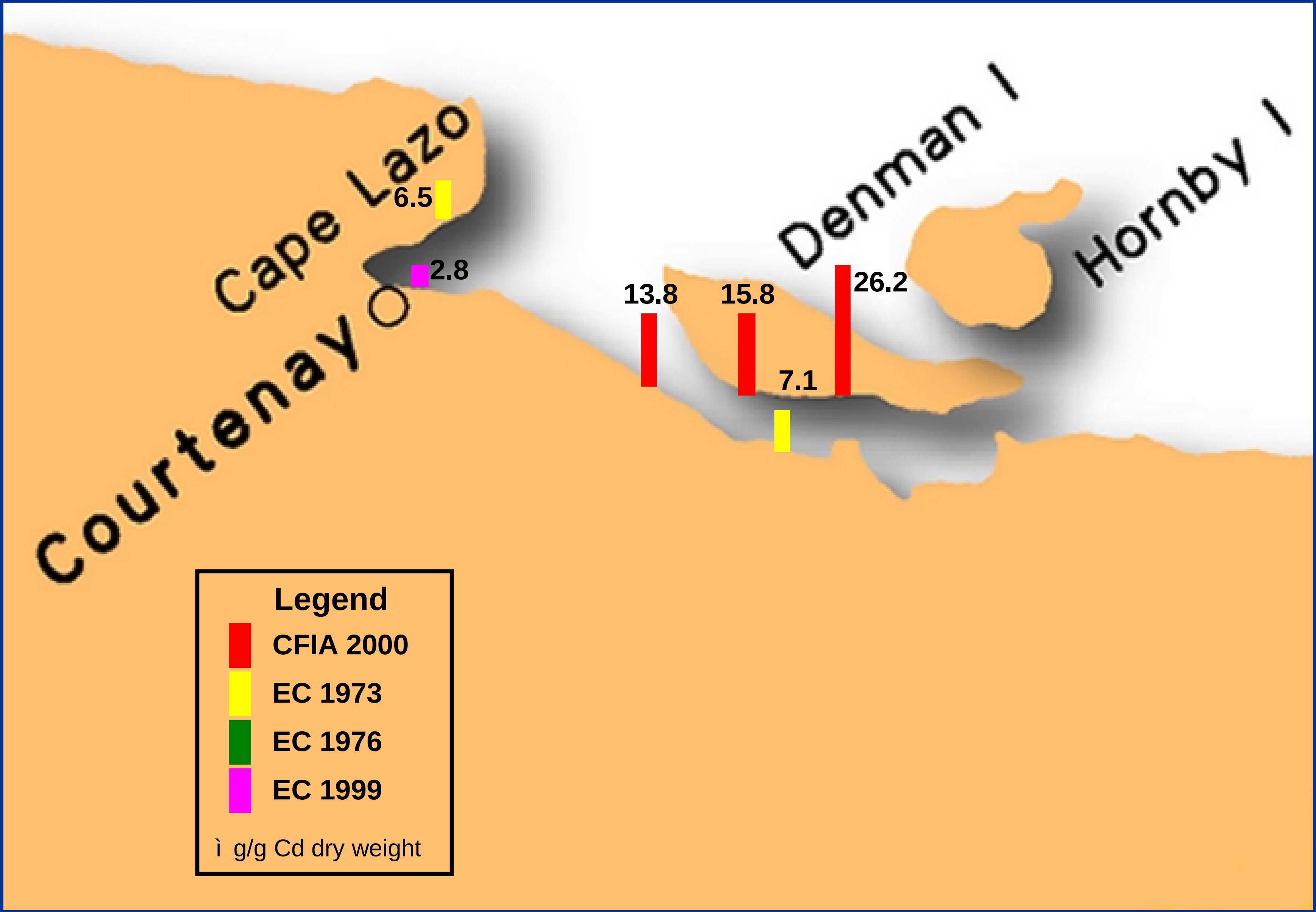
Desolation Sound Showing Historically Elevated [Cd]



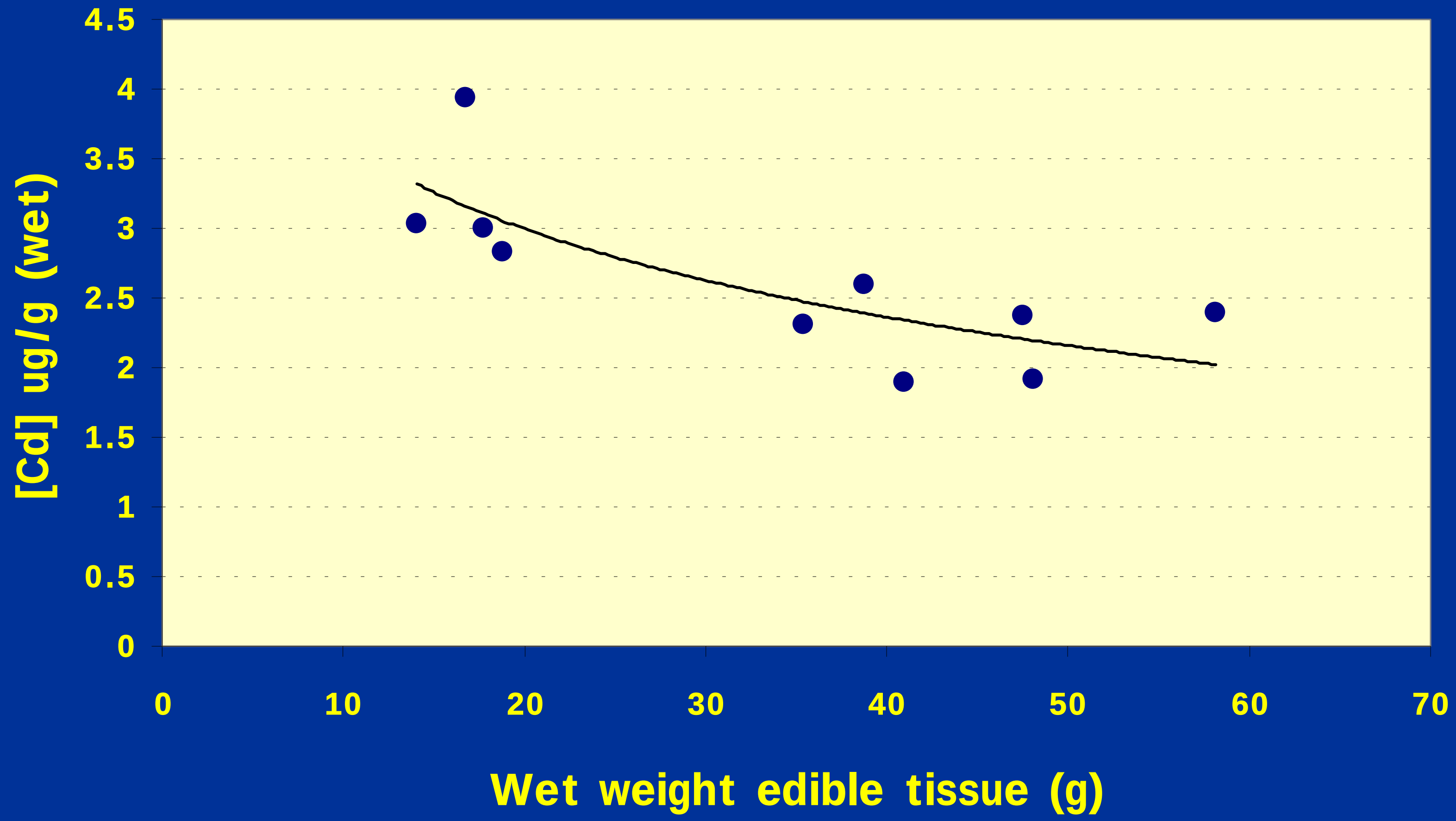
Jervis Inlet Showing Historically Elevated Cadmium

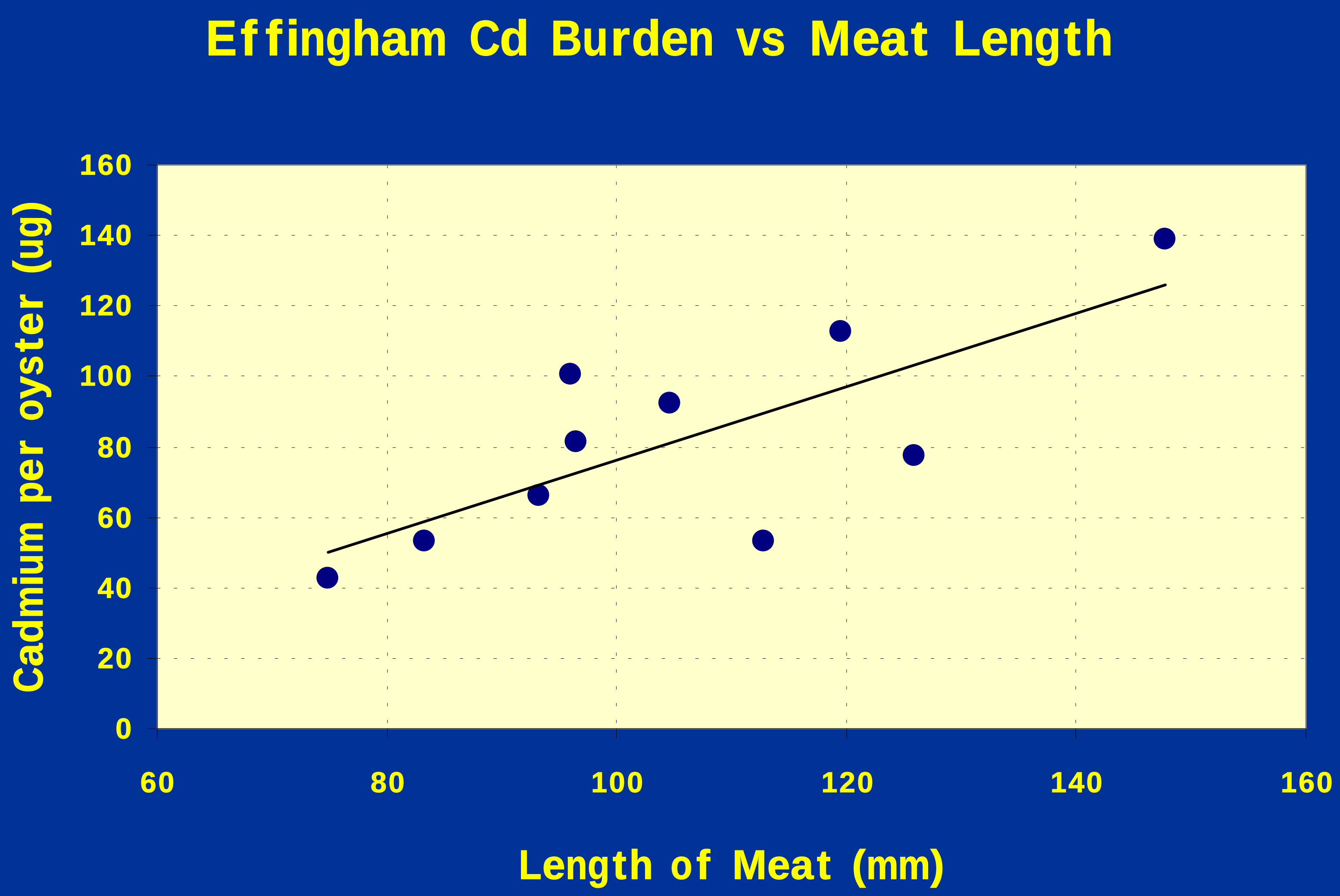


Contrast of Historical Wild with CFIA 2000 Data

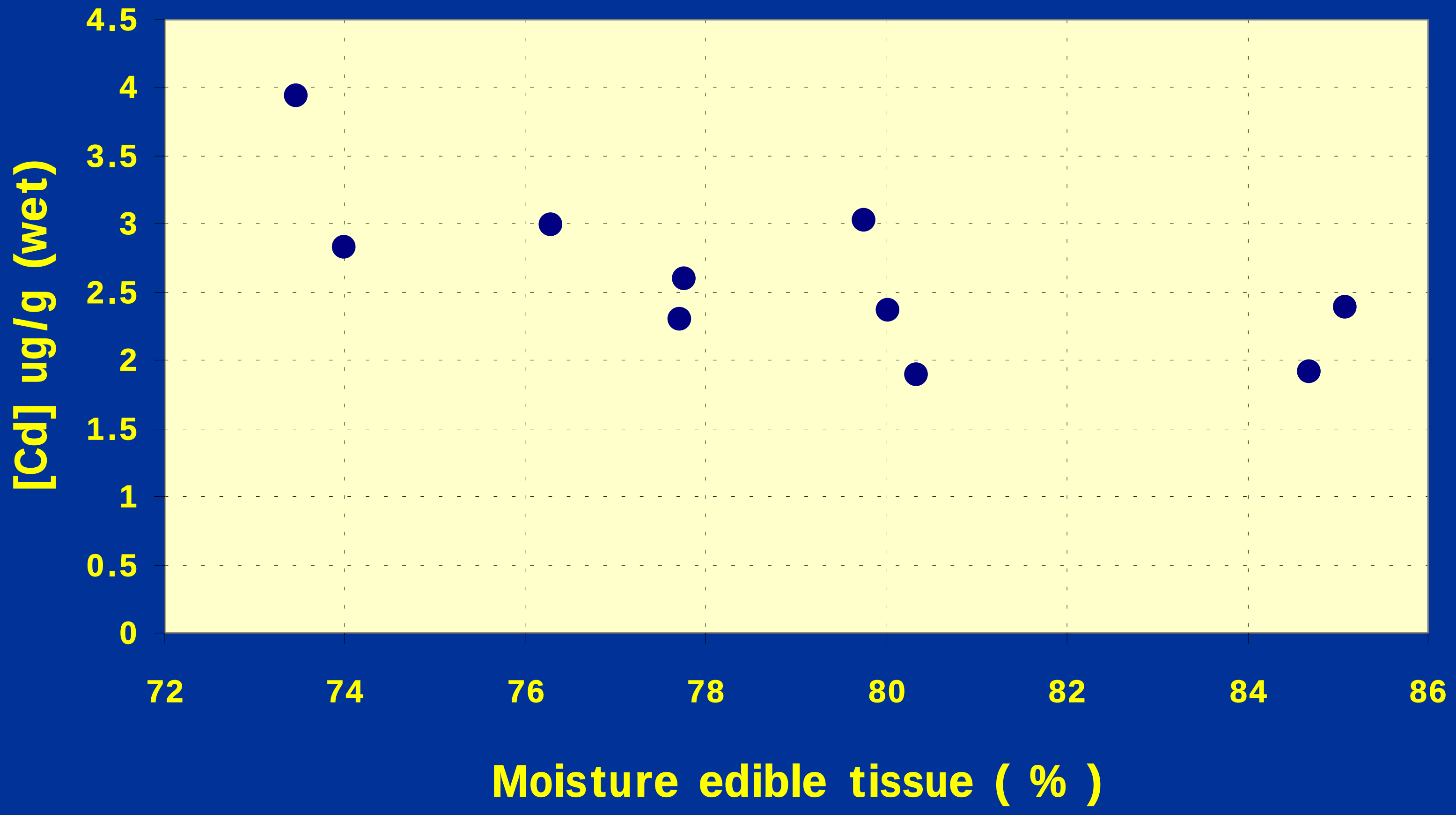


Effingham Wet Weight vs Cadmium




Effingham Cd Burden vs Meat Length
Cadmium per oyster (ug)
0
20
40
60
80
100
120
140
160
60
80
100
120
140
160
Length of Meat (mm)

Effingham % Moisture vs Cadmium



US Food and Drug Administration
Center for Food Safety & Applied Nutrition
Guidance Document for Cadmium in Shellfish, 1993

USA Daily Intake*

Food		10.0 ug
Water		1.2 ug
Air		0.5 ug
Smoking	1 pckg	10.0 ug

TOTAL 21.7 ug

* Not including shellfish

Fate of Ingested Cadmium

- 5% Gastrointestinal Absorption.
- Cadmium > Liver> hepatocytes synthesize Metallothionine (MT)
- Cd in plasma bound to MT> kidney > filtered from plasma then reabsorbed into cells of kidney tubules.
- Failure of tubule function > Proteinuria
- Half Life in kidney 14-44 years
- Critical threshold kidney cortex 180-220 ug
- Chronic exposure accelerates loss of renal capacity in elderly

Tolerable Daily Intake:

FDA 55 ug/day ; WHO 60 ug/day

MEAL OF OYSTERS AT HK LIMIT

6 oysters x 50 g/oyster x 2 ug Cd/g = **600 ug Cadmium**

Weekly Intake Limit from All Sources

USFDA 385 ug

WHO 420 ug

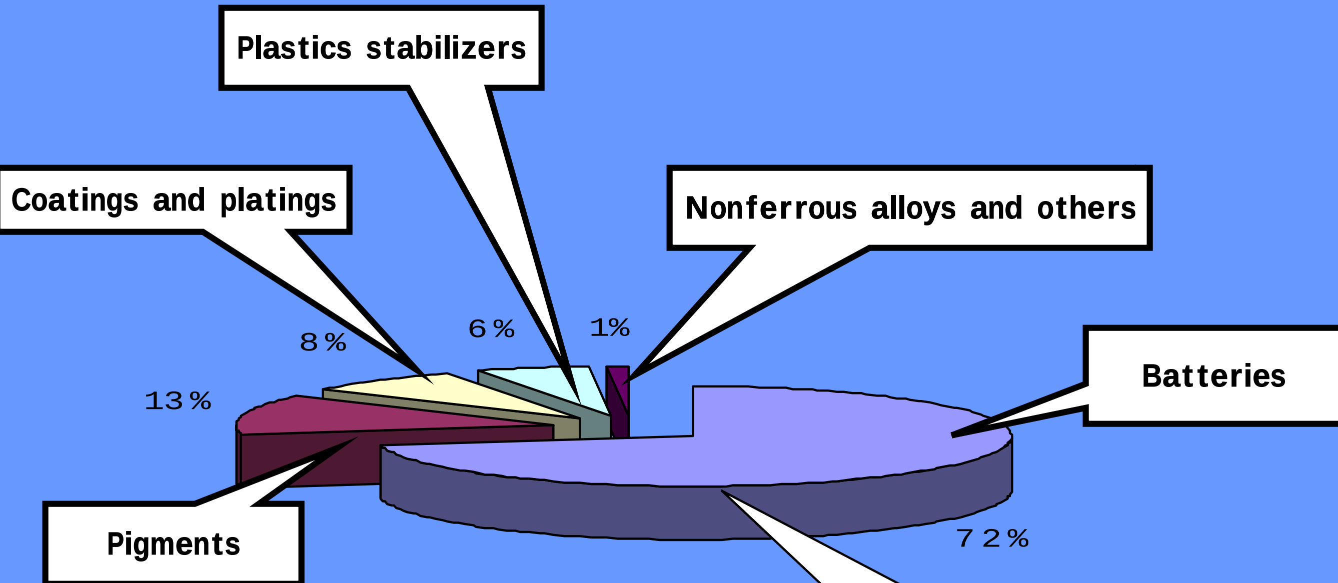
FDA Guidance Document for Cadmium in Shellfish, 1993

- Not a Regulation.
- Some interpret 4 ppm as “acceptable”.
- Meant to be modified.
- Based on outdated information ?
- Needs clarification in context of B.C. data.

FAO/WHO CODEX ALIMENTARIUS 1ppm ?

- What are Regulations in Canada ?
- Canada’s Position at CODEX ? >CFIA>HC

Cadmium Use USA 1998



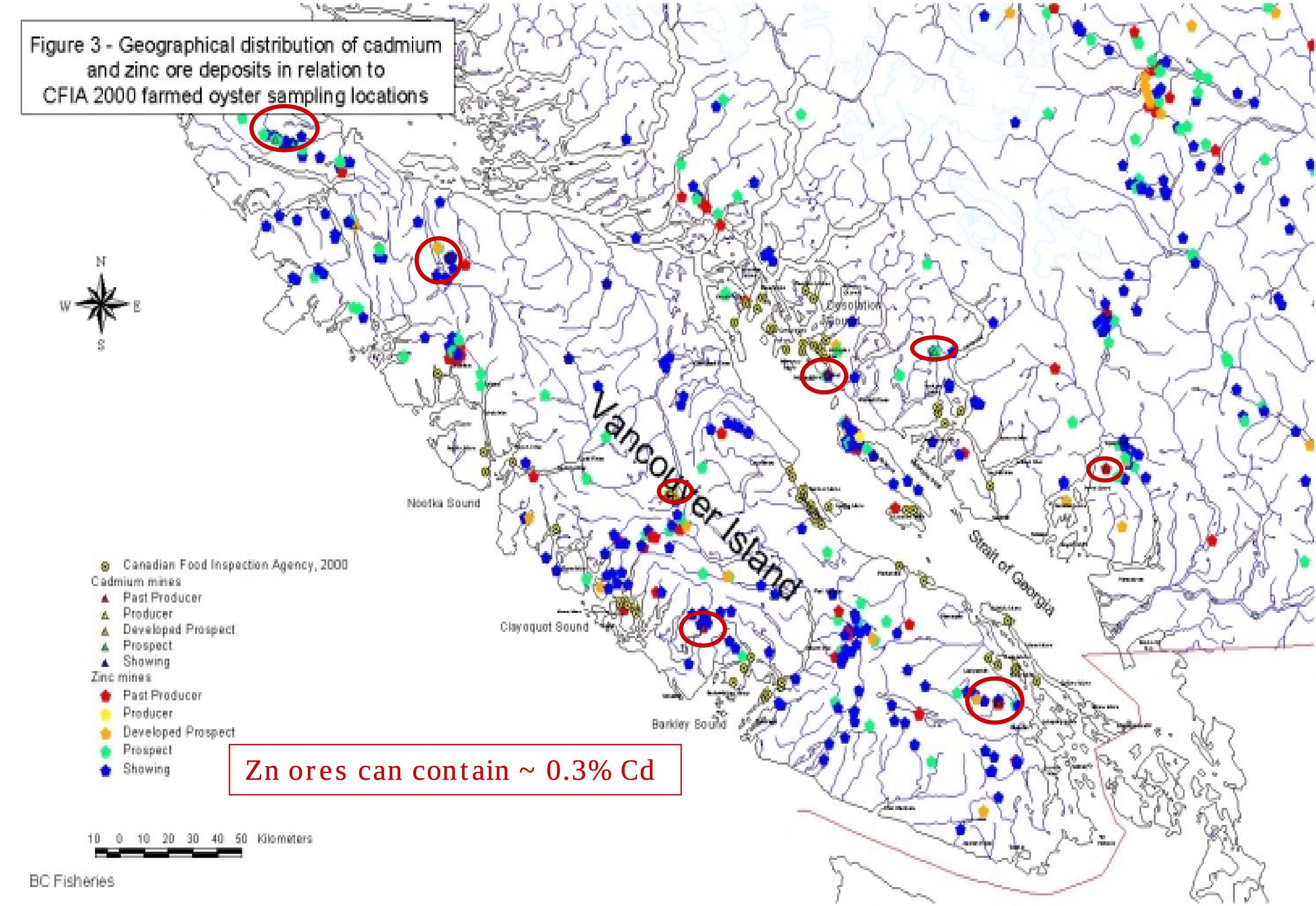
25% is in Industrial Batteries which are recycled @ ~80%

75% in Consumer Batteries most are discarded in municipal solid waste. (12-15% Cd by weight)

Potential Cadmium Sources

- Geology/Mining
- Logging Practices/Forest Fertilization
- Liquid and Solid Municipal Waste
- Stormwater
- Agricultural Input and Fraser River Plume
- Oceanographic Factors
- Culture Equipment
- Fish Farms

Cadmium and Zinc Deposits in Relation to CFIA Oyster Sites



Zn ores can contain ~ 0.3% Cd

RGS Stream Sediment [Cd] in relation to CFIA Oyster Sites

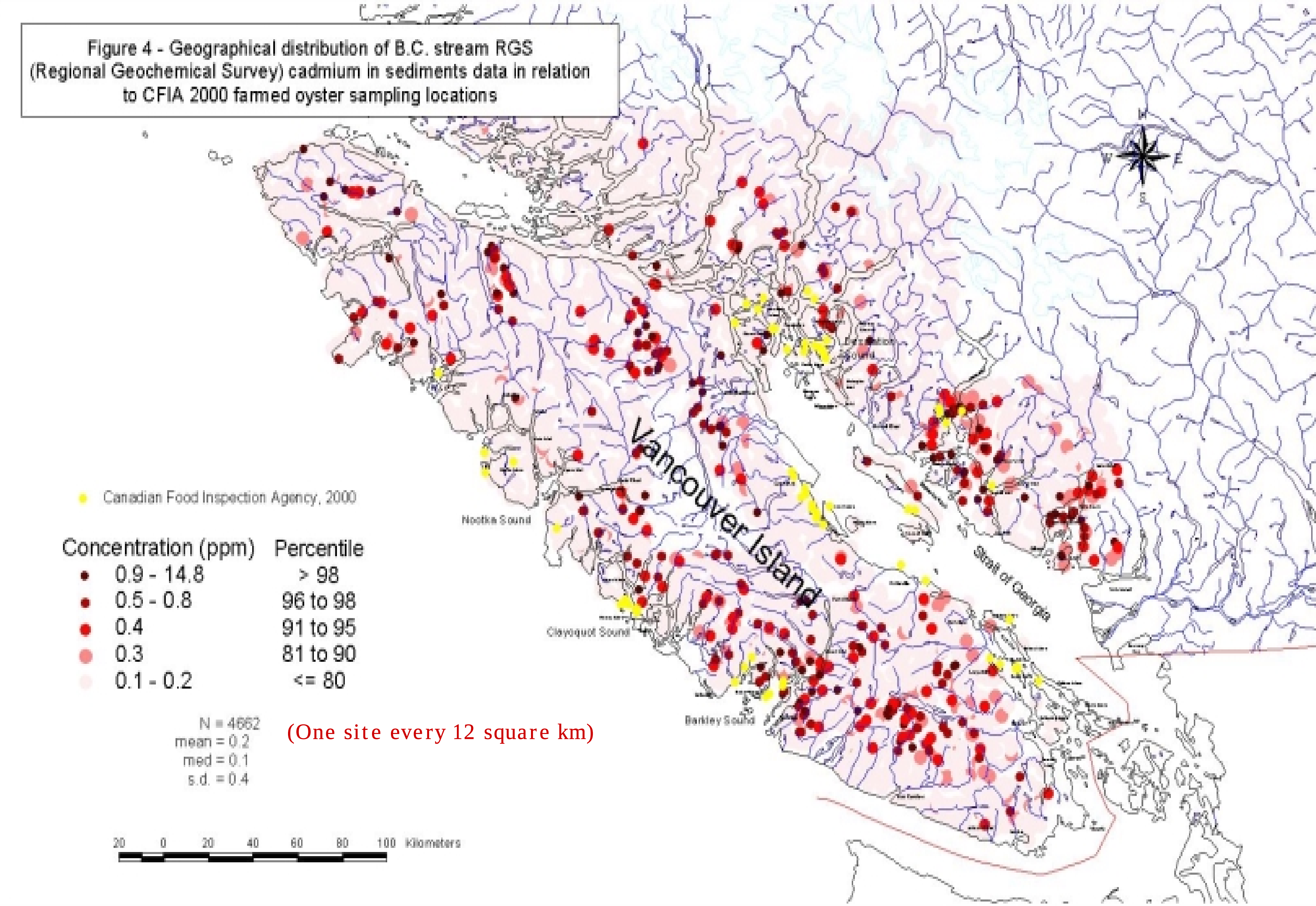
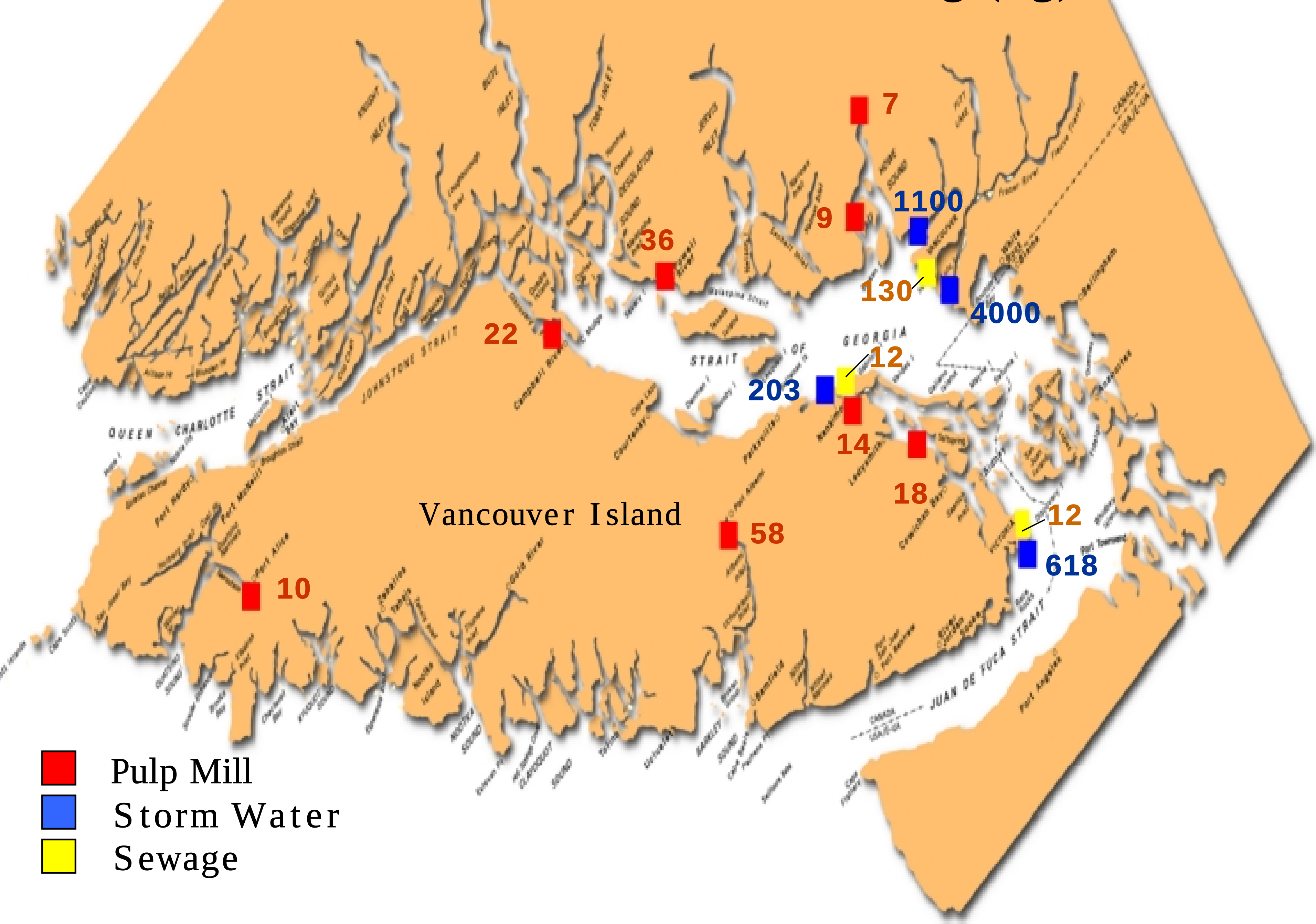


Figure 4 - Geographical distribution of B.C. stream RGS (Regional Geochemical Survey) cadmium in sediments data in relation to CFIA 2000 farmed oyster sampling locations

Estimated Annual Cd Loading (kg)



Cadmium in Taylor Shellfish Company Oysters Washington, USA

(A few samples from 1993-94)

DFO Institute of Ocean Sciences

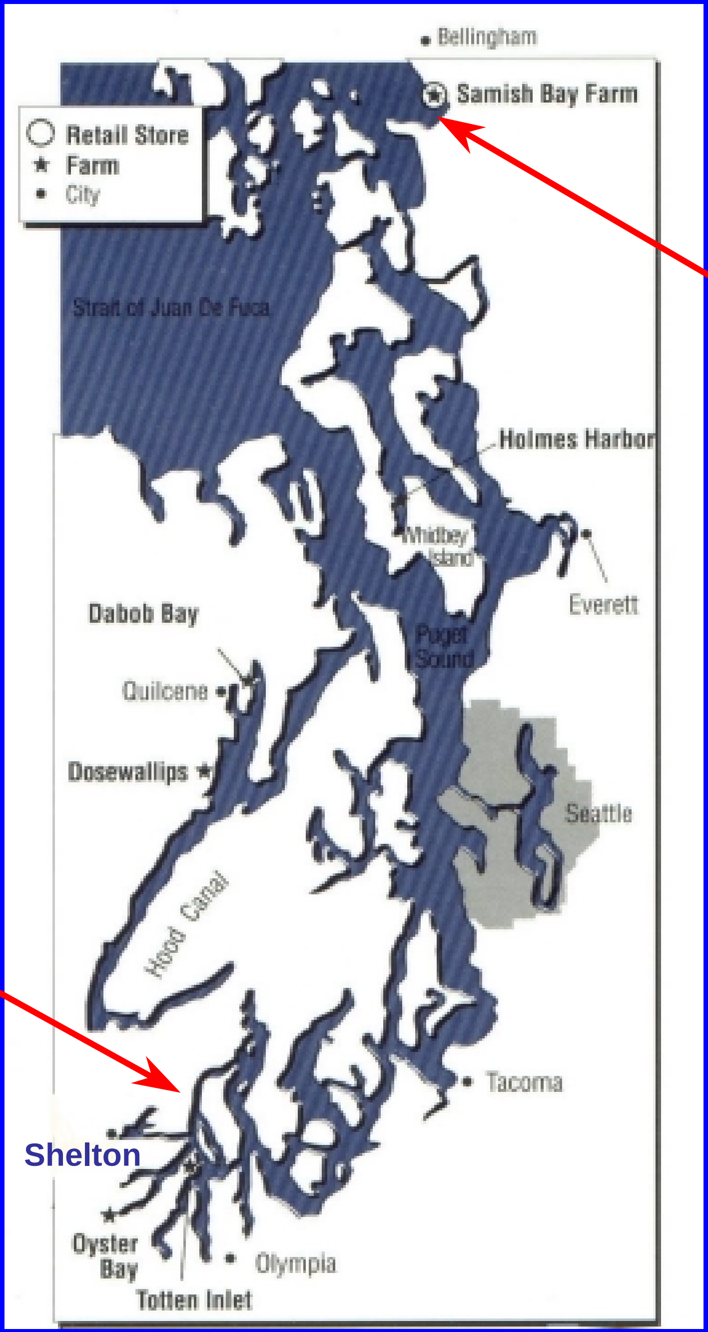
Cadmium Workshop

March 6, 2001

Taylor Shellfish Company Oyster Cadmium Levels

Sample	Location	Date	Cadmium wet wt. (ug/g)	Cadmium dry wt. (ug/g)
oyster	Samish Bay	12/7/93	1.50	10.00
oyster	Samish Bay	12/7/93	0.65	4.30
oyster	Samish longline	4/3/94	1.64	10.90
oyster	Samish bottom	4/3/94	2.09	13.90
mud	Samish	4/3/94	0.04	0.26
oyster	Pickering Pass	4/3/94	0.66	4.39

Puget Sound Washington

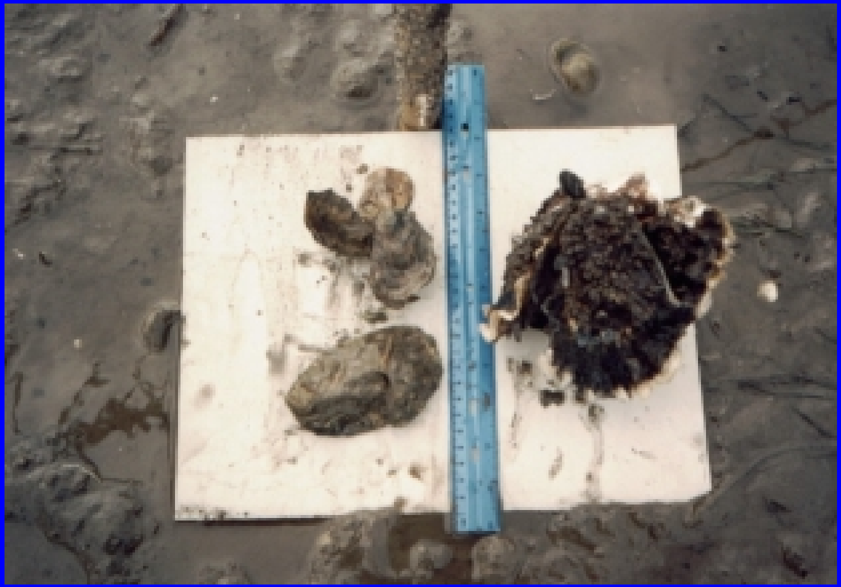


Samish Bay

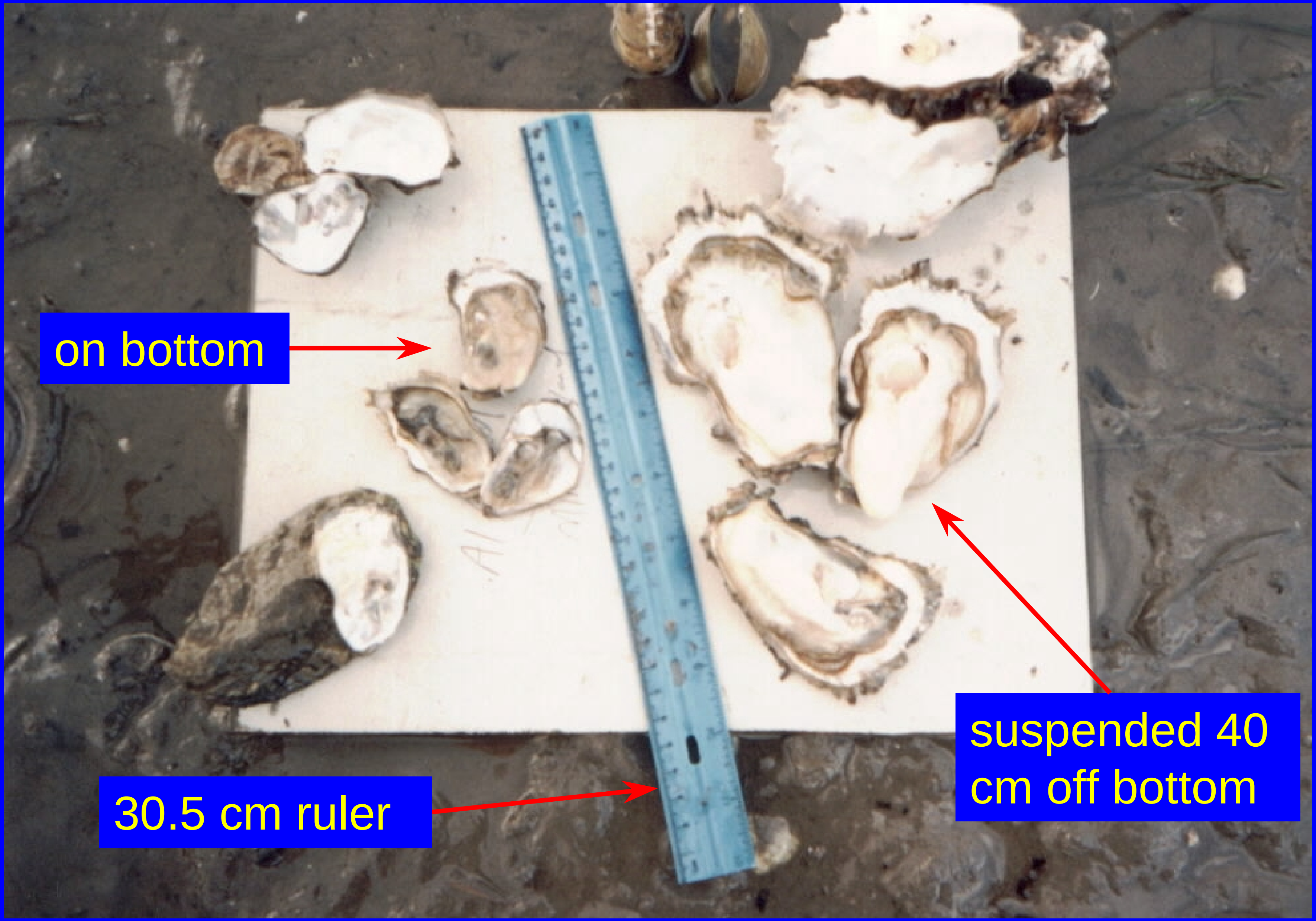
Pickering Pass

Why were we looking?

Dramatic meat and growth variances longline vs bottom



18 month old Pacific oysters



18 month old Pacific oysters

Why am I here?

Taylor Fine Foods Ltd.

Site Selection Considerations for Shellfish Farming

Bill Heath, Ph.D., P.Ag.
Shellfish Production Specialist
BC Fisheries

BC Fisheries Mandate

- BC Fisheries, part of the Ministry of Agriculture, Food and Fisheries, leads the provincial government’s efforts to build and sustain healthy fish populations **and to develop and diversify the fisheries and aquaculture sectors.**

Seafood Diversification

- Diversification of the seafood sector is a priority for the provincial government, with the objective of achieving sustainable social and economic benefits for workers, processors and coastal communities. **Seafood diversification is defined broadly to include (among others):**
  - Aquaculture
  - New and emerging global markets
  - Product Quality

Shellfish Site Selection: It's Everything!

- Choose a site for the wrong reasons, and you will likely spend the rest of your career trying to compensate for its problems.
- Factors to consider include: **biophysical** and **suitability** criteria.

“Site Capability Index” or **SDI**

- Combines these criteria in a numerical index [$0 \leq SDI \leq 1$]
- Most of the BC coast is now surveyed for Shellfish Capability for Pacific oyster, Manila clam and Japanese scallop
- Caution: these are baseline surveys only!
- More information (e.g. local knowledge; or Cd levels!) and an intensive sampling program for site-specific evaluation should also be considered.

Socio-economic Factors

- **Infrastructure & marketing considerations affecting business viability**
  - Growing water classification under CSSP (Fecal coliforms, Biotoxins)
  - Power (Hydro grid or self-generated?)
  - Labour pool (availability?)
  - User conflicts
  - Economies of Scale
- **Points to the need for sound Business Planning along with Site Selection**

Examples from Shellfish Culture Capability Appraisals

- Information for Site Capability determination is based on oceanographic & beach survey methods outlined in “Assessing Shellfish Culture Capability in Coastal BC: Sampling Design Considerations for extensive Data Acquisition Surveys” by Cross 1993.

Shellfish Culture Capability Parameters used in Surveys 1

- Salinity -summer/winter extremes (bottom culture/ off-bottom culture)
- Water Temperature: summer/winter extremes (bottom / off-bottom culture)

Shellfish Culture Capability Parameters used in Surveys 2

- Relative Exposure or Fetch: distance/direction (bottom culture/ off-bottom culture)
- Intertidal slope/composition: (bottom culture)
- Tidal height or water depth: (bottom culture/ off-bottom culture)

Parameter Estimation

- The procedure for evaluation is described by Cross & Kingzett (1992): “Biophysical criteria for shellfish culture in British Columbia. A site evaluation system.”, based on the Habitat Suitability Index approach.

Specific Examples from Barkley Sound Appraisal Survey

- Minimum winter salinity (0-5m) : can be limiting for survival/growth of cultured shellfish
- See presentation of Barron Carswell for suitability maps of Barkley Sound

Additional Considerations

- Carrying or Productive Capacity: what quantity of shellfish can be grown in a given area without negative impacts to existing operations or the environment?
- Cadmium levels for various natural sources (within tolerable limits for markets?)

The BC Shellfish Development Initiative process and the relevance of cadmium concentration data in BC cultured oysters to industry development

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A/Manager Resource and Community Planning Unit
Sustainable Economic Development Branch
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Victoria, BC
V8W 9M2
☎(250)356-2237
(250)356-7280
Barron.Carswell@gems8.gov.bc.ca

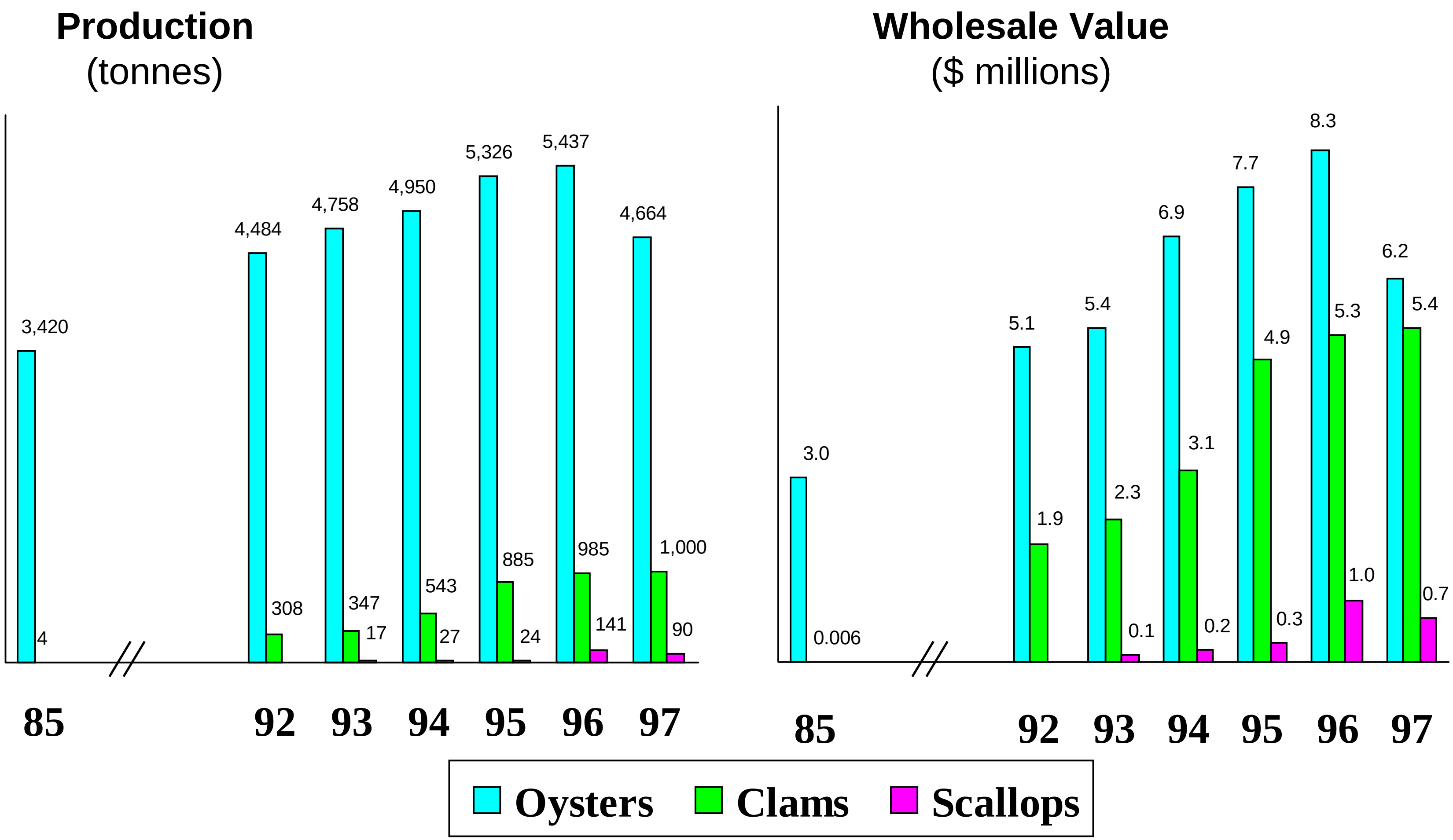
1997 Industry Snapshot

258 companies	***423 crown land tenures***	***2,115 hectares*** ➢ ***½ intertidal*** ➢ ***½ deepwater***	***1,000 full-time and part-time jobs (approx.)***

Species	Production (tonnes)	Wholesale Value ($ million)
Oysters	4,700	6.2
Clams	1,000	5.4
Scallops	90	0.7
Total	5,790 tonnes	$12.3 million

For comparison, Washington State's annual production of farmed shellfish is valued at about $80 million.

Shellfish Aquaculture: Industry Snapshot
Production

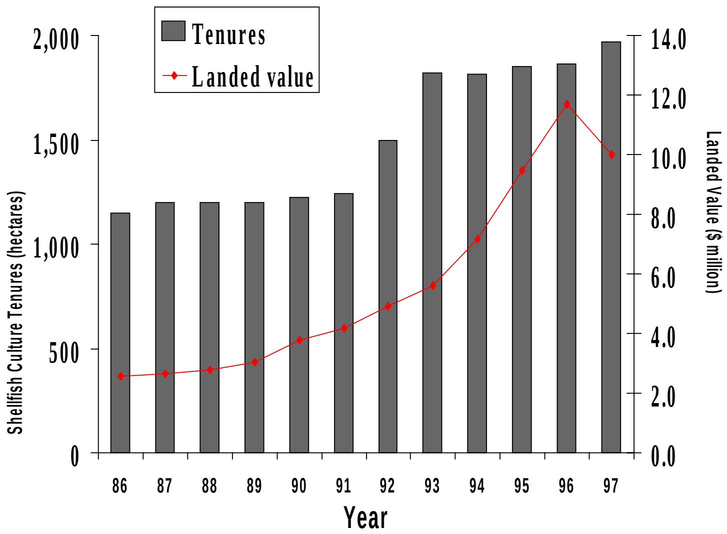


Shellfish Aquaculture: Industry Snapshot

Notes

- Production values fell in 1997 due to closures resulting from a *Vibrio parahaemolyticus* outbreak that affected the entire coast. As a result marketing of product was curtailed.
- New shellfish culture species are coming onstream and show promise (geoduck clam, giant rock scallop) - many provide a high value product.
- Commercial mussel culture is now underway.

Shellfish Aquaculture: Industry Snapshot
Tenure area and productivity

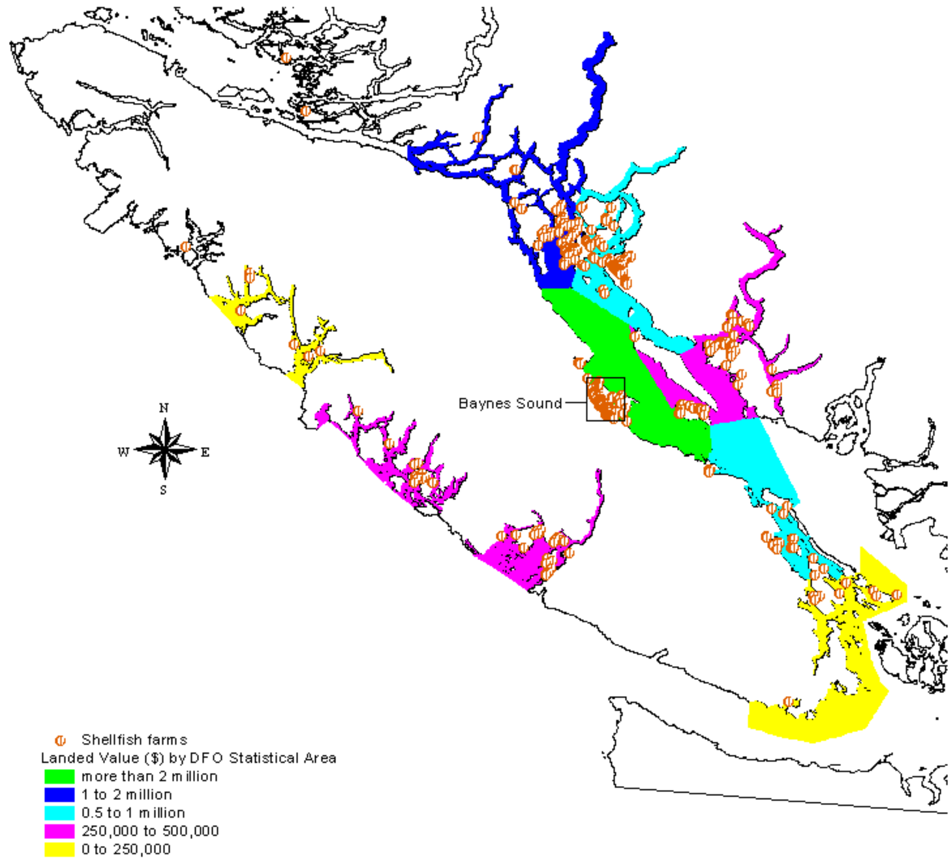


- Recent growth due primarily to more intensive cultivation of sites - trend can not continue indefinitely.
- 1993-1995: technological improvements increased productivity by 28% for shucked oysters and 45% for clams.
- Key development constraint - access to new capable aquatic lands for culture.
- 2,115 hectares is less than 10 square miles.

Shellfish Aquaculture: Industry Snapshot
Distribution

- Shellfish culture is a “South Coast” activity with 90% of production coming from sites located on the east coast of Vancouver Island. There is pilot work underway on the North Coast to establish growth rates and site suitability.
- Highest concentration of farms in the Baynes Sound area - which produces 39% (oysters) and 55% (clams) of the total industry landed value for each species.
- Production comes entirely out of rural coastal areas, where farms offer economic opportunities to local communities.

Geographic Distribution & Landed Value of Cultured Shellfish 1997



Total 1997 Landed Value: $10 million (preliminary)

Shellfish 2000

Provincial/Federal Government Partners in Development

BCFisheries

- Industry development

BCMELP

- Crown land policy

BCALC

- Crown land tenure

DFO

- Industry development
- Interface with wild fishery

CFIA

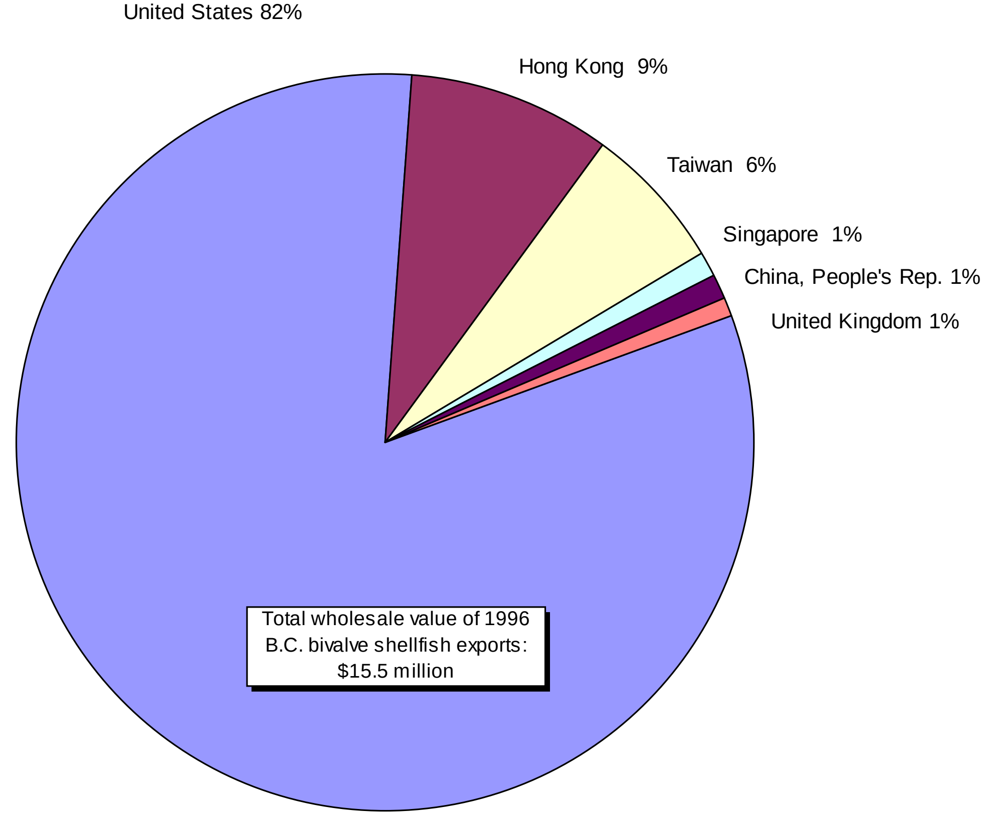
- Product safety

DOE

- Water quality

Figure 3 **Destination of BC Bivalve Shellfish Exports - 1996**

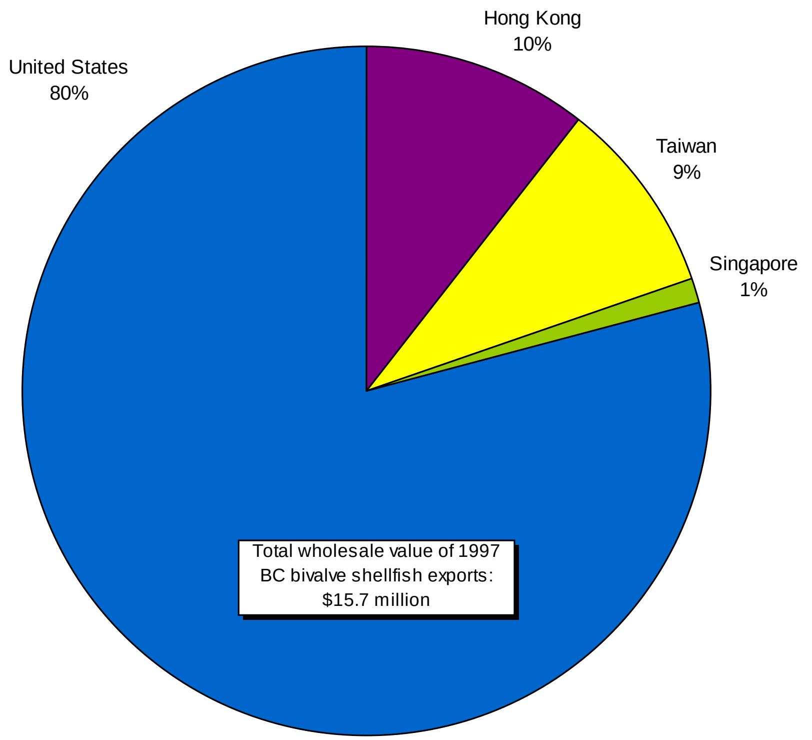
(Includes both wild and farmed oysters, clams and scallops)



Source: *Canadian Exports Statistics By Province, 1996-1995*, Department of Fisheries and Oceans, Ottawa

Figure 3 **Destination of BC Bivalve Shellfish Exports - 1997**[1]

(Includes wild and farmed shellfish)



1 Excludes geoduck clams

Source: *Domestic Exports - 1997,* Department of Fisheries and Oceans, Ottawa

Shellfish 2000
Economic Potential

- Economic Potential of the British Columbia Marine Aquaculture Industry, Phase 1: Shellfish. Coopers and Lybrand. June 1997.
- Potential over next 10 years
  - Increase wholesale value - $13 to $100 million
  - 1,000 new person years employment in coastal communities that face job losses in other resource sectors
  - Seasonal/part-time employment converted to full-time
  - Economic opportunities for First Nations

Shellfish 2000
Economic Potential

Growth can be achieved through:

- Continued productivity improvements
- Culture of new species
- 10% increase in tenures per year for next 10 years (2115 to 4230 hectares)

Shellfish Aquaculture
Opportunities

- Contribute to strengthening the provincial economy
  - create new jobs
  - diversify and enhance the profitability of BC fisheries
  - strengthen regions and coastal communities
  - promoting social stability and regional development
- Small-scale, labour-intensive operations that require little infrastructure and a relatively low level of investment capital.
- Compatible with the coastal environment

Shellfish Development Initiative
Provincial Announcement

- November 24, 1998 - Ministers of Fisheries and of Environment, Lands and Parks announced provincial government support for expansion of shellfish aquaculture.
  - Applications for expansion of farms where culture is already underway to be accepted immediately.
  - Processing of applications for new sites to begin March 1999.
- BC Assets and Land Corporation in Nanaimo will manage the process of expanding existing shellfish tenures, allocating new Crown land tenures and issuing aquaculture licences on behalf of the province.

Shellfish Development Initiative
Objectives

- Realize economic potential of shellfish aquaculture for communities and First Nations
- Enhance utilization of existing tenures
- Improve administrative process for issuance of tenure and aquaculture licenses
  - Consolidate and streamline process
  - Revise the land-application process to remove barriers, enable tenure expansion, provide a fair return for use of public resources
  - Review the existing fee schedule
- Increase number of tenures in 1999-2000 from 450 to 550

Shellfish Development Initiative
Consultation Process

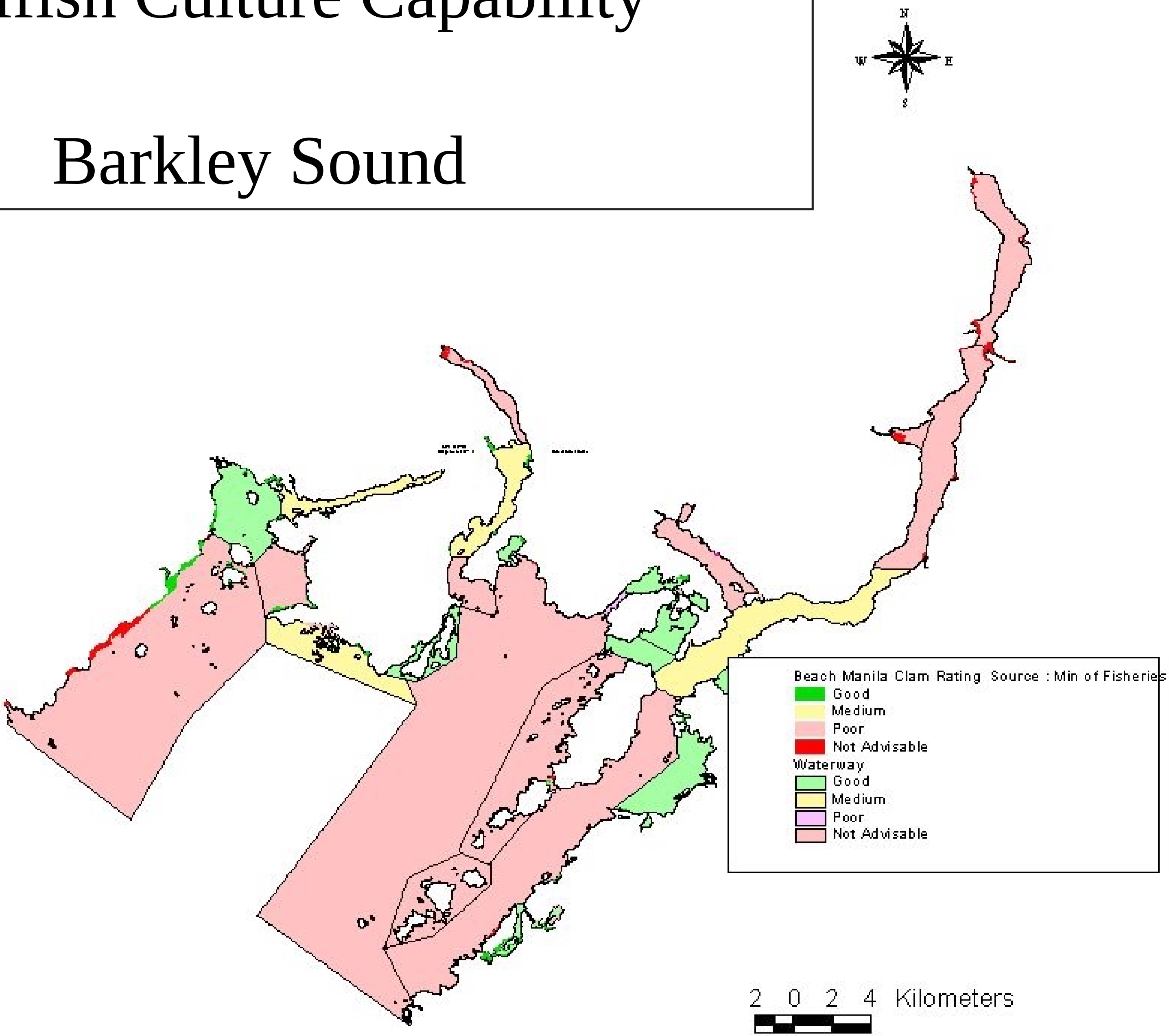
- Development to be preceded by consultation with First Nations, other government agencies, communities, industry
- How and where industry develops will be determined through consultation.
- New sites will be tenured according to:
  - biological capability of the local resource
  - willingness of communities to support the industry.

Shellfish Development Initiative
Steering Committee Process

- Consult with local governments and First Nations to determine where shellfish aquaculture development can occur (e.g. capability ratings, existing resources users)
- Use regional district boundaries and capability assessments to establish regional targets for new tenures
- In consultation, develop site selection and application criteria
- Solicit regional applications for sites with publicly stated selection criteria

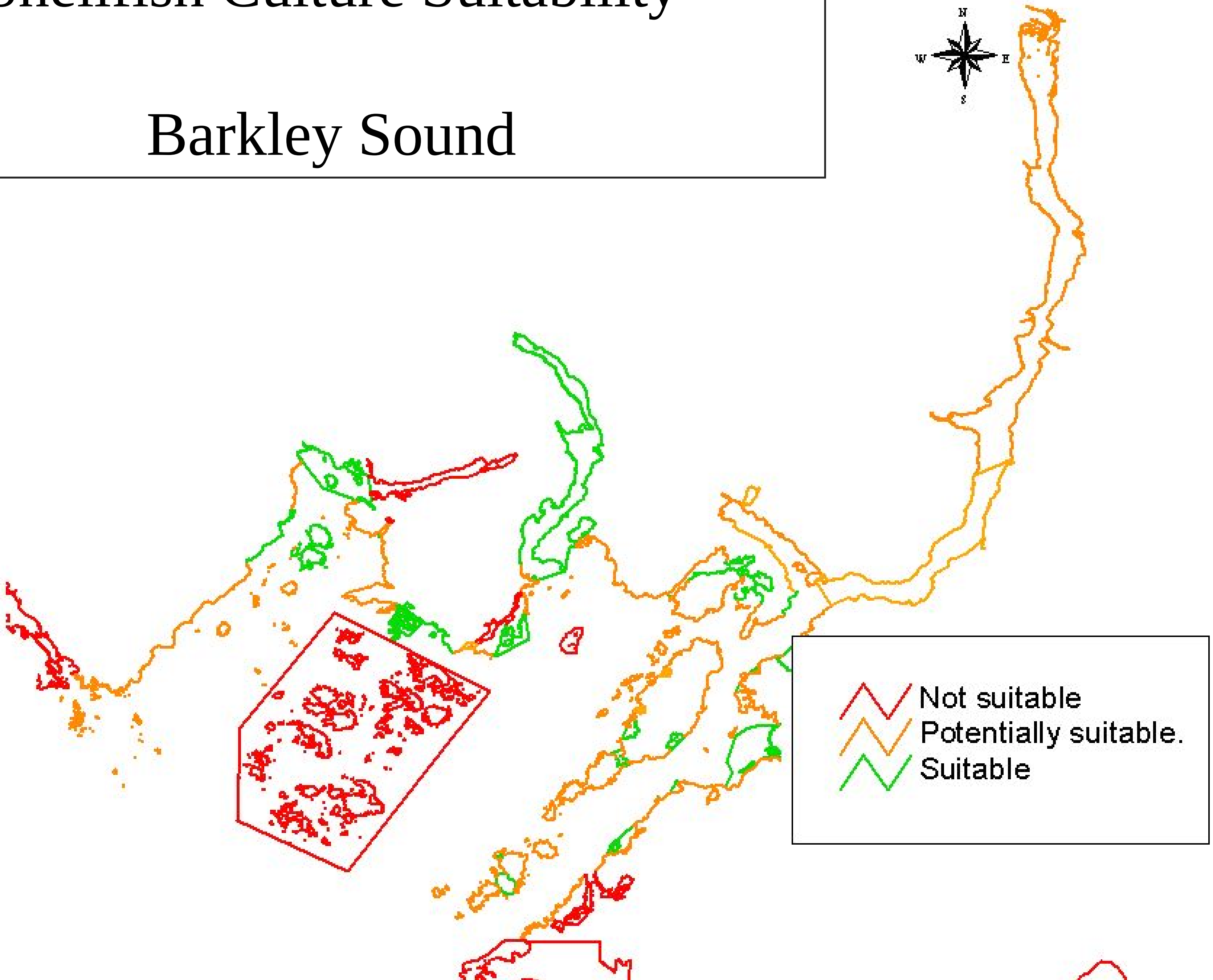
Shellfish Culture Capability

Barkley Sound

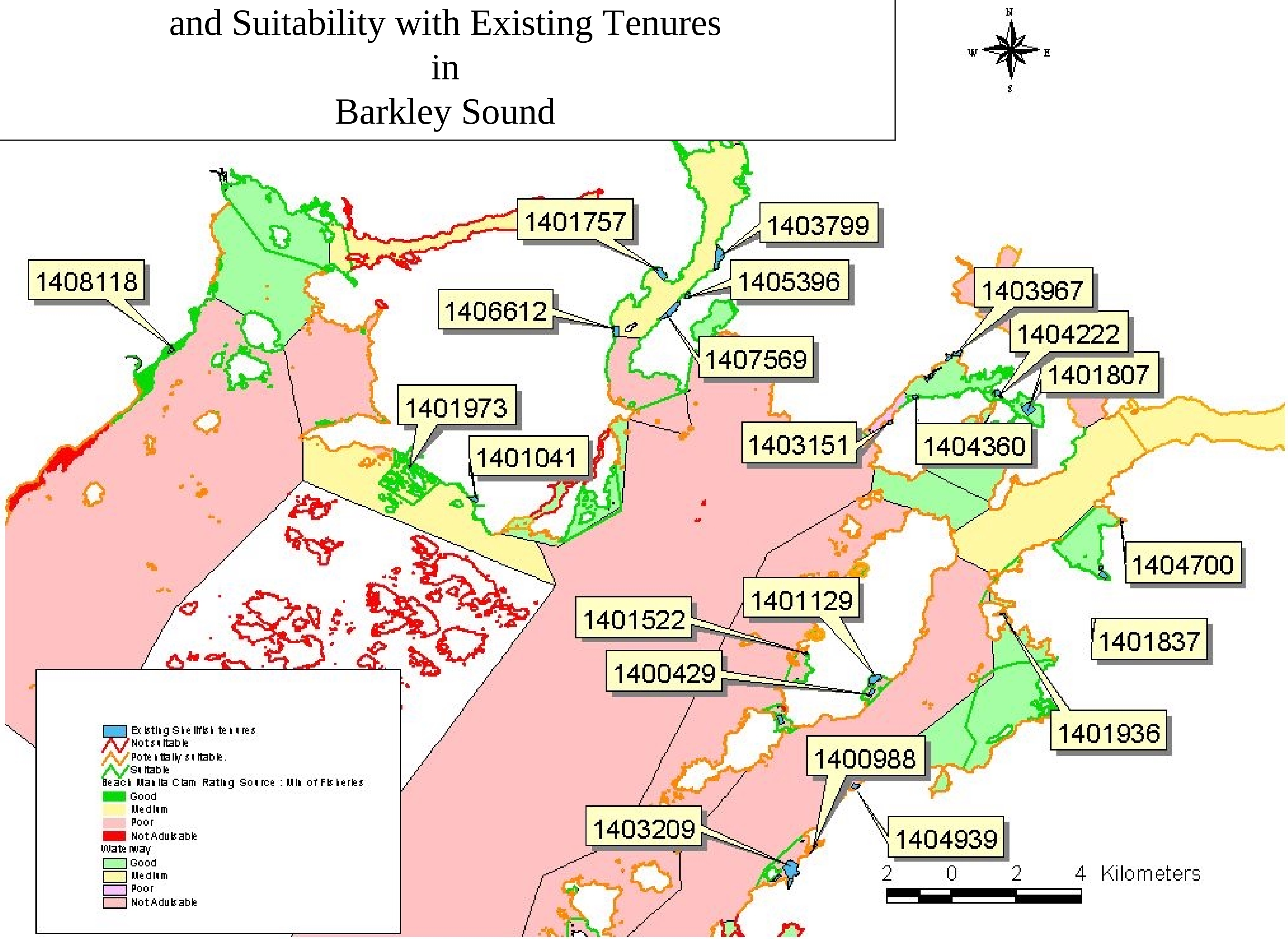


Shellfish Culture Suitability

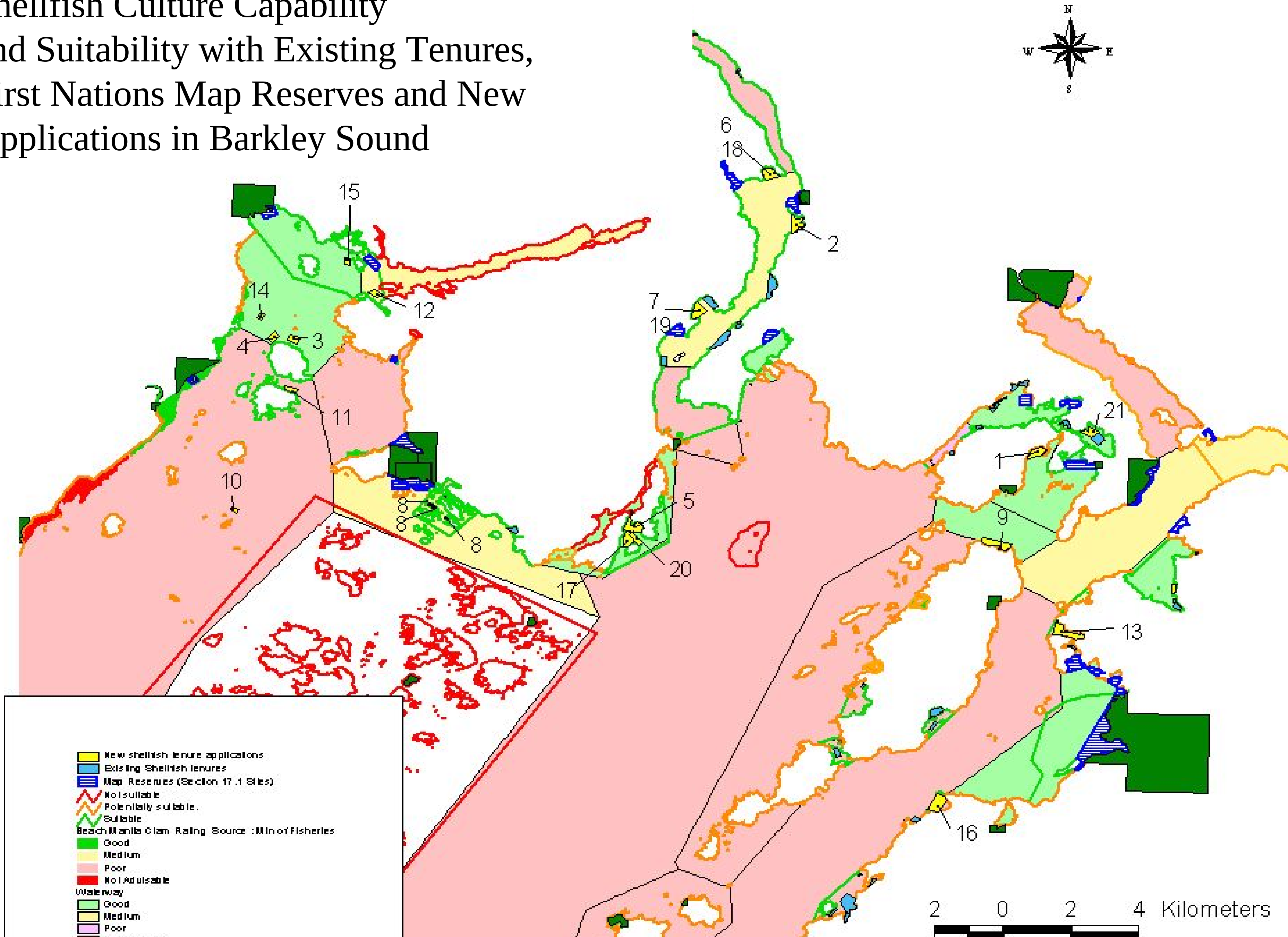
Barkley Sound



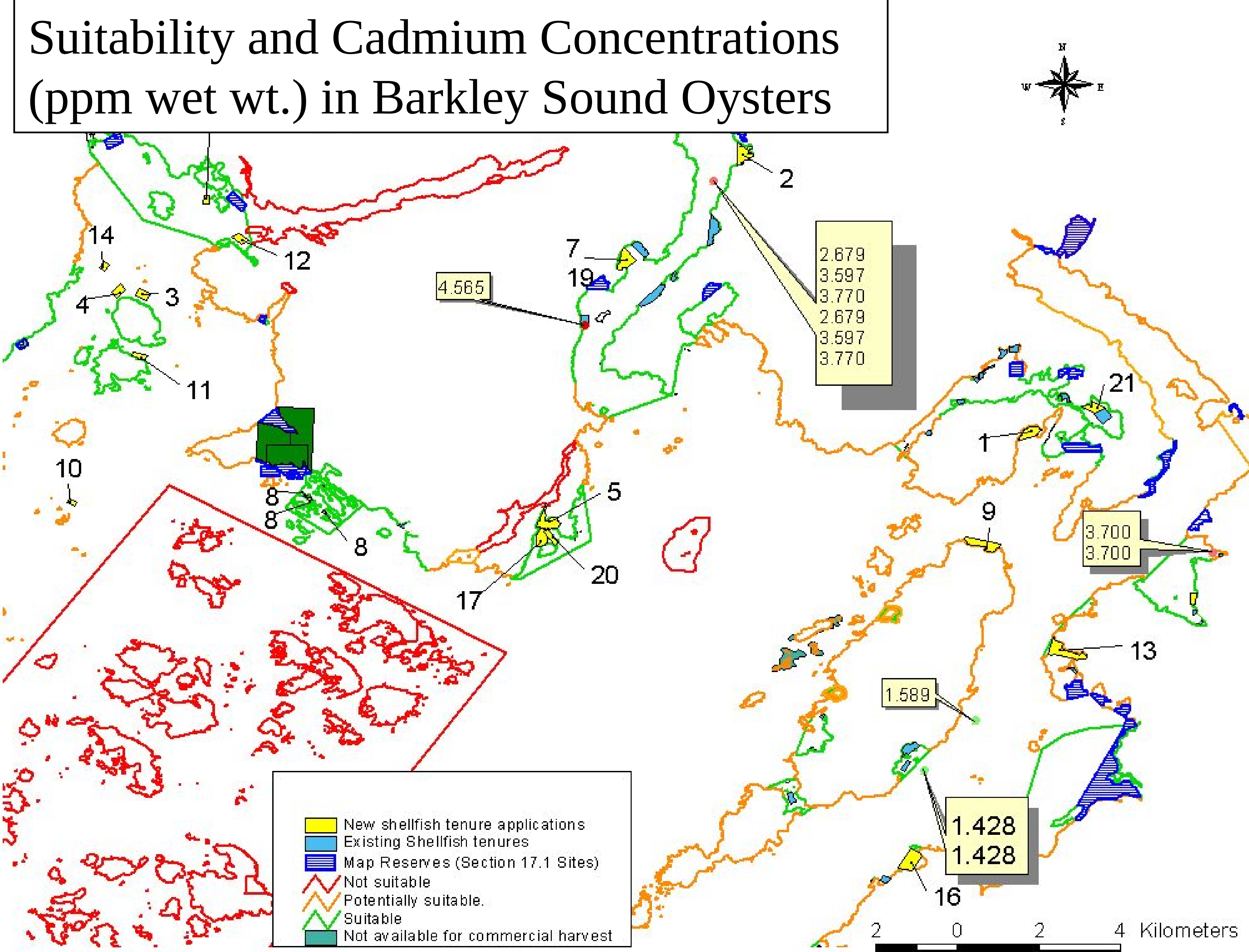
Shellfish Culture Capability and Suitability with Existing Tenures in Barkley Sound



Shellfish Culture Capability and Suitability with Existing Tenures, First Nations Map Reserves and New Applications in Barkley Sound



Suitability and Cadmium Concentrations (ppm wet wt.) in Barkley Sound Oysters



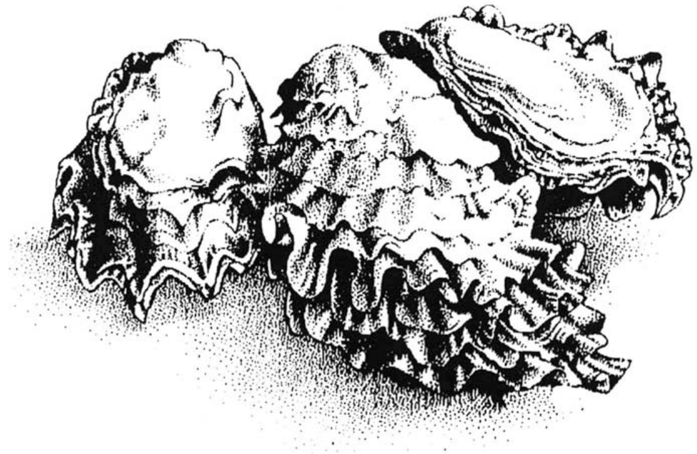
Presentation to the Cadmium and Oysters Workshop

March 6, 2001

Allison Webb, West Coast Advisor, OCAD

Outline

- Overview of OCAD
- Involvement in Shellfish
- interface with cadmium workshop



Mandate of OCAD

- To promote the sustainable development of the aquaculture sector in Canada
- this is a clear advocacy and business development role
- The Commissioner reports directly to the Minister of Fisheries and Oceans

Priorities

- Legal review (completed June 2000)
- Changing the attitude of Canadians towards aquaculture by providing good, objective, factual information
- Enhancing ocean productivity by developing a better relationship between aquaculture and the fisheries

Other Initiatives

- Aquaculture Partnership Program to encourage partnerships and broad based initiatives
- Shellfish Monitoring Project

Objective of Shellfish Monitoring Project

- To increase the participation of the aquaculture industry in shellfish monitoring programs.
- This will be done in a way that assures public health and safety are maintained.
- Cost effectiveness (for both industry and government) will be a key consideration in evaluating any potential changes to delivery of the CSSP.

Project Organisation

- Management Committee comprised of EC, CFIA, DFO, OCAD, industry (BCSGA, AANS, CAIA)
- Steering Committee made up of EC, CFIA, DFO, OCAD, industry (BCSGA, AANS, PEIAA, NAIA, AANS, Quebec)
- OCAD to chair
- Kingzett Professional Services - contractor for project

Status

- Multiphased approach
- Phase 1 identified projects
- Phase 2 was completed in the Winter of 2000 which involved developing project design and detailed budgets for several projects
- At this time a prioritization exercise took place to identify the key projects

Status cont'd

- Phase 3 began in the Summer of 2000 with Kingzett Professional Services being contracted to complete work on 2 priority projects
- These were the HACCP Project and the Commercial Species Project
- to date funding for these initiatives has come from OCAD, CFIA and industry

Interface with this workshop

- Under the auspices of the HACCP project there have been preliminary discussions regarding possible inclusion of contaminants monitoring through a farm based HACCP program
- the issue was considered as the project moves towards more advanced forms of safety assurance and as a result of the cadmium situation in BC

Connection to Cadmium Workshop cont’d

- QA/QC for marketing purposes is important
- currently gathering information to discuss this issue further under this project
- next conference call March 28, 2001

Next Steps

- Determine whether or not Shellfish Monitoring Project will consider contaminants monitoring under farm based HACCP
- consider outcome of this workshop
- continue linkages and information sharing with appropriate parties

Conclusion

- OCAD will continue to work to facilitate industry development and will work proactively with all stakeholders to ensure that issues such as cadmium or other contaminants are not barriers to industry viability or expansion

CFIA's Role
Food Safety Mandate

S. Liem

Fish Program Network - Western Area

CANADIAN FOOD INSPECTION AGENCY (CFIA)

Shared responsibility

- Health Canada
- Prior to 1997 - Delivery / Enforcement by
  - Agriculture Canada
  - Fish Inspection Branch (DFO)
  - Health Protection Branch (HC)
- 1997 - Canadian Food Inspection Agency (CFIA)

Health Canada

- Food Safety Mandate for Canada
- Sets Policies & Standards
- Audits delivery of Food Safety Program
- Represents Canada at Codex

CFIA

Canadian Food Inspection Act - Mandate to CFIA for Administration / Enforcement of Federal Legislation for:

- **Food Inspection**
- **Agricultural Inputs**
- **Animal and Plant Health**
  - **Excluding Fish Health (DFO)**

CFIA continued

- Work in partnership with Provinces
  - MOU's
  - Complimentary Legislation

CFIA -Fish, Seafood & Production Division

- Mandate: Fish - Safe; Wholesome; Acceptable Quality; Fairly Traded
- Fish Inspection Act and Regulations
- Transportation, Unloading, Handling, Processing, Labeling, Product Certification

Fish Program elements

- Quality Management Program (QMP)
- Import Product Inspection and QMPI
- Offshore Inspection Program

Fish Program Elements Cont'd

- Product Background Program
  - Monitoring; Surveillance; Compliance
- Canadian Shellfish Sanitation Program (CSSP)
  - Policies and Controls for the safety of shellfish

CSSP Delivery

- Shared by DFO, Environment Canada, CFIA
- MOU

CSSP Delivery Continued

- DFO - Harvesting
  - Management of Contaminated Fisheries Regulations
  - Enforcement of Closures
- EC - Classification of shellfish growing waters

CSSP Delivery Continued

- **CFIA - Product**
- **Product Handling, Processing, Import , Export**
- **Monitoring programs : Marine Toxin; Pathogens; Contaminants**
- **Lead Agency for liaison with foreign governments**

CANADIAN FOOD INSPECTION AGENCY (CFIA)

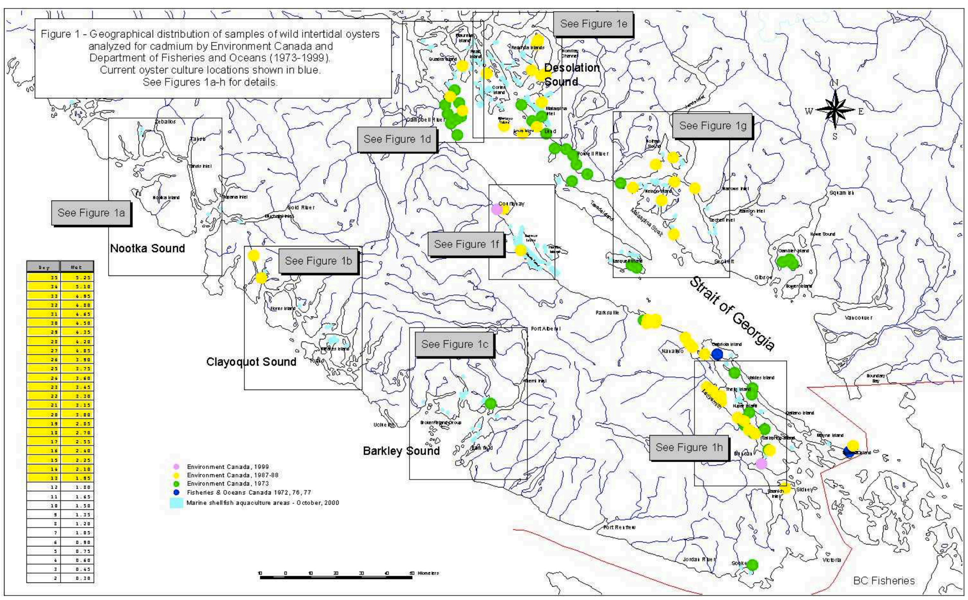


Figure 1 - Geographical distribution of samples of wild intertidal oysters analyzed for cadmium by Environment Canada and Department of Fisheries and Oceans (1973-1999). Current oyster culture locations shown in blue. See Figures 1a-h for details.

Cadmium Contamination of Shellfish
Habitat Management Roles and Responsibilities

Cadmium in Shellfish Workshop
March 6-7, 2001
Institute of Ocean Sciences, Pat Bay

Wayne Knapp
Water Quality Unit
Habitat and Enhancement Branch
Fisheries and Oceans Canada
Vancouver

3 Aspects to the Issue

- Identification of scope and source of the problem
- Health Hazard Assessments
- Implementation of Harvest restrictions as necessary

Why are we concerned?

- Responsibilities for fish and fish habitat protection
- Contamination may affect both wild and cultured species
- ensuring the quality and integrity of fishery products

What can DFO offer?

- Scientific assessment of the issue
- Provision of support information to other authorities (e.g. CFIA, HC)
- Assistance in sample collections and analyzes
- Implementation of closures/advisories as necessary
- Problem resolution (e.g. pollution abatement)

Health Hazard Assessments

- DFO relies on health agencies (e.g. HC) to provide advice on human health issues
- HM co-ordinates Regional DFO requests for Health Hazard assessments
- Provision of contaminant data; managed according to the fed-prov agreement.
- resource harvest/utilization information
- Implementation of HC/CFIA advice as necessary.

Management of Contaminated Fisheries Regulations

- “Contaminated”:
  - fish in or on which ...chemical compounds or other substances are present to a degree that may constitute a danger to public health;
- Prohibition Order (Sect. 3(1))
  - where any species in any area are contaminated the RDG may issue an order prohibiting fishing in that area for that species.

Fisheries General Regulations (Variation Orders)

- Used where commercial harvesting is closed, but recreational harvesting is permitted with consumption limits on certain tissues (e.g. crab hepato)
- By regulation commercial fisheries are closed unless an order (Variation Order) is issued varying the closure time(s).

Fisheries Act
Pollution Prevention (Section 36.3)

- '...no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.'

Fisheries Act: Deleterious Substances (Sect. 36(3))

- Could be used where anthropogenic sources of substances (i.e. cadmium) are identified.

- DFO collaborates closely with EC which has the lead in administering Section 36 of the FA

Summary

- DFO can provide scientific expertise on the scope and significance of the issue
- DFO relies on HC advice on consumption and health implications; but provides contaminant and resource harvest information
- DFO has the legislation and mandate to implement harvest closures and/or consumption advisories

Assessment of Risk to Human Health from Contaminants in Foods

Carl Alleyne, Ph.D.
Health Products and Food Branch
Health Canada
Burnaby, B.C.

Cadmium in Oysters Workshop
Sidney, B.C.
March 6-7, 2001

Health Canada Santé Canada

OVERVIEW

- Role of Health Canada in Food Safety
  - Core Activities
- Process for Risk Assessment of Contaminants in Foods
  - TDI and PDI
- Canadian Data on Dietary Cadmium Uptake
- International Guidelines for Cadmium
  - Codex Alimentarius Commission
- Improving the Confidence of Cadmium Risk Assessments - Data Gaps

Health Canada's Mandate in Foods

- We are part of a national food safety program that involves Health Canada, CFIA, provinces/territories, and municipalities.

- The role of the Health Canada Food Program is to protect and improve the health and well-being of the Canadian public by defining, advising on, and managing risks and benefits associated with the food supply.

Core Activities of Health Canada's Food Program

- Policy development
- Standard-setting
- Risk-benefit assessment
- Research
- Pre-market review
- Surveillance

It's the Dose that Makes the Poison

…………. **Paracelsus (16th Century)**

Health Canada Santé Canada

Risk Assessment Approach

- **Inherent Toxicity of Chemical**
  - Tolerable Daily Intake (TDI),

    mg/kg body weight/day

- **Exposure to Chemical**
  - Probable Daily Intake (PDI)

    mg/kg body weight/day

- **Comparison**
  - If PDI exceeds TDI, then risk management options need to be considered, including:

    - *guidelines* or legally-binding *tolerances* for the contaminant,
    - *advisory notices* about consumption of contaminated food
    - nutritional benefit vs. restricted consumption

Health Canada Santé Canada

Estimation of Tolerable Daily Intake (TDI)

- Based on Toxicology Studies with Experimental Animals
  - No Observable Effect Level (NOEL)
  - Safety Factor
- Human Epidemiology Studies

The WHO/FAO Provisional TDI for cadmium is 7 µg/kg BW/week

Health Canada Santé Canada

Estimation of Probable Daily Intake *(Dietary Exposure)* (PDI)

- Amount of food item consumed (g)
- Level of contaminants in food item (µg/kg)

Intake of Contaminant (µg) = Amt of food x contaminant level

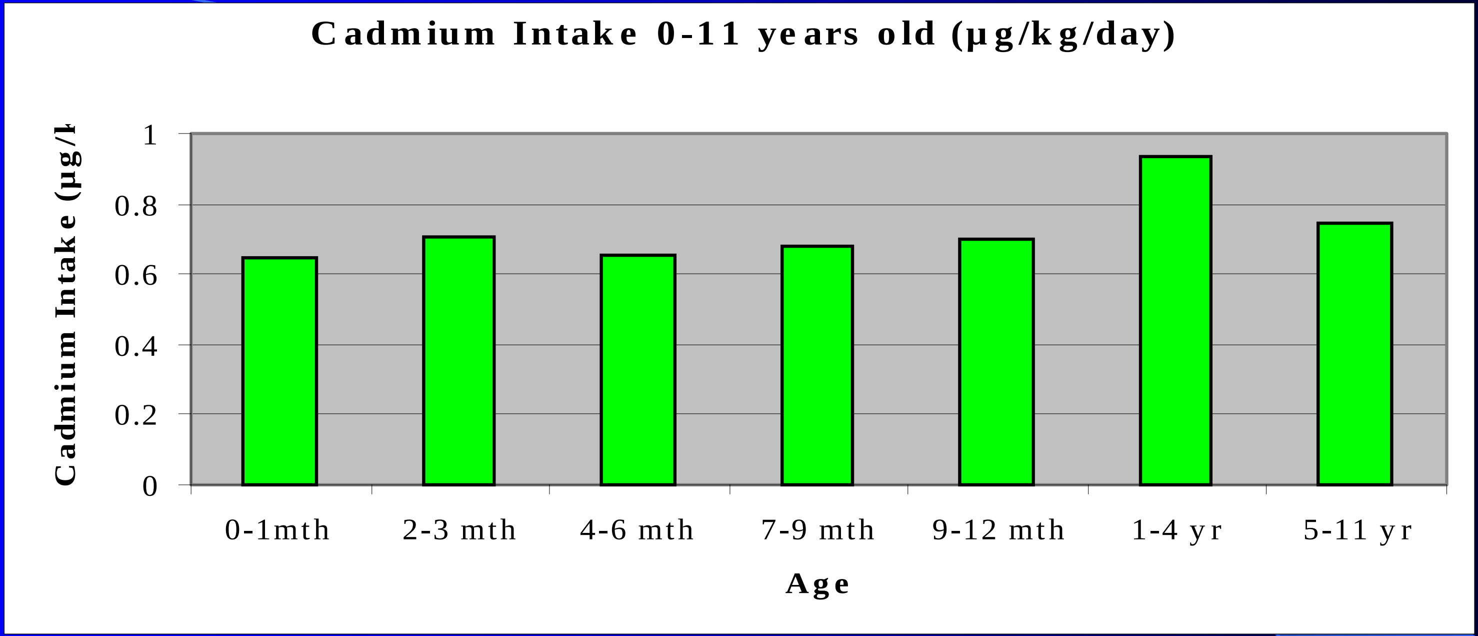
Other routes of exposure to the contaminant (air, water) are also considered

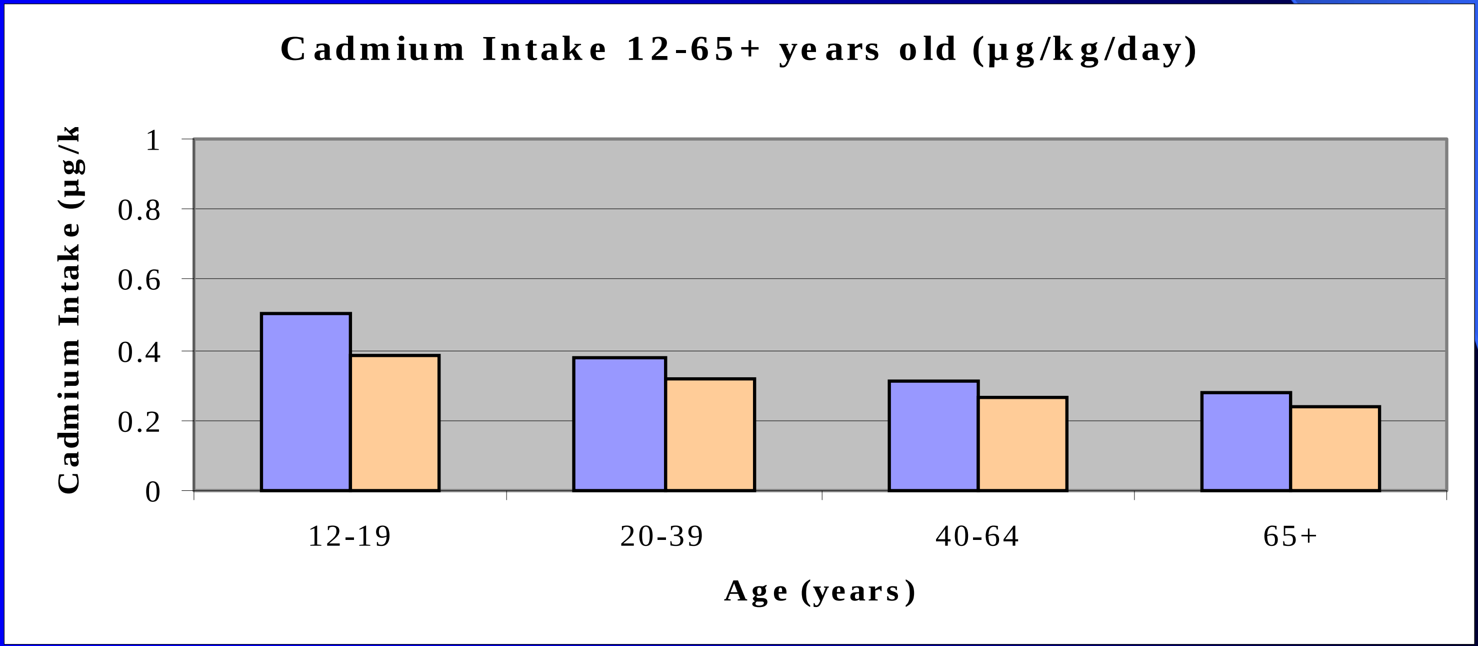
Safety Factor

- Large (100 – 5,000)
- Depends on size, quality, and nature of Toxicological Database
- Because of this, and because chronic toxicity is usually the issue, infrequent exposures above TDI, even frequent exposures, can be accommodated depending on the situation.

The Canadian Situation on Cadmium Exposure

- Health Canada has **not** set a Maximum Level guideline or tolerance for cadmium in any type of food.
- The overall dietary exposure of Canadians to cadmium is relatively consistent over the years.
- The cadmium levels found in Canadian foods are generally comparable to those in other countries, except for special cases, *e.g.*, industrial contamination, or isolated asian consumers of rice.
- Cadmium levels found in the “average” Canadian diet have not been a cause for concern.





Health Canada Santé Canada

Personal Exposure to Cadmium

The average 60 kg Canadian receives about 20 µg cadmium every day from his/her food *(Health Canada, Total Diet Studies)*

Leafy green vegetables, potatoes, liver, and milk are major sources of cadmium in the diet.

Cigarettes are a major source of cadmium exposure – Smokers are exposed to ~10 µg/day (or about 20 µg/day/person) more than non-smokers.

Health Canada Santé Canada

Cadmium Guidelines in Other Jurisdictions

- WHO/FAO (1989) recommends a max. Tolerable Weekly Intake = 7 µg Cd/kg body weight
  (60 µg/person/day for a 60 kg person)

- The U.S. Food and Drug Administration (FDA) proposes a max. TDI of 55 µg/person/day (1993) to calculate **Levels of Concern.**

- Codex Alimentarius (FAO/WHO) will be discussing a **proposed draft standard** this week to set the Maximum Level for cadmium in molluscs at 1.0 ppm. *Can you live with this?*

Health Canada Santé Canada

Proposed Draft Standards for Cadmium - Codex

Commodity	Proposed ML, mg/kg (ppm)
Molluscs	1.0
Crustaceans	0.5
Wheat grain, rice	0.2
Cereals, pulses, legumes	0.1
Cattle, poultry, pig, and sheep	0.05
Vegetables	0.05

Codex Alimentarius Commission

- Codex was established by the Food and Agriculture Organization (FAO) and World Health Organization (WHO). One of its main responsibilities is in establishing and harmonizing international food safety standards.

- Many countries, including Canada, align their national food standards, or parts of them, with those of the Codex Alimentarius. This is particularly so for contaminants and pesticide/veterinary drug residues, and food additives.

Procedure for Setting a Codex Standard…1

This is an 8 step process:

Step 1: Decision is taken to elaborate a world-wide Codex standard and which subsidiary body will do the work.

Step 2: A ***proposed draft standard*** is prepared by a member country that is charged to take the lead on it. It is basically a discussion paper at this point.

Step 3**:** The proposed draft standard is sent to Members and interested international organizations for comments on all aspects, including possible implications for economic interests. *The proposed draft standard for Cadmium in molluscs is at this stage. Denmark has the lead.*

Procedure for Setting a Codex Standard…2

Step 4: Comments received are sent to the subsidiary body *(e.g., Codex Committee on Food Additives and Contaminants)* for consideration and amendment of the proposed standard.

Step 5: The proposed standard is submitted to the Commission with a view to its adoption as a ***draft standard***.

Step 6: The draft standard is sent to all Members for comment on all aspects.

Procedure for Setting a Codex Standard…3

Step 7: Comments received from Members are sent to the subsidiary body for consideration and amendment of the draft standard

Step 8: The draft standard is submitted to the Commission together with any proposal received from members for amendments with a view to its adoption as a ***Codex standard***.

Finally, Member States notify the Secretariat if they wish to accept the Standard

Health Canada Santé Canada

Improving the Confidence of Cadmium Risk Assessments

- Toxicological data:
  - Toxicokinetics of dietary cadmium intake and urinary excretion in the general population and high risk groups *(e.g., those with iron deficiency or diabetes)*
  - Bioavailability from specific foods and factors which affect this *(e.g., age, health status, and dietary nutrients)*
  - Influence of cadmium on calcium metabolism and osteoporosis
- Epidemiological studies to assess the risk of cadmium to human health and the potential adverse health effects.

Improving the Confidence of Cadmium Risk Assessments...2

- Better dietary consumption data for molluscs:
  - Frequency of consumption
  - Average/median amounts consumed per day
- Much more data on cadmium concentrations in different molluscs – wild and cultured.

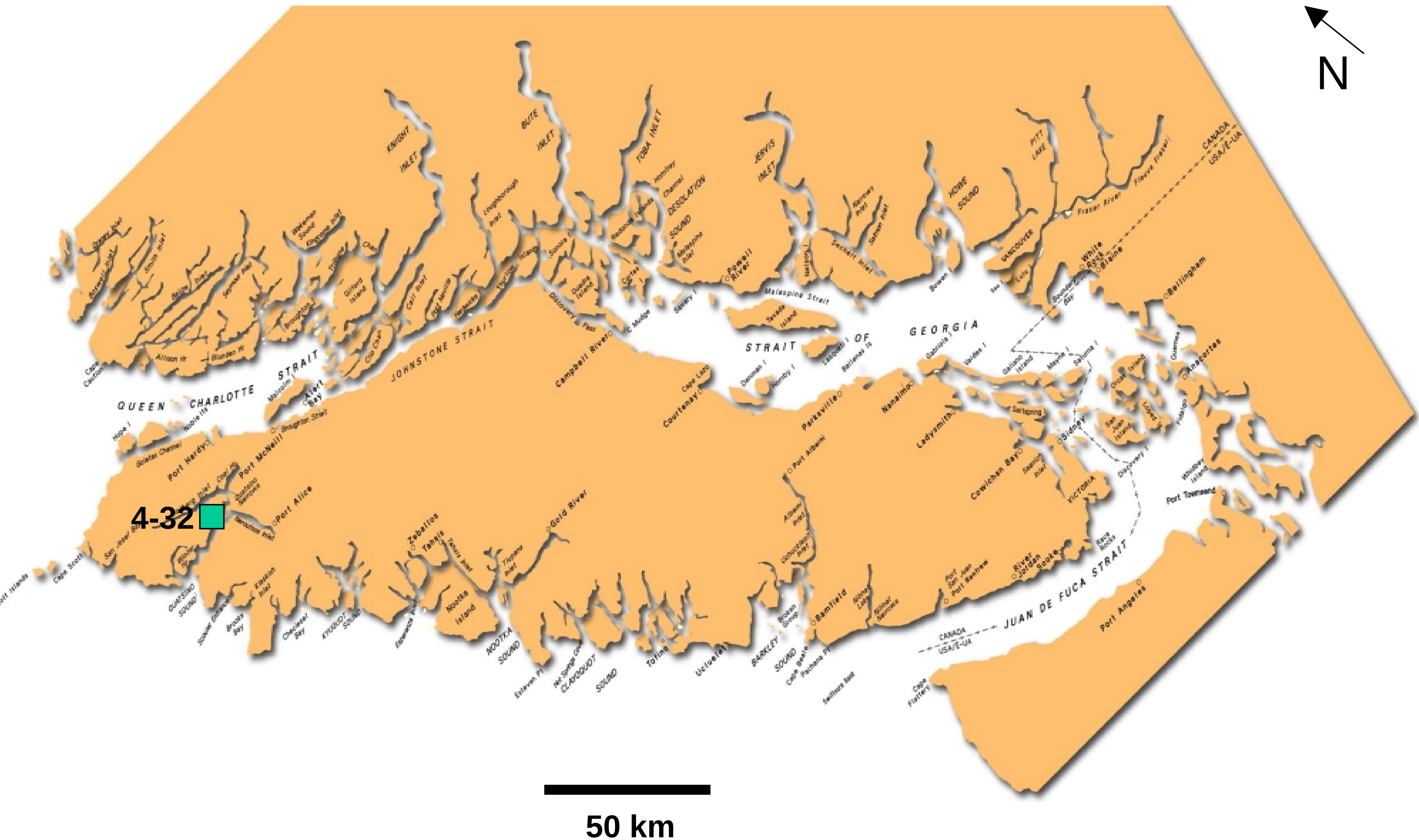

N
4-32
50 km

Table 1. Cadmium Application Rates, Nanaimo Watershed

Year	Area(ha)	Fertilizer	Fertilizer Added (kg)	Cd concentration ($\mu g\ g^{-1}$)		Cd added (kg)
				Range	Mean	
1998	175	Dawson Seed 25-9-9	5920	0.5 – 42	26	0.154
1998	165	Dawson Seed 25-9-9	4925	0.5 – 42	26	0.128
1999	108	Dawson Seed 25-9-9	3717	0.5 – 42	26	0.097
1999	150	Dawson Seed 26-25	4401	1[a]	1	0.004
2000	255	Nutri-Pak 25-8-8	13823	<0.6 – 7.5	6.1	0.040
2000	205	Nutri-Pak 26-9-9	10135	6.1[a]	6.1	0.062

[a] D. Brinkman, pers. comm. July 2000

Table 2. Possible Cadmium (Cd) Application Rates from Forest Fertilization

Planting versus Stand Development

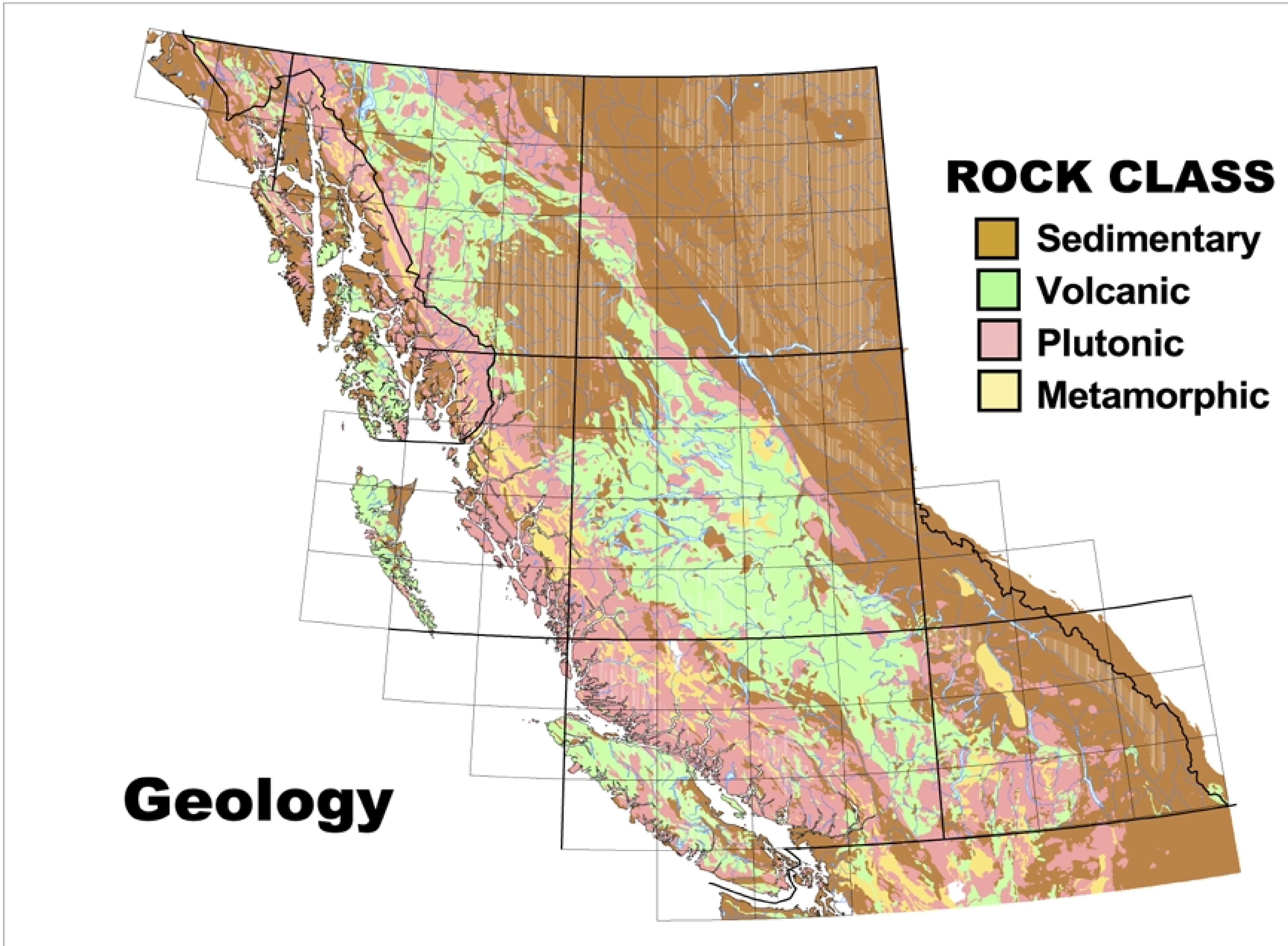
Variable	Planting	Stand Development
Cd concentration in fertilizer (µg g^{-1})	12 (range 0.6-42)[a]	15[b] 115[c]
Fertilizer added (kg ha^{-1})	<65[d]	385[e]
Maximum Cd added per application (kg ha^{-1})	0.003[f]	0.006 – 0.043
Frequency (applications per rotation)	1	2-3
Rotation Length (years)	80-150[g]	80-150[h]
Area fertilized (ha $year^{-1}$)	2000-3000	971 (0-3416)

[a]/ mean concentrations in fertilizers applied at planting 1998-2000, Greater Nanaimo Watershed (www.city.nanaimo.bc.ca/speed/gnwd/src/fertilizer.pdf)
[b]/ triple super phosphate (Brown, unpubl. data)
[c]/ triple super phosphate (Washington Dept. of Agriculture; www.wa.gov/agr/pmd/fertilizers/index.htm#database)
[d]/ assuming 40 g fertilizer per seedling and 1600 seedlings ha^{-1}
[e/] current Western Forest Products operational fertilization rates of 75 kg P ha^{-1}
[f/] assuming maximum Cd concentration of ca. 45 µg Cd g^{-1} fertilizer
[g/] for Douglas-fir and western hemlock
[h/] for western hemlock

Cadmium in B.C. Stream Sediments

Ray Lett and Wayne Jackaman

BRITISH COLUMBIA GEOLOGICAL SURVEY

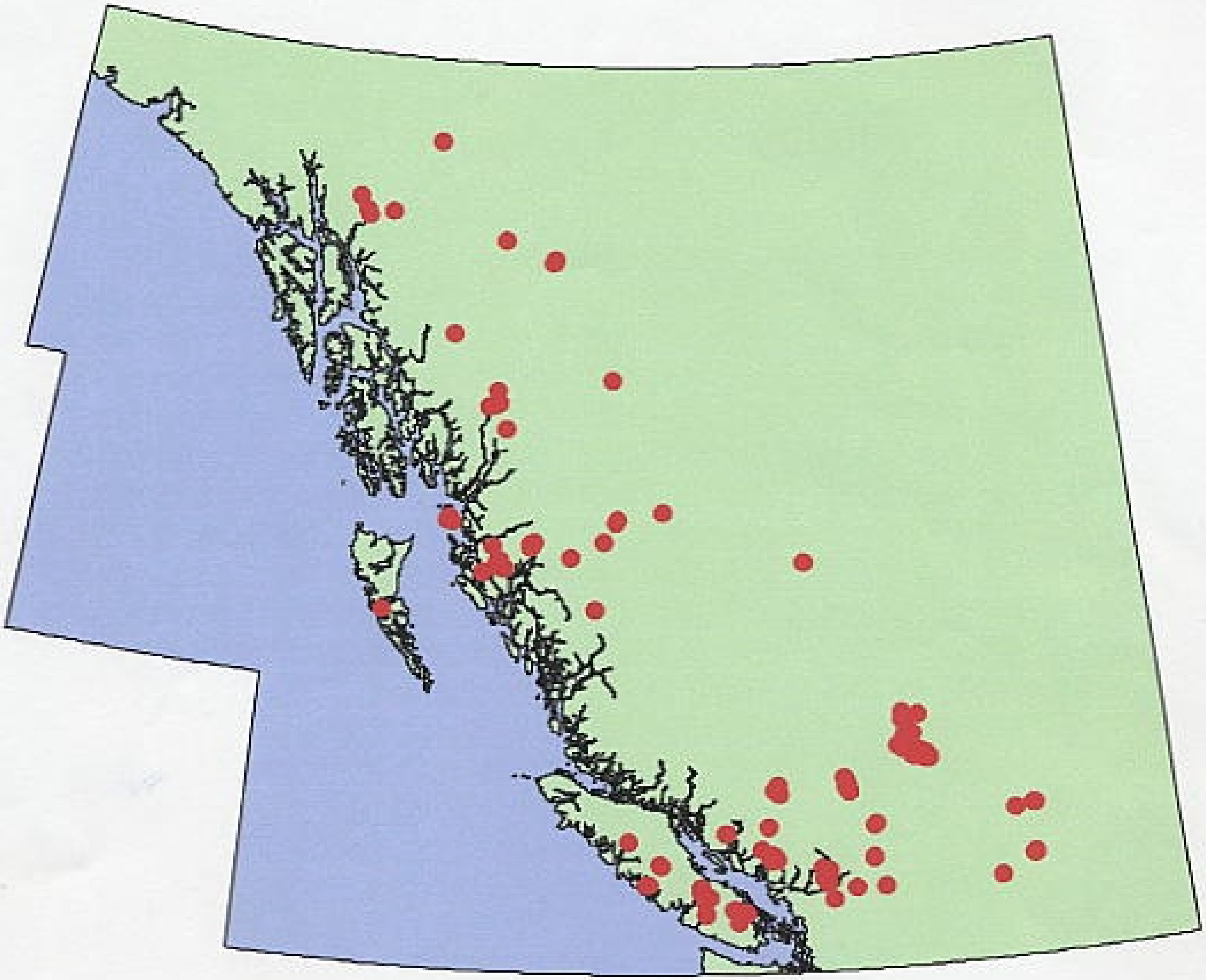

ROCK CLASS
Sedimentary
Volcanic
Plutonic
Metamorphic
Geology

Geological Sources for Cd

- **Rock-Forming silicate minerals (e.g. plagioclase) -** Typical levels < 1 ppm Cd
- **Zinc sulphide - sphalerite -** Typical levels to 1 % Cd
- **Cadmium sulphide -** Typical levels to 50 % Cd
- **Secondary zinc minerals (e.g. smithsonite) -** Typical levels to 2000 ppm Cd

Potential Sources of Cadmium

Copper-lead-zinc massive sulphide deposits

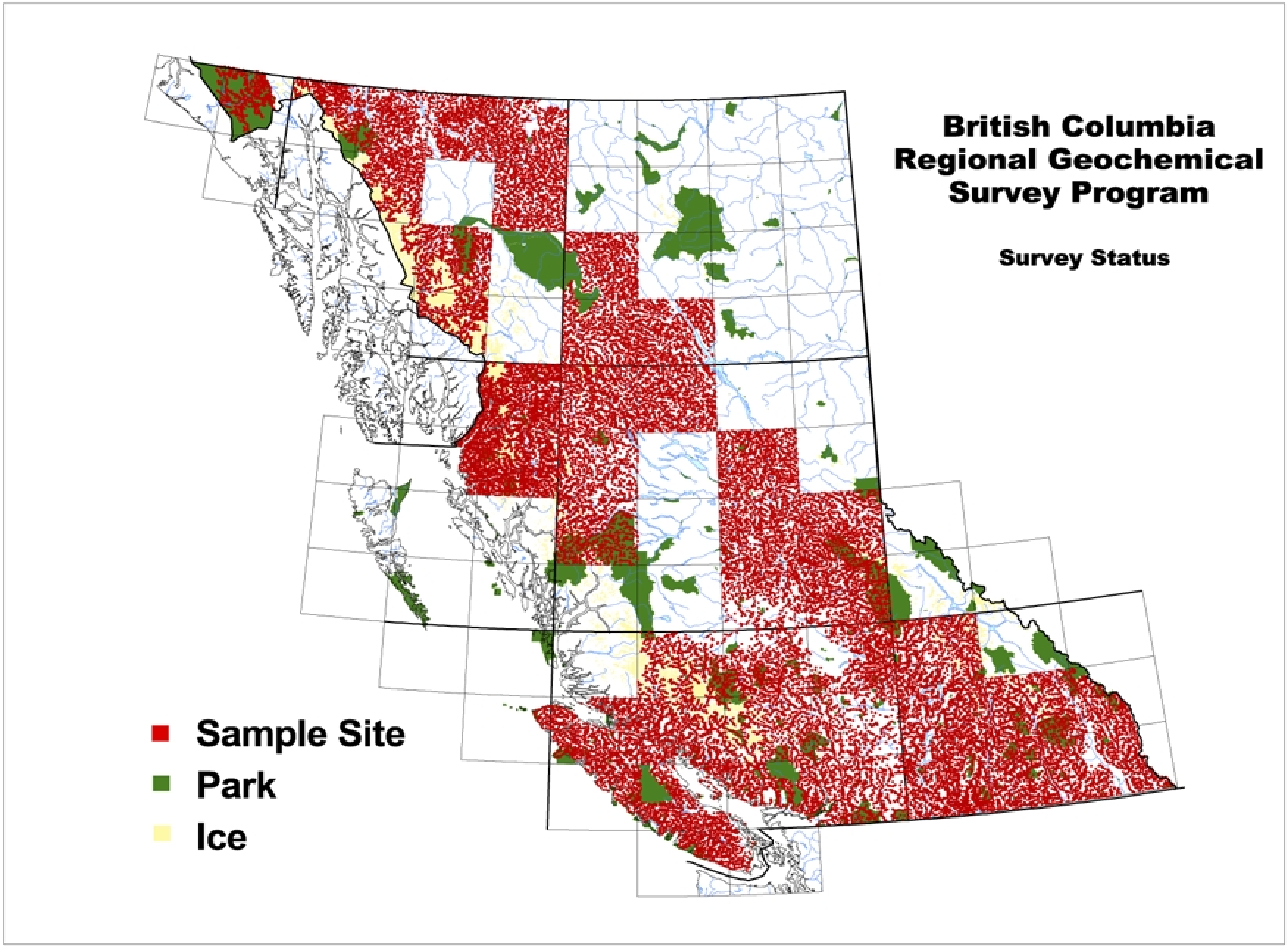


Cd background levels

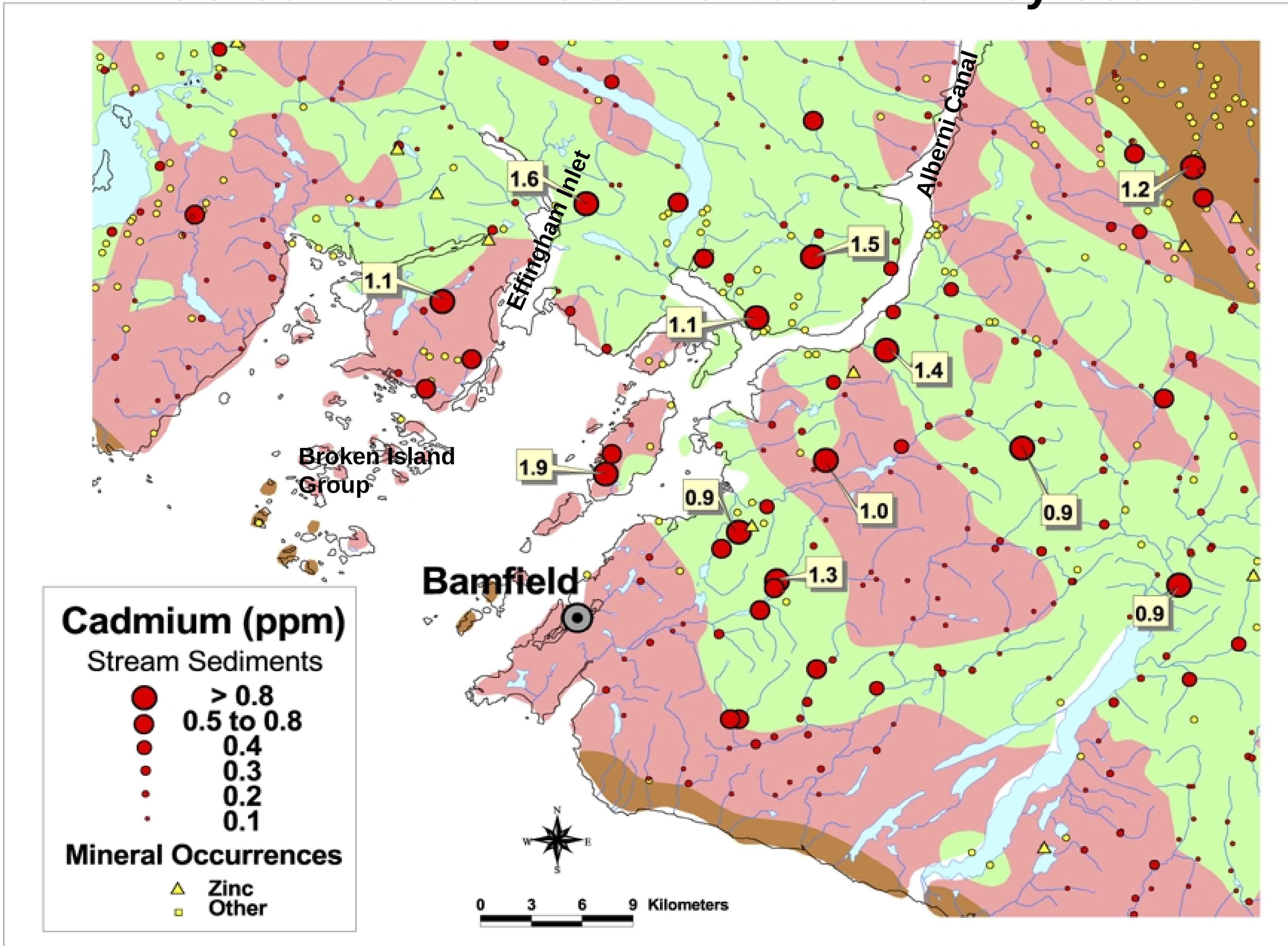
- **Granites** - 0.1 to 0.2 ppm
- **Volcanic rocks** - 0.2 to 0.3 ppm
- **Sedimentary rocks** - Up to 500 ppm in shale
- **Recent marine sediments** - 0.1 to 1 ppm
- **Marine Mn nodules** - up to 8 ppm

GSB RGS Database

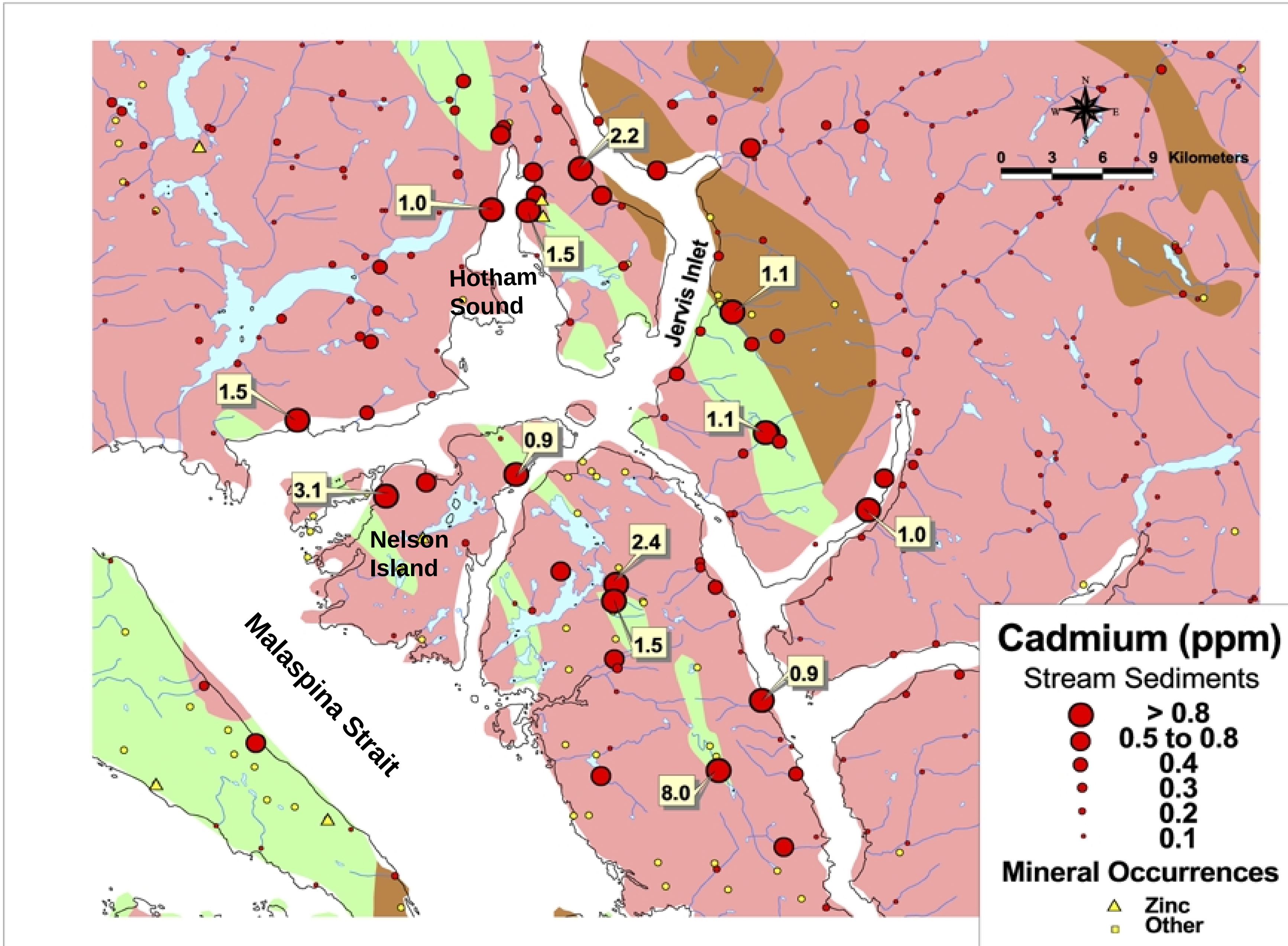
- Data used to stimulate exploration for new mineral resources in BC and geochemical baseline studies
- Contains multi-element geochemical data for 45,000 stream water and sediment samples
- Sample collection and analysis conforms to national standards set by GSC
- Over 70% of BC covered by RGS
- 40% of sediment samples analysed for Cd


British Columbia
Regional Geochemical
Survey Program
Survey Status
Sample Site
Park
Ice

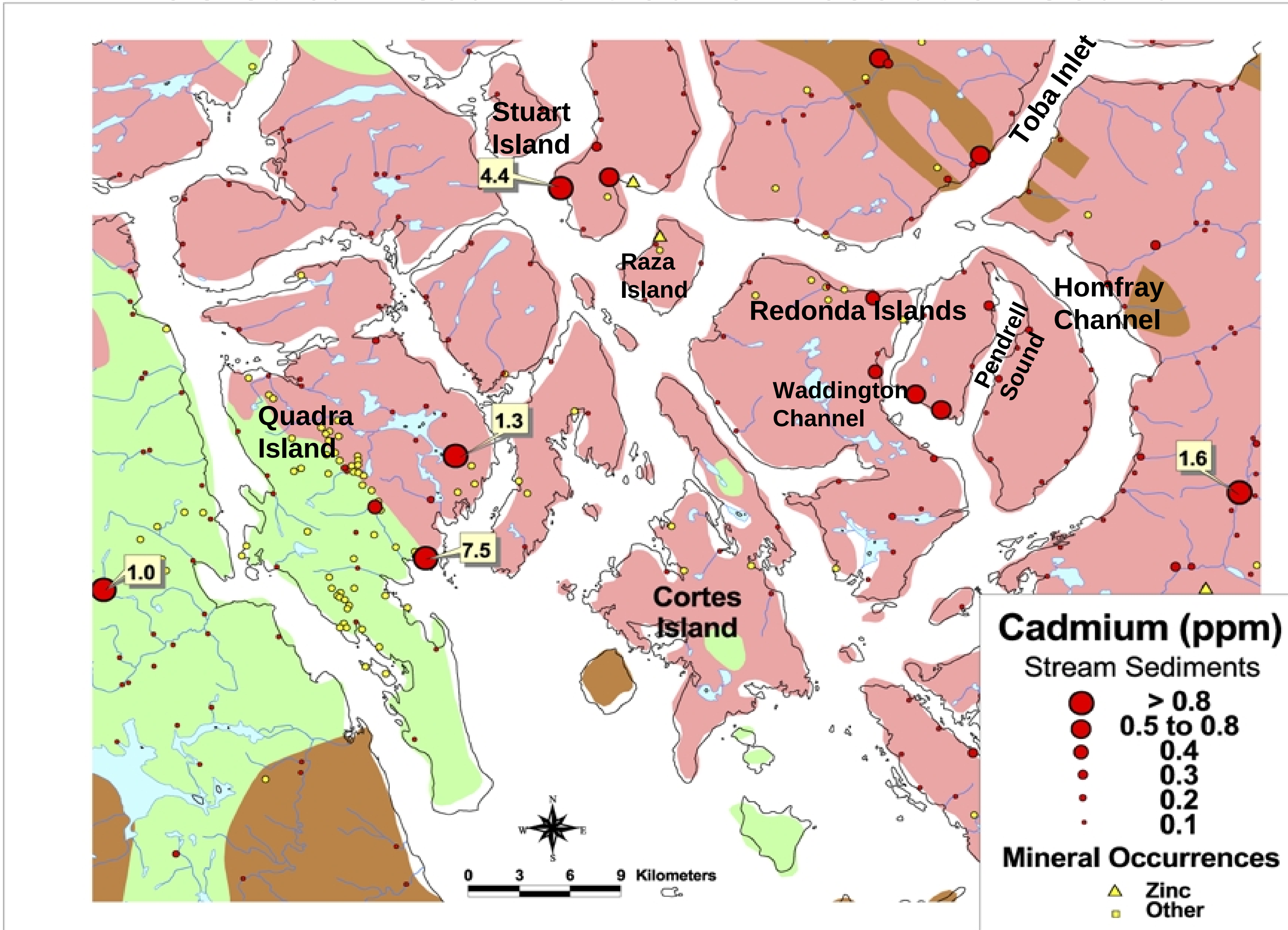
RGS Cd in Stream Sediments for Barkley Sound



RGS Cd in Stream Sediments for Jervis Inlet and Hotham Sound



RGS Stream Sediment Cd for Desolation Sound



Mean (max) Cd in sediments and water

Material	Cadmium	Zinc
Till (435 NVI sites)	0.6 (7.5) ppm	81 (857) ppm
Stream sediments (41045 BC sites)	0.35(109.9) ppm	81(88000)ppm
Iron spring deposits (43 NE BC samples)	26 (186) ppm	8484 (23173) ppm
Stream water (218 sites around Adams Lake)	0.02 (0.32) ppb	1.2 (20.4) ppb
Spring water (50 NE BC sites)	9.3 ppb	91 ppb

OTHER GSB DATA RESOURCES

- The Map Place
- MINFILE - Mineral Inventory
- Mineral Potential Database
- ARIS Assessment Reports
- Digital Terrain Stability Map Library

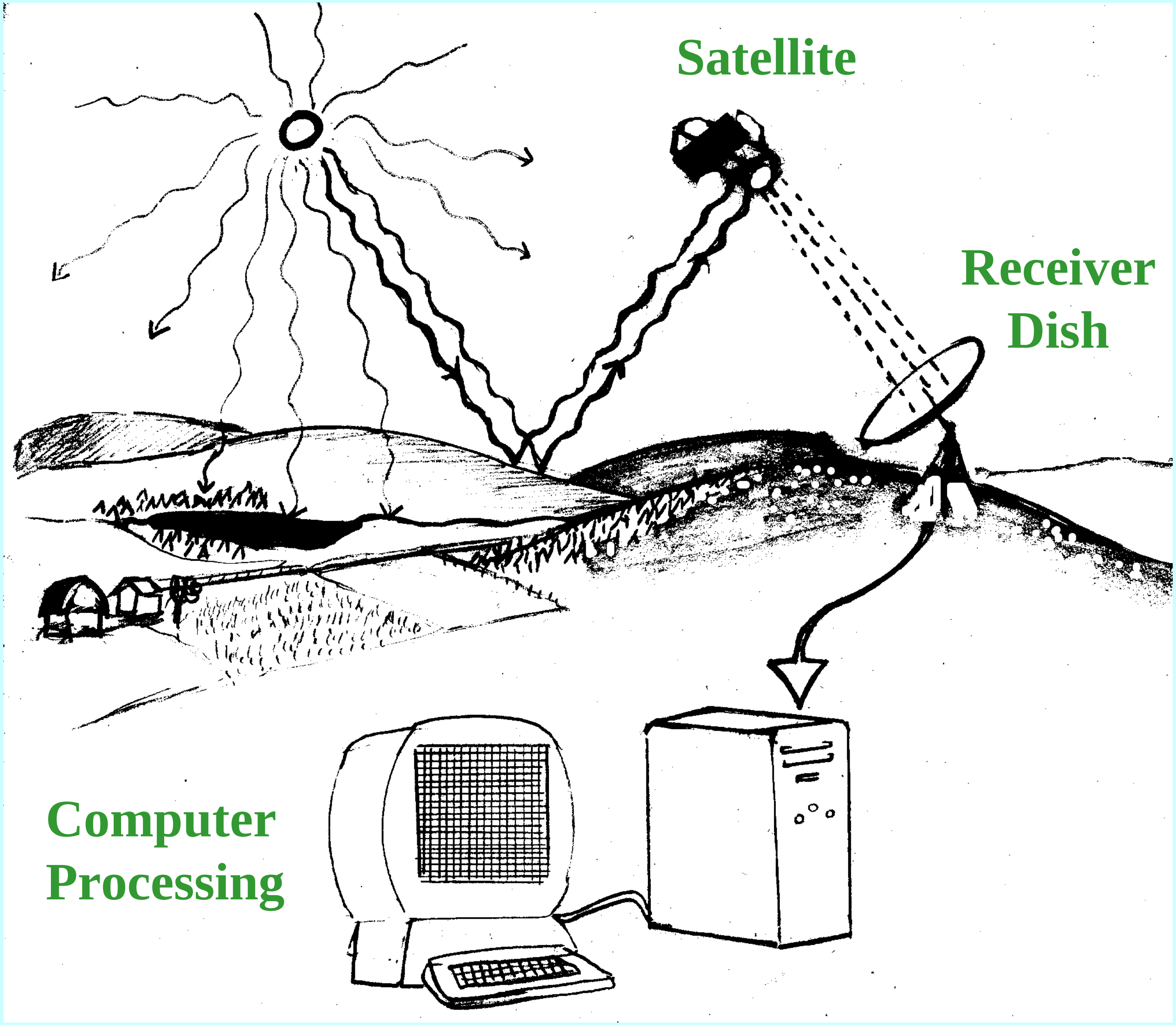
Geology and Minerals Information:

http:/www.em.gov.bc.ca/Mining/Geolsurv/MapPlace

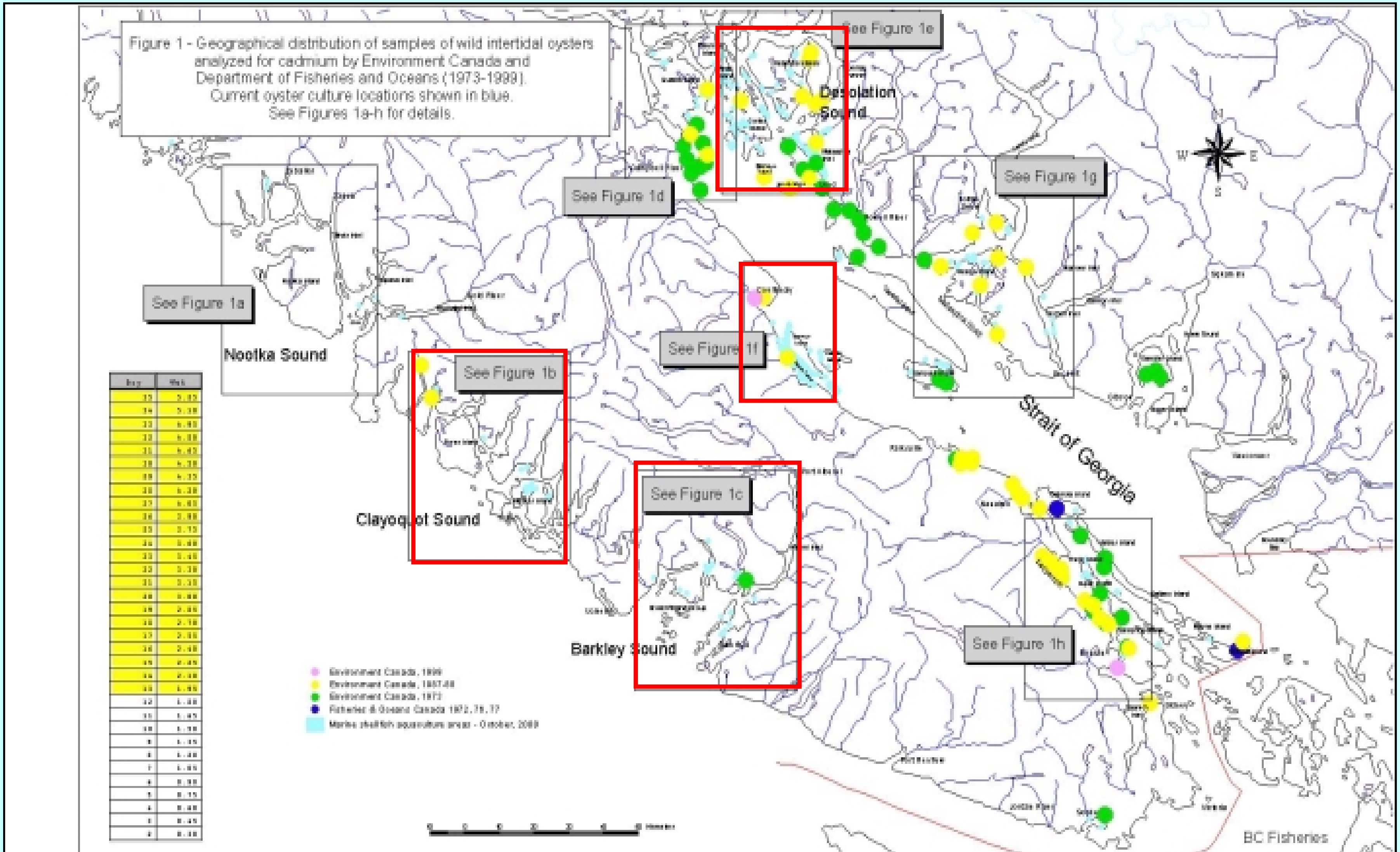
How Satellite Imagery Can Help To Understand Cadmium Contamination In Oysters

By
Will Burt
Marcella Snijders
University of Victoria
Geography

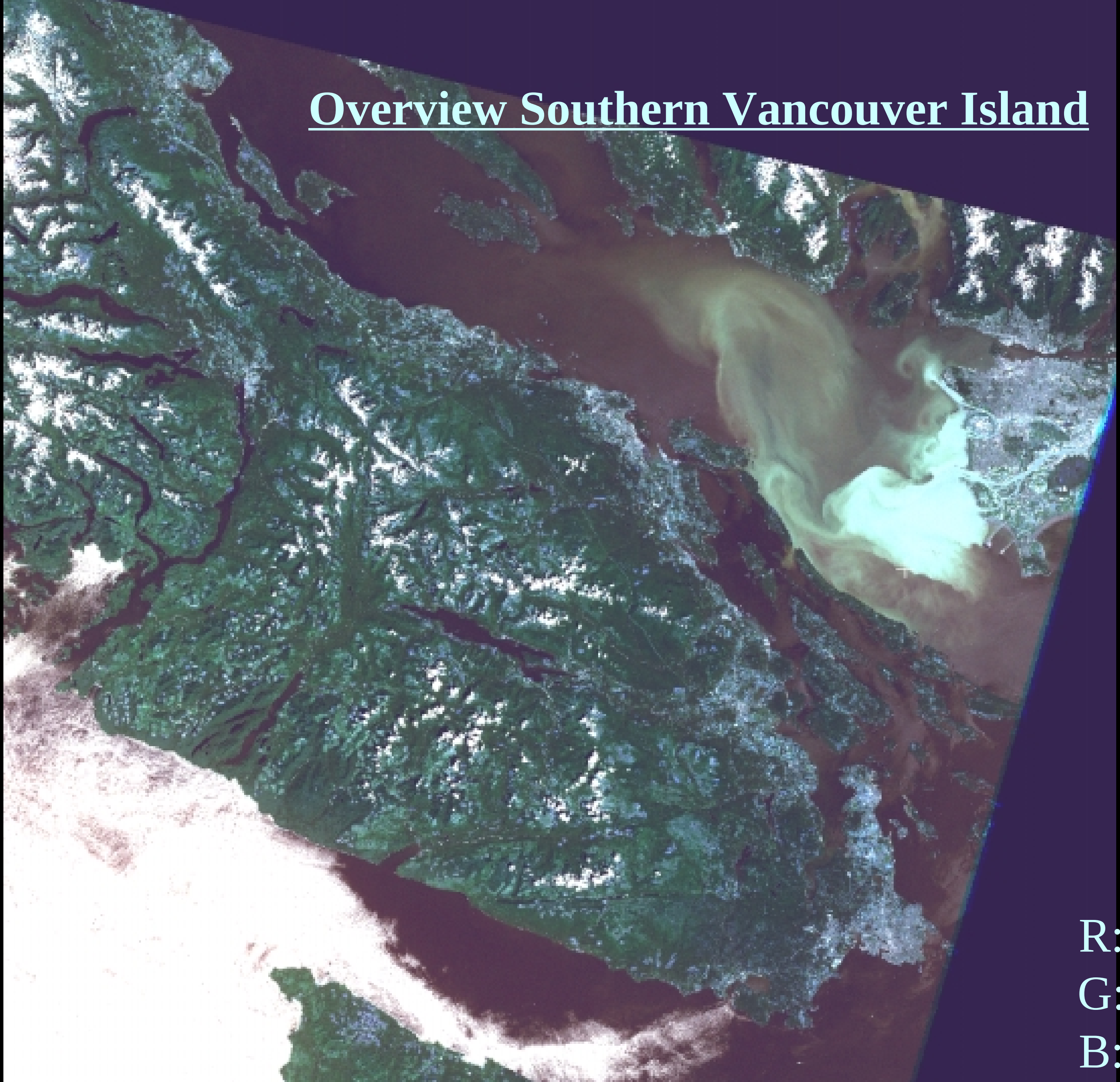
What is Remote Sensing?


Satellite
Receiver Dish
Computer Processing

Regions of Interest: Figures 1b, 1c, 1e, 1f

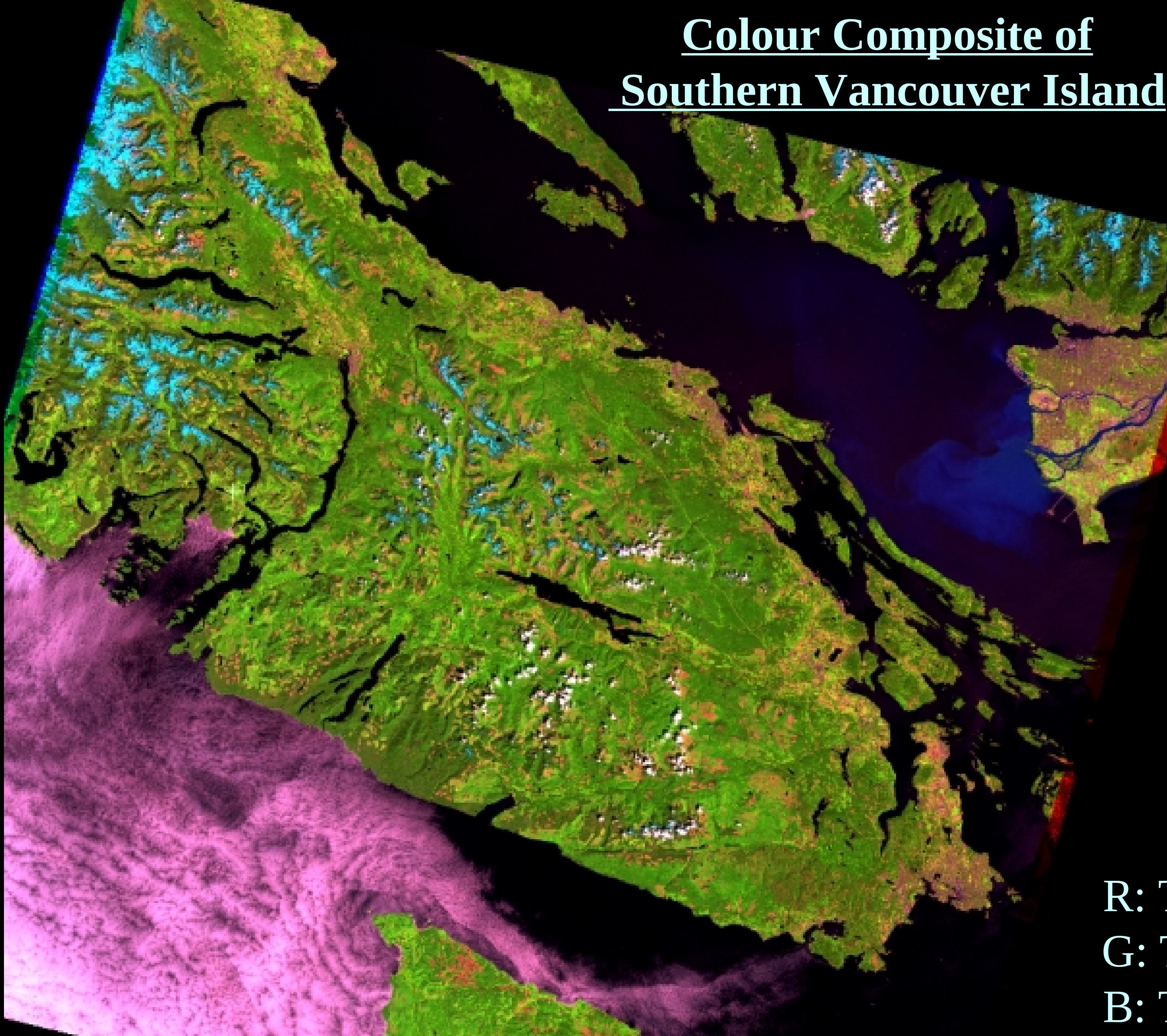


Overview Southern Vancouver Island



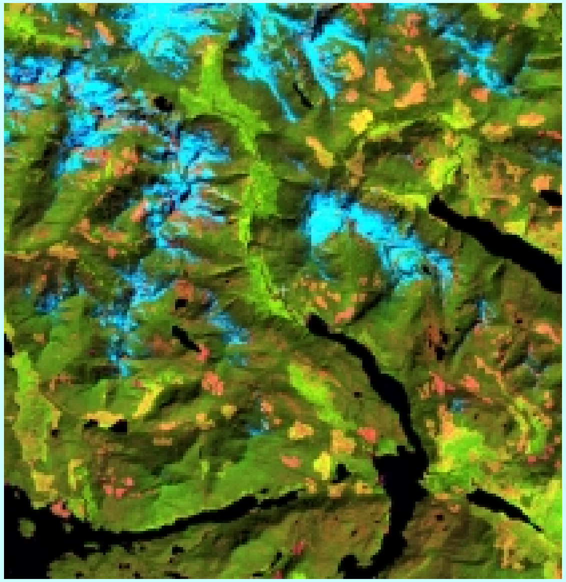
R: TM 3
G: TM 2
B: TM 1

Colour Composite of Southern Vancouver Island



R: TM 5
G: TM 4
B: TM 3

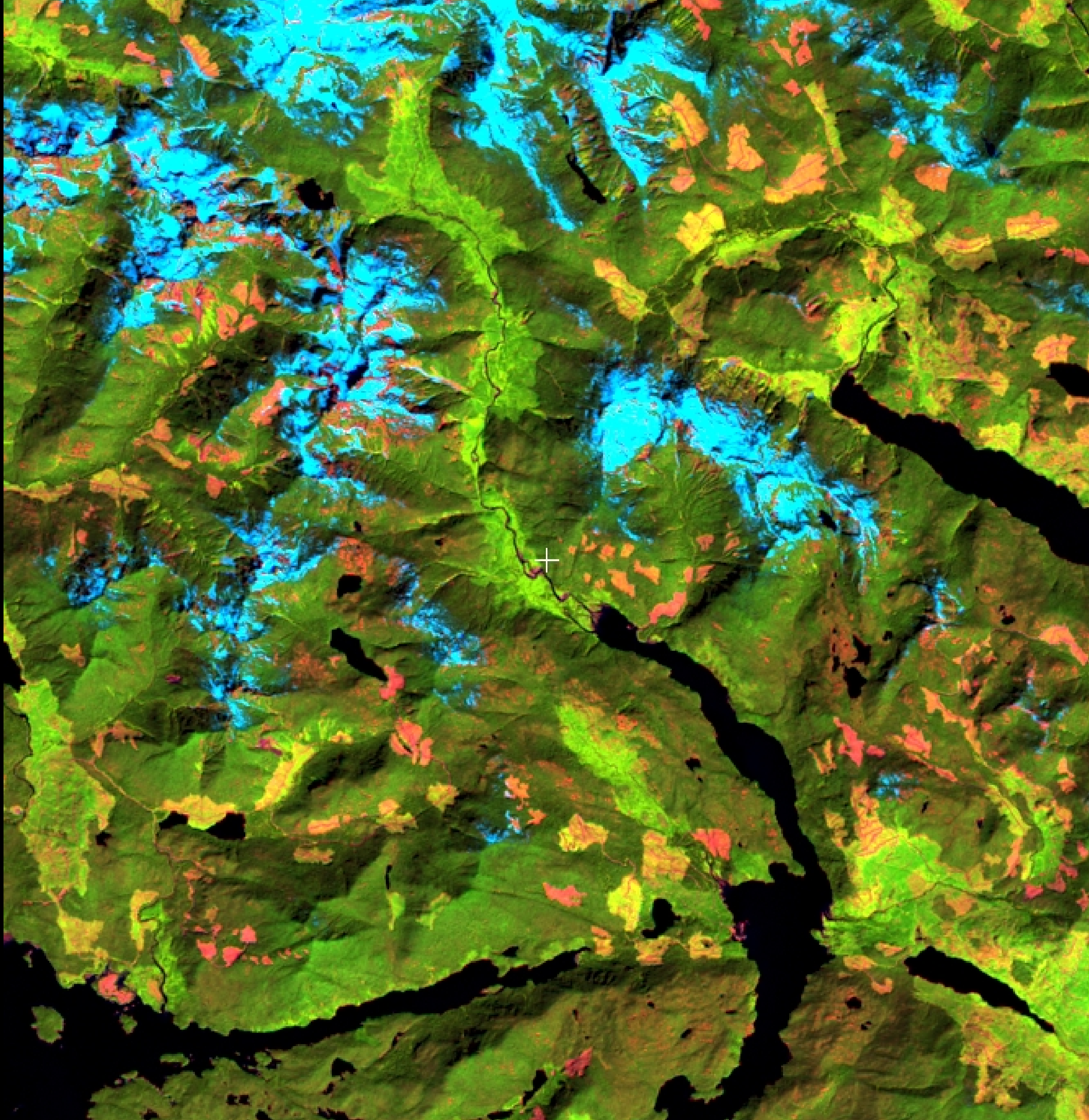
Barkley Sound



Land Cover in the Effingham Watershed

Re: Figure 1c

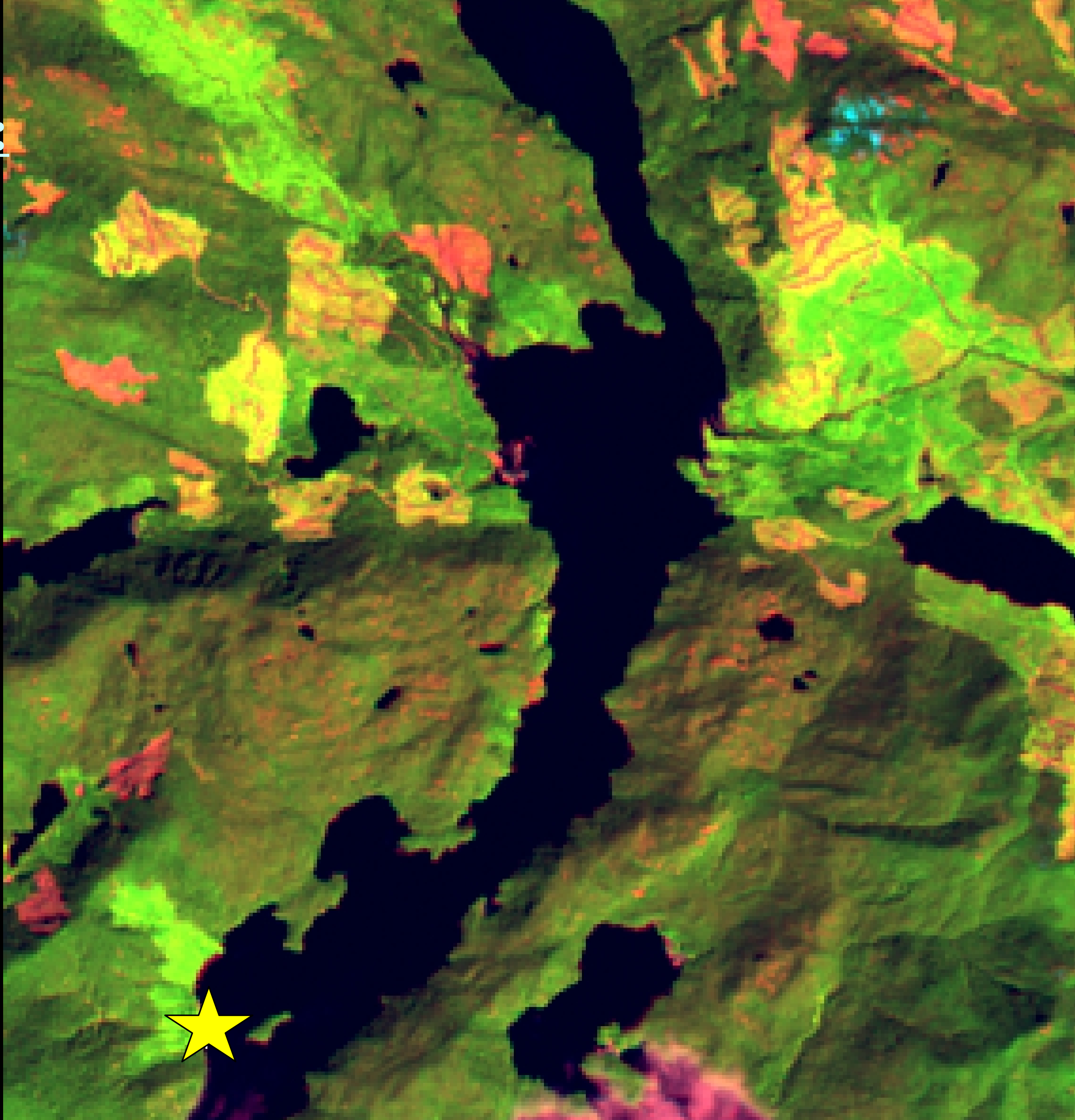
Effingham Inlet Watershed



R: TM 5
G: TM 4
B: TM 3

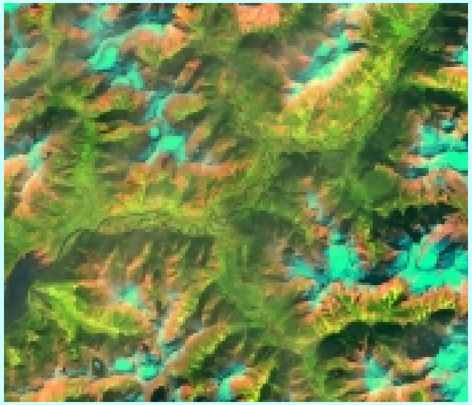
Effingham Inlet: Oyster Lease Site

★ 30.4 ug Cd/g



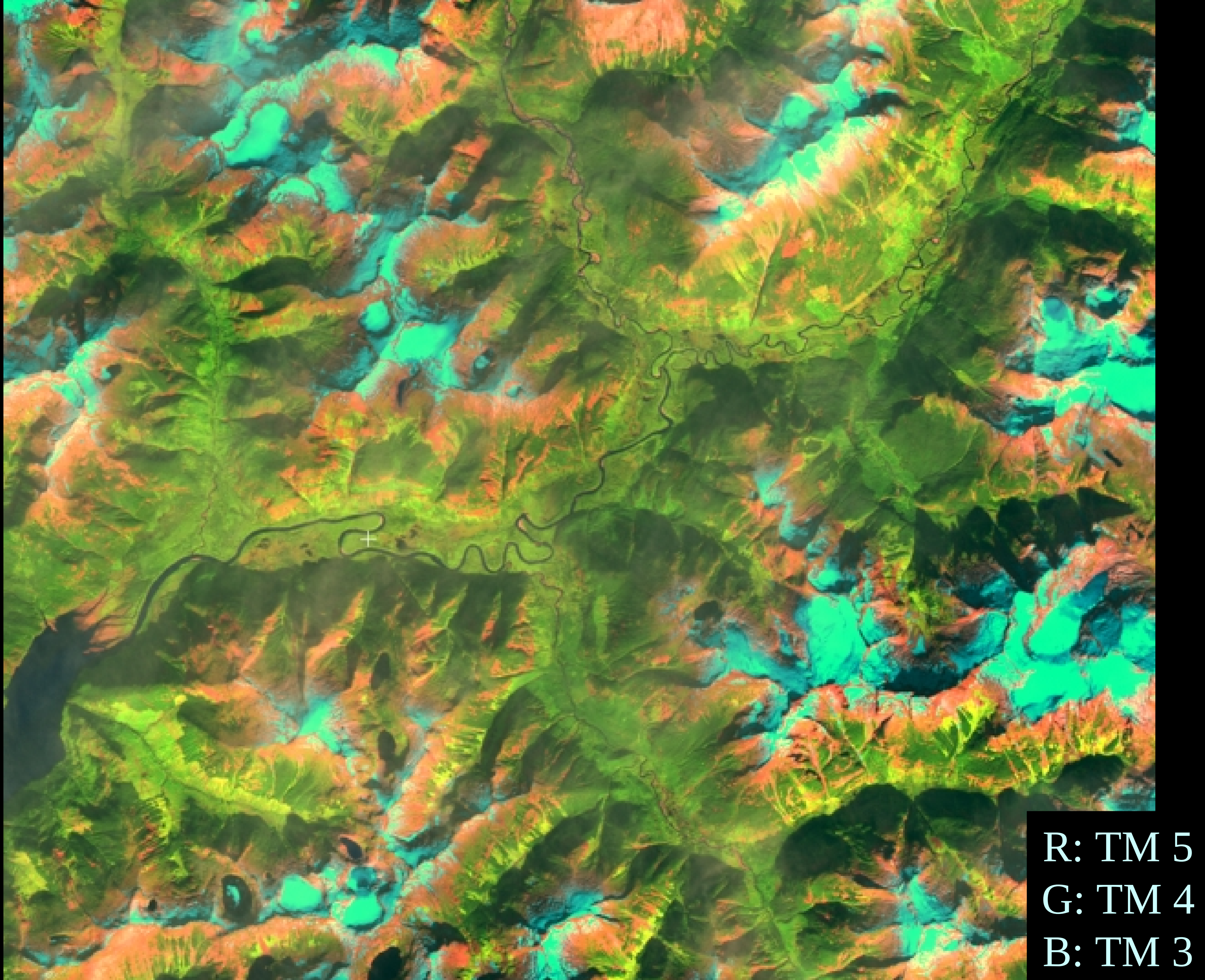
R: TM 5
G: TM 4
B: TM 3

Desolation Sound



Land Cover in the Toba Inlet Watershed

Re: Figure 1e


R: TM 5
G: TM 4
B: TM 3

Desolation Sound Oyster Lease Sites

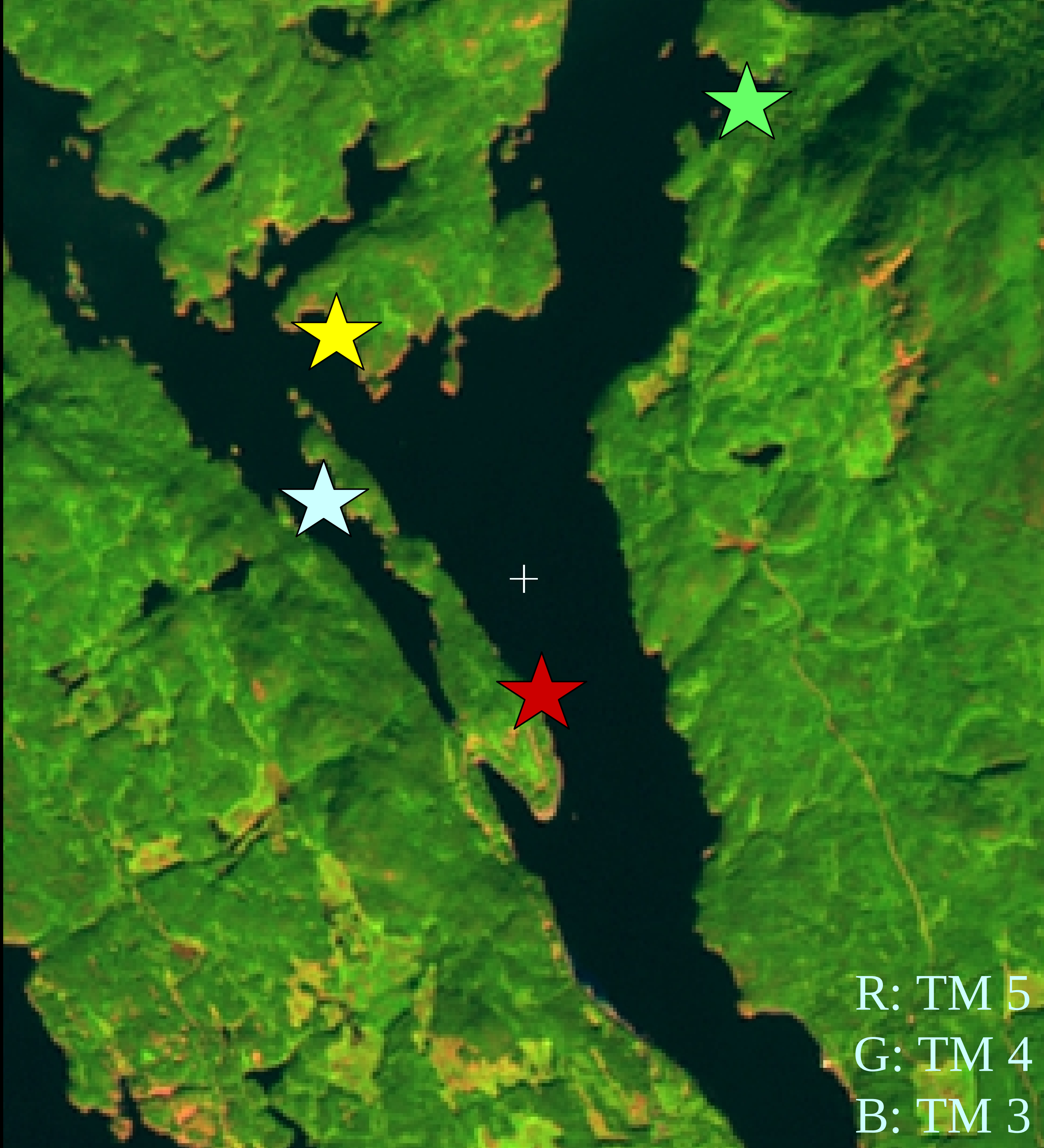
★ 37.0 ug Cd/g

★ 36.4 ug Cd/g

R: TM 5
G: TM 4
B: TM 3

Malaspina and Okeover Inlets Oyster Lease Sites

- Yellow star: 25.3 ug Cd/g
- Red star: 24.8 ug Cd/g
- Green star: 22.3 ug Cd/g
- White star: 17.3 ug Cd/g



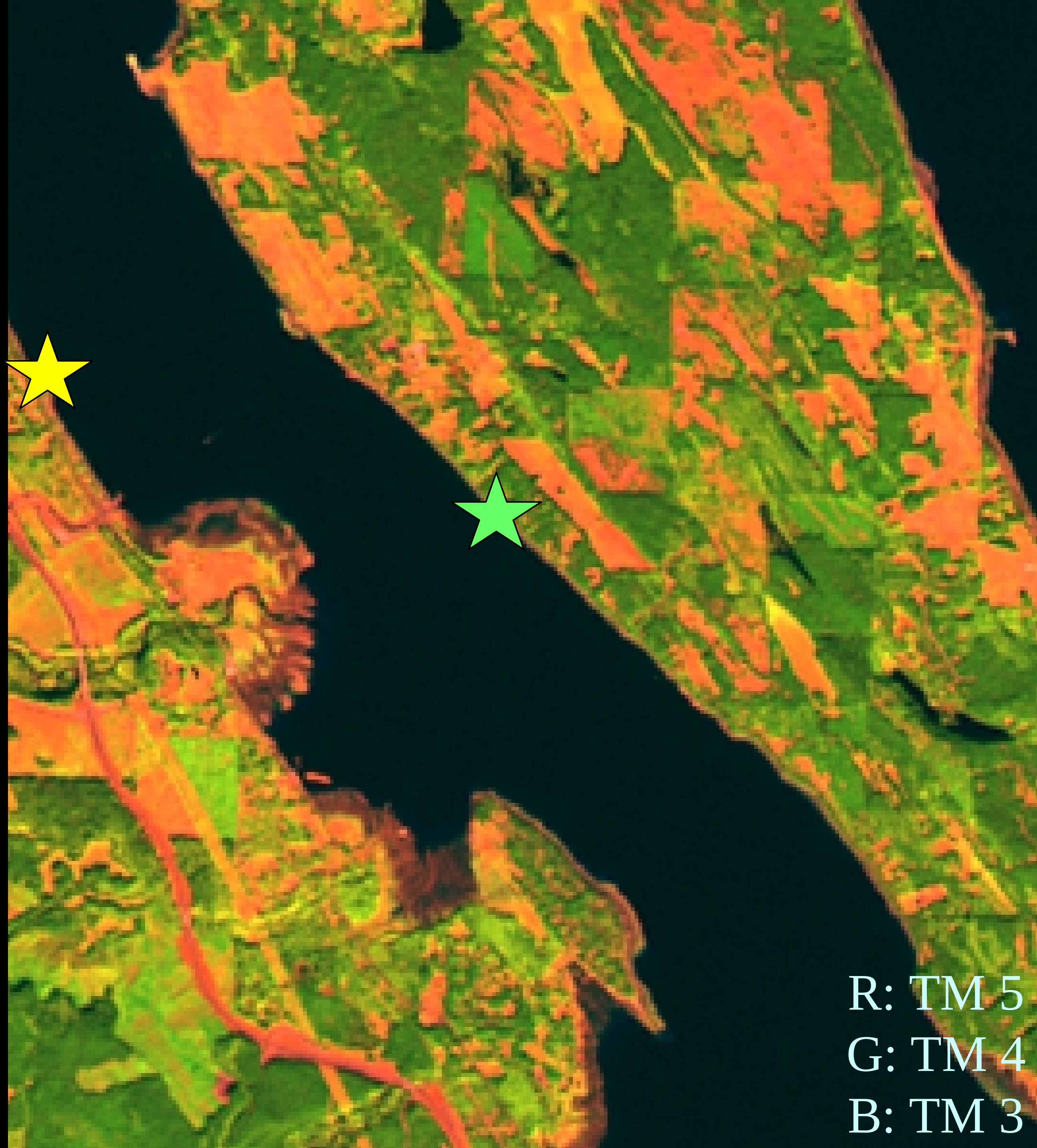
Baynes Sound

Land Cover in the Rosewall CreekWatershed

Re: Figure 1f


R: TM 5
G: TM 4
B: TM 3

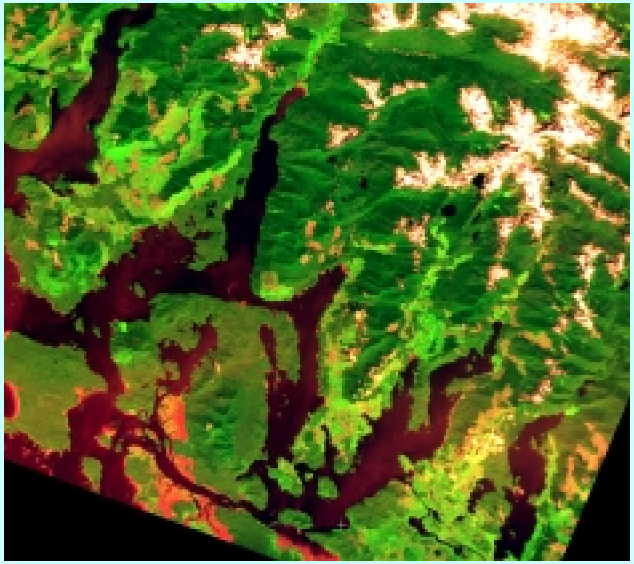
Baynes Sound Oyster Lease Sites



★ 26.2 ug Cd/g

★ 14.7 ug Cd/g

Clayoquot Sound



Land Cover in the Meares Island Region

Re: Figure 1b

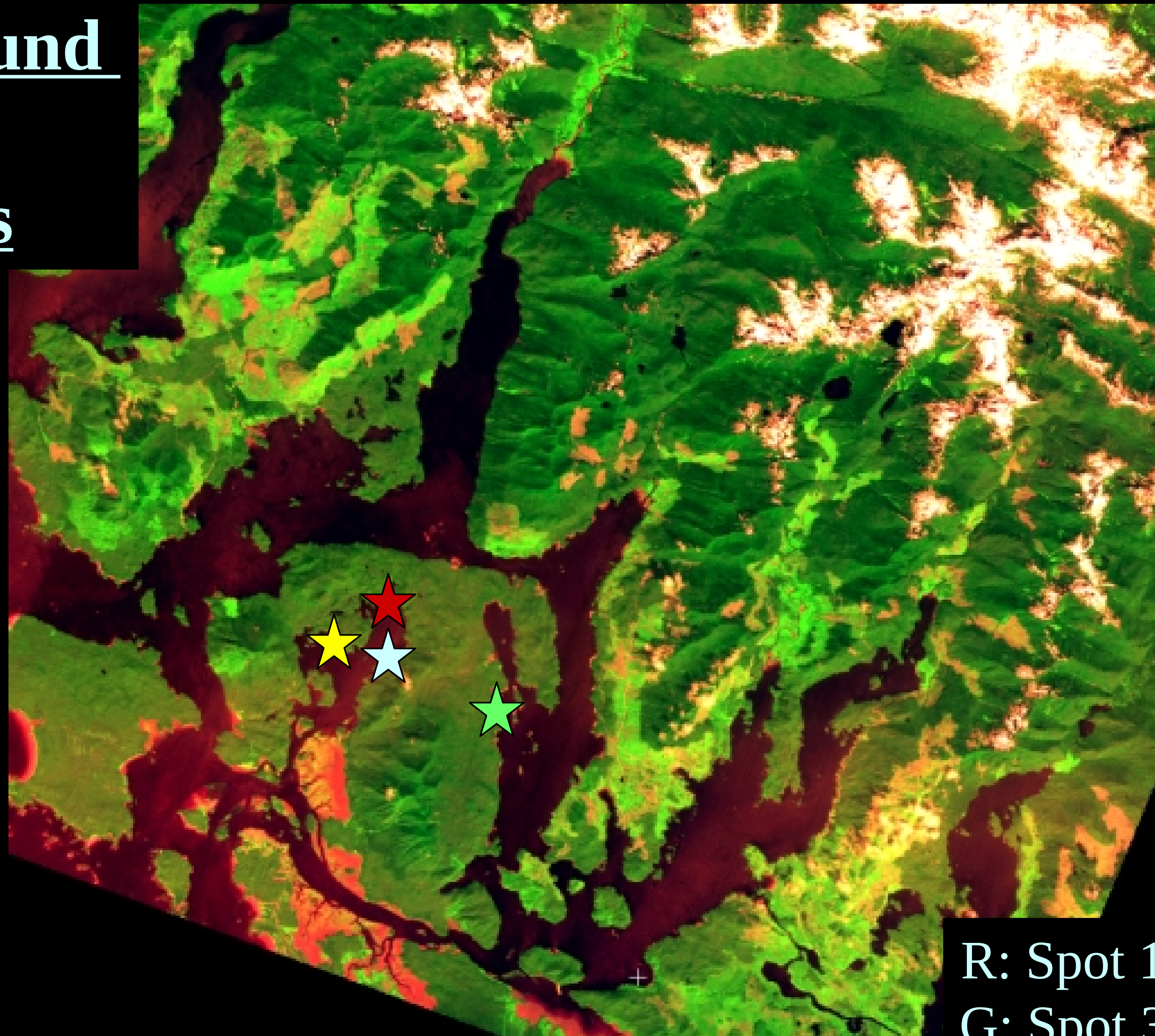
Clayoquot Sound Oyster Lease Sites

★ 10.2 ug Cd/g

★ 13.2 ug Cd/g

★ 13.8 ug Cd/g

★ 13.3 ug Cd/g



Detecting Sediment Load In Streams and Rivers

Cadmium Mobilization


Thank You !

Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD) - An Overview

A.S. (Pal) Bhogal, D.G. Goodenough, A. Dyk, R. Hall, J. Iisaka, D. Leckie, A. Hollinger (Canadian Space Agency), J. Pearlman (TRW), J. Miller (York University), Olaf Niemann (University of Victoria), Karl Staenz (NRCan CCRS), Harold Zwick (MDA)

http://www.aft.pfc.forestry.ca

To: Oyster Workshop - Terrestrial Cd Pathways Group, March 7 2001

Natural Resources Canada
Canadian Forest Service

Ressources naturelles Canada
Service canadien des forêts

Outline

- Hyperspectral data and forestry
- EVEOSD Project
- AVIRIS hyperspectral data - examples
- Summary

Introduction

- The forestry sector of Canada contributes more than $71 Billion in sales to Canada's economy and more than $50 Billion to the country's Gross Domestic Product.
- The forestry sector provides more than 850,000 jobs.
- Under the Kyoto Protocol, Canada must report: on reforestation, afforestation and deforestation; on 1990 forest carbon stocks and later years; and on land use change and forest inventory.
- Canada contains more than 10% of the world's forests (418 million hectares).
- Across Canada there is evidence that there are places where the present harvesting rates are not sustainable.

Trends in Remote Sensing

- High spatial resolution. - will lead to individual tree recognition and information systems for managing data from individual trees to watersheds to regions to the nation.
- Hyperspectral sensors. - will lead to tracking chemistry of vegetation to measure environmental state, vegetation health, and local atmospheric properties.
- Multi-frequency, multi-polarization radars. - will lead to direct measurements of biomass and timber volume.

Why Hyperspectral for Forestry

- Hyperspectral sensors can provide data for measuring the chemical properties of vegetation, such as chlorophyll, nitrogen, lignin, water, and other molecules.
- Canada contains 10% of the world's forests ($70 B /yr.). Hyperspectral data can be used for measuring indicators of sustainable development, such as forest area, forest type, biomass, disturbance, above-ground carbon, reforestation, afforestation, and deforestation, forest health, etc.
- Laboratory studies have shown remote sensing detectable chemical differences between old and new foliage, and damaged and undamaged foliage.
- NOTE: We are not at a point where we can measure inorganic constituents in foliage using hyperspectral data

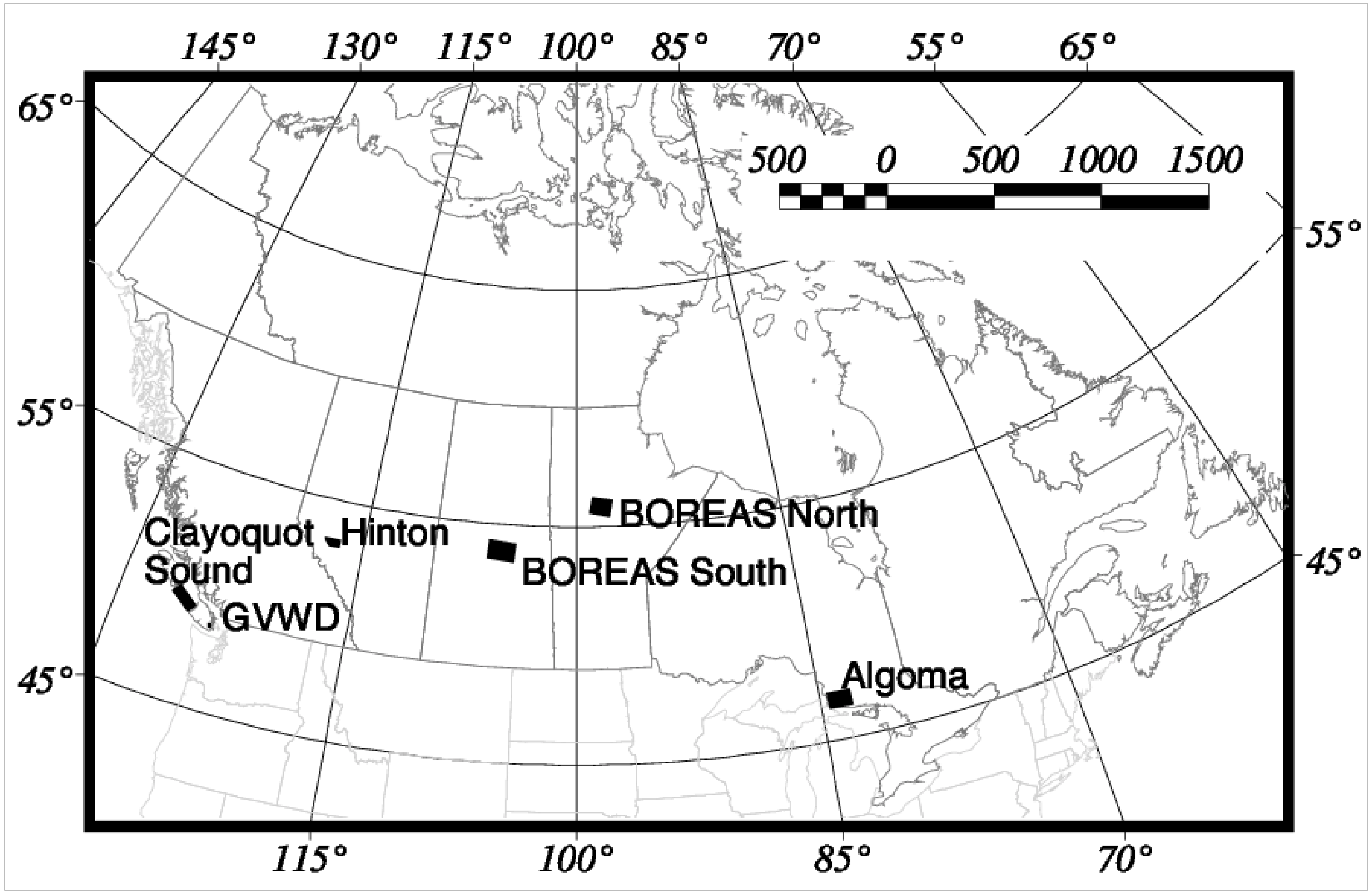
The Hyperspectral Opportunity

- Participation with NASA in the first spaceborne hyperspectral mission gains experience for CSA and the rest of the Canadian team.
- Participation with NASA enables Canada to be prepared for the Landsat 7 follow on satellites and the trend towards quantitative hyperspectral measurements from space.

Evaluation and Validation of EO-1 for Sustainable Development of Forests (EVEOSD)

- On November 21 2000, NASA launched a new experimental spacecraft carrying 3 new sensors (ALI, Hyperion, LAC).
- We were one of four successful international proposals to be selected for the EO-1 Mission. Twenty-seven proposals were selected from the US. The other 3 foreign proposals are from Australia, Japan, and Singapore.
- Partners in EVEOSD include: CFS, CSA, CCRS, MDA, University of Victoria (Geography, Computer Science), and York University (Physics).
- EVEOSD is interagency, and cross-sectoral. Academic and industrial involvement is included.
- EVEOSD will conduct experiments on 6 sites

EVEOSD Test Site Distribution



One U.S. Site : Hoquiam, Washington

What is EO-1 ?

- EO-1 is space technology development of NASA under their New Millennium Program. EO-1 has three missions: a) Landsat continuity; b) Hyperspectral development; c) Atmospheric correction.
- EO-1 is a prototype spacecraft to validate and demonstrate sensor technologies and lower cost methods for space platforms.
- EO-1 has three sensors: the Advanced Land Imager (ALI); a hyperspectral sensor Hyperion; and an atmospheric correction sensor: LAC.

The EO-1 Sensors

- ALI: 10 bands, 30 m plus 10 m panchromatic; 12 bit quantization; 37.5 km swath.
- Hyperion: 220 bands, 30 m, 10 nm bandwidth, 400 nm to 2500 nm; 12 bit quantization; 7.5 km swath.
- LAC: 256 bands, 250 m, 2 to 6 nm bandwidth, 900 nm to 1600 nm, 12-bit quantization, 185 km swath.

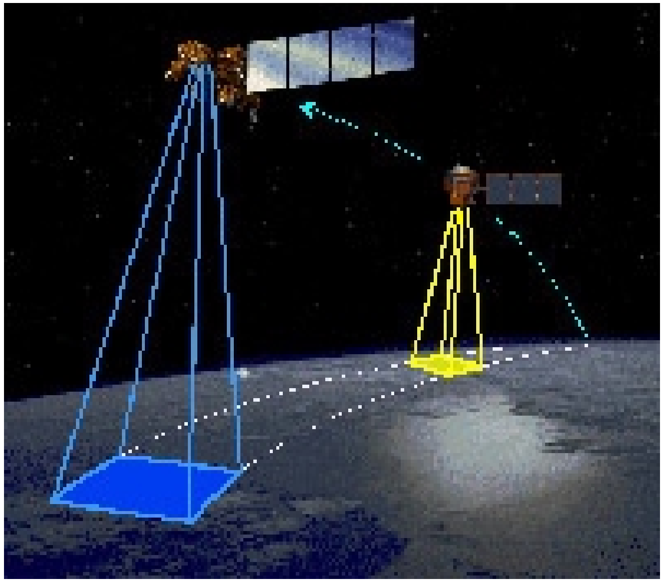
Mission Overview

- Validate revolutionary technologies contributing to the reduction of cost and increased capabilities for future land imaging missions
- Revolutionary land imaging instruments on EO-1
  - Hyperion
  - Advanced Land Imager (ALI)
  - Atmospheric Corrector (AC)

- Revolutionary Spacecraft technologies on EO-1
  - X Band Phased Array Antenna (XPAA)
  - Pulse Plasma Thruster (PPT)
  - Light Weight Flexible Solar Array (LFSA)
  - Carbon-Carbon Radiator (CCR)
  - Enhanced Formation Flying (EFF)

More on website: eo1.gsfc.nasa.gov

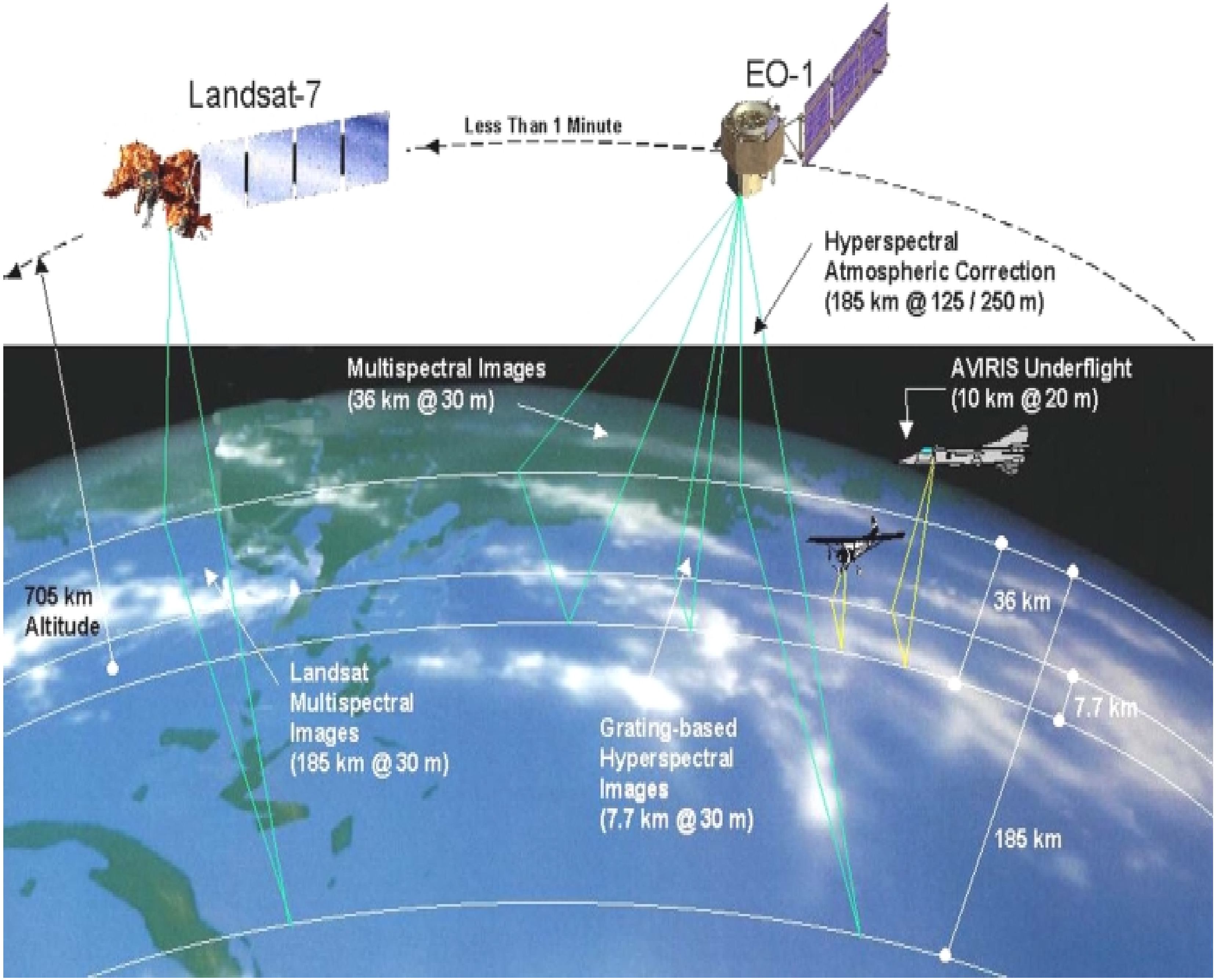
Mission Overview



- Launched November 21 2000 from Vandenberg Air Force Base on a Delta launch vehicle
- Orbit: 705 km circular sun synchronous, 98.2 degree inclination
- Flies one minute behind Landsat and collects nearly identical images for comparison purposes

- For each image collected
  - Approximately 13 Gbits of scene data from Hyperion, ALI and AC is collected and stored on the on-board solid state data recorder at high rates
  - When in range of ground station, data is transmitted to ground and forwarded via tape to GSFC for analysis and validation by EO-1 science and technology teams

Pictorial Overview of Science Objectives



EO-1 Coordinated Image Collection Opportunities

Parameters	Landsat 7 ETM+	EO-1 Multispectral	EO-1 HYPERION	EO-1 AC	A/C Underflight AVIRIS	A/C Underflight TRWIS III
Spectral Range	0.4 - 2.4* µm	0.4 - 2.4 µm	0.4 - 2.5 µm	0.9 - 1.6 µm	0.4 - 2.5 µm	0.4 - 2.5 µm
Spatial Resolution	30 m	30 m	30 m	250 m	20 m	1-8 m
Swath Width	185 Km	36 Km	7.5 Km	185 Km	11 Km	0.3 - 2.0 Km
Spectral Resolution	Variable	Variable	10 nm	6 nm	12 nm	6 nm
Spectral Coverage	Discrete	Discrete	Continuous	Continuous	Continuous	Continuous
Pan Band Resolution	15 m	10 m	N/A	N/A	N/A	N/A
Total Number of Bands	7	10	220	256	224	384

* *Excludes thermal channel*

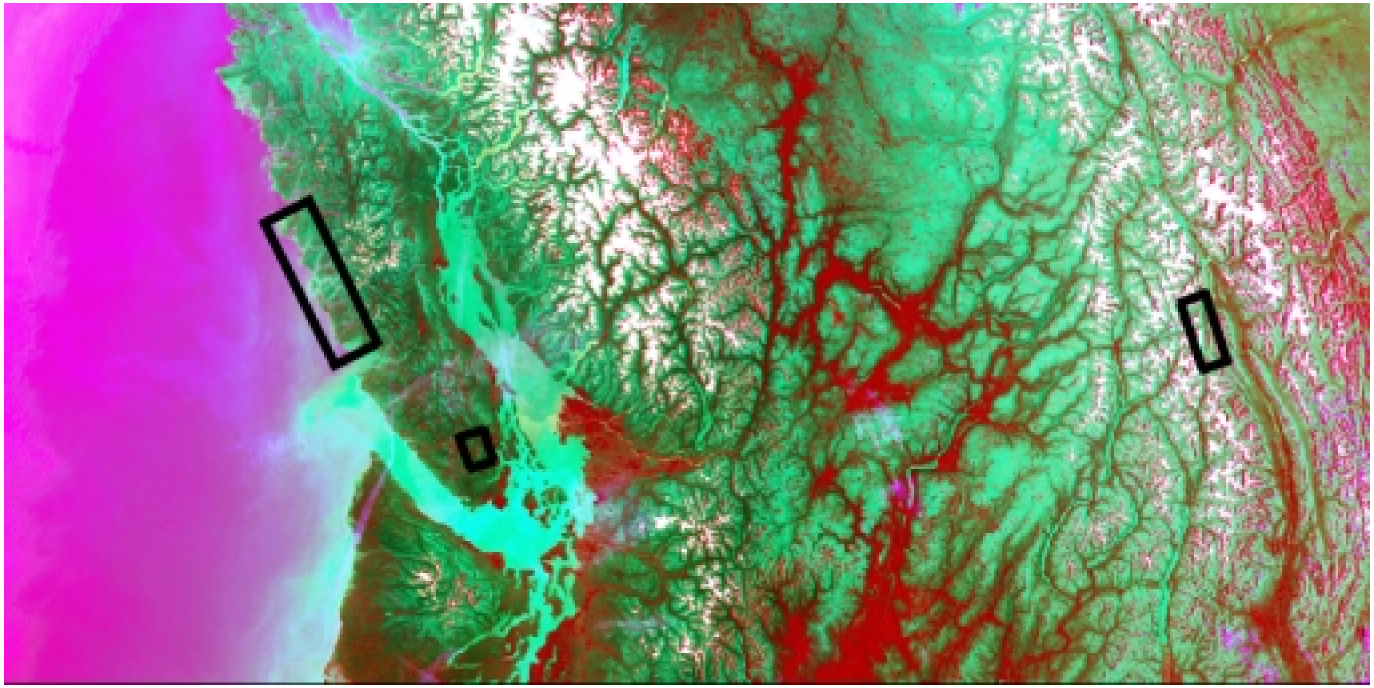
Hyperion Science Application Topics

- Produce Landsat-type products, e.g., spectral vegetation indices, closed/sparse canopy, thematic maps (urban studies), snow and land cover/land use change, land surface temperature (day/night), fire, thermal anomalies and burn scars
- Assess the capability of MS/Pan to meet the needs of Landsat user community
- Assess capabilities of MS/Pan and hyperspectral over the growing season to evaluate seasonal variations
- Extract biophysical properties, e.g., fraction absorbed photosynthetically-active radiation (FPAR), leaf area index (LAI), and net primary production (NPP)
- Study bi-directional reflectance distribution function (BRDF) and surface reflectance products
- Determine surface spectral bi-directional reflectance corrected for atmosphere
- Conduct regional field studies, field data campaigns

Hyperspectral work with AVIRIS Data (Airborne Visible Infra-red Imaging Spectrometer)

- We have used 1993-1994 AVIRIS data for hyperspectral research
- Data has been acquired over the GVWD and Clayoquot Sound test sites
- We present some examples using AVIRIS data

SEIDAM TEST SITES (GVWD, CLAYOQUOT SOUND, PARSON)

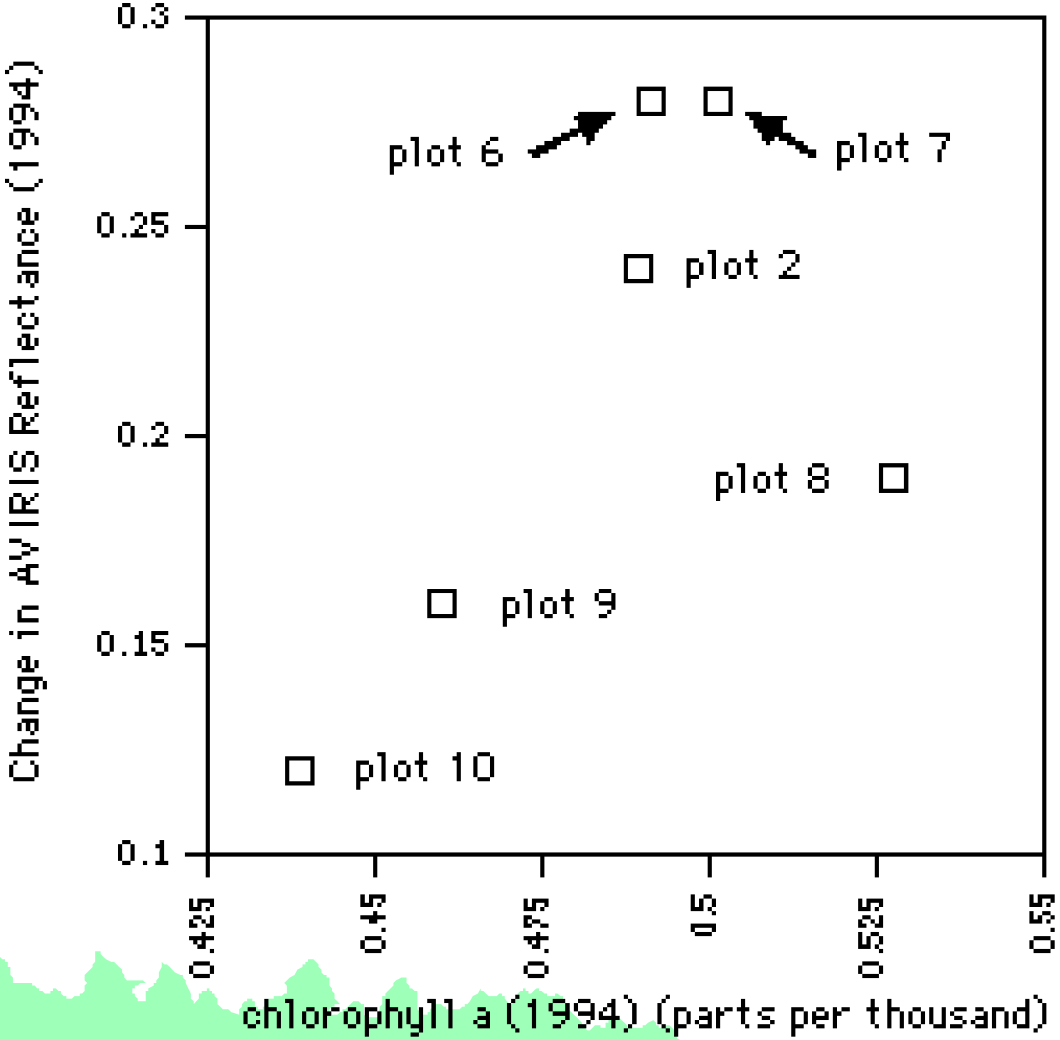


GVWD = 10 km by 23 km

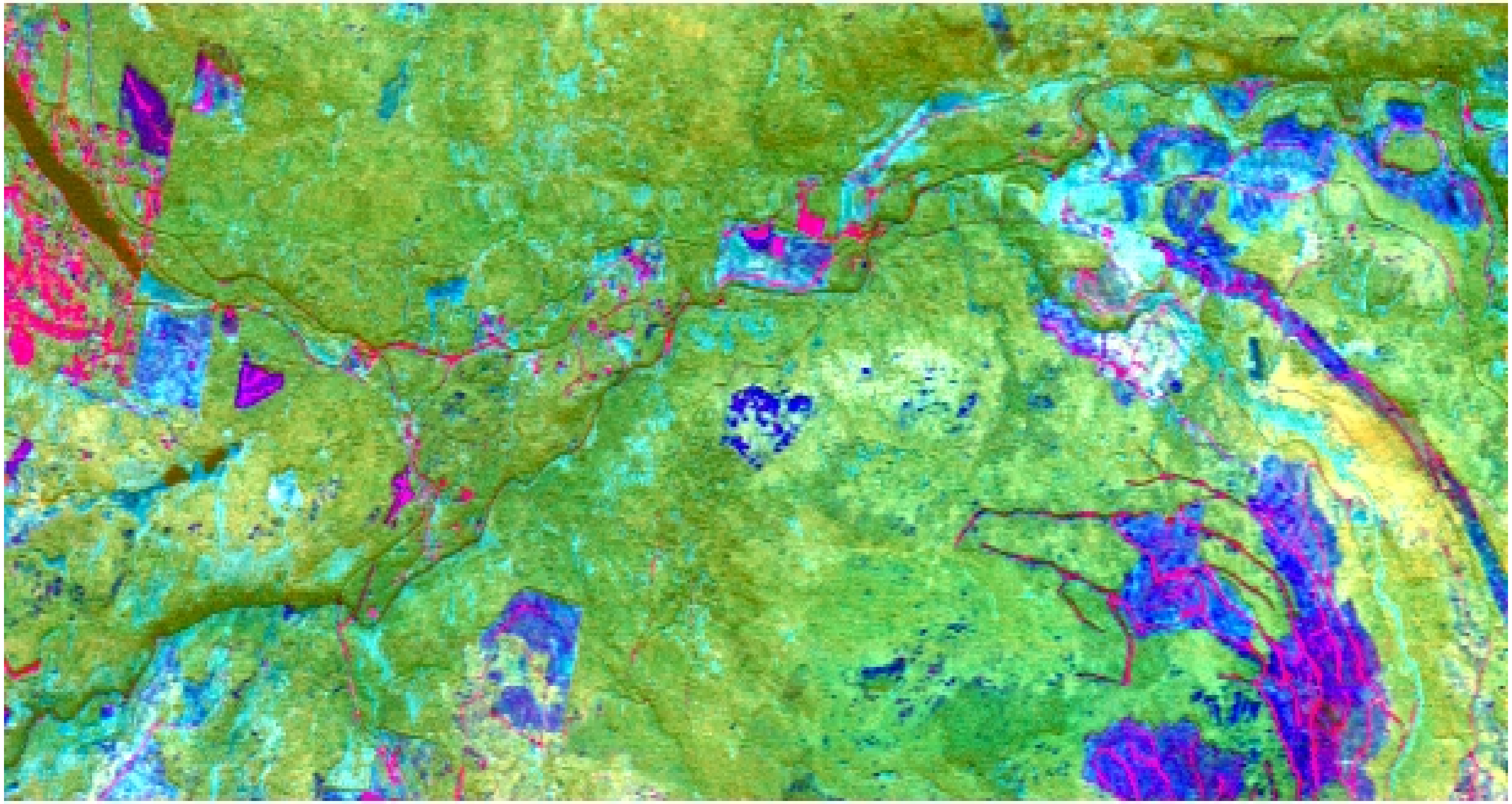
Clayoquot Sound = 70 km by 125 km

Parson = 10 km by 30 km

Chlorophyll a - Measured and Remotely Sensed by AVIRIS in Tofino Creek, Clayoquot Sound

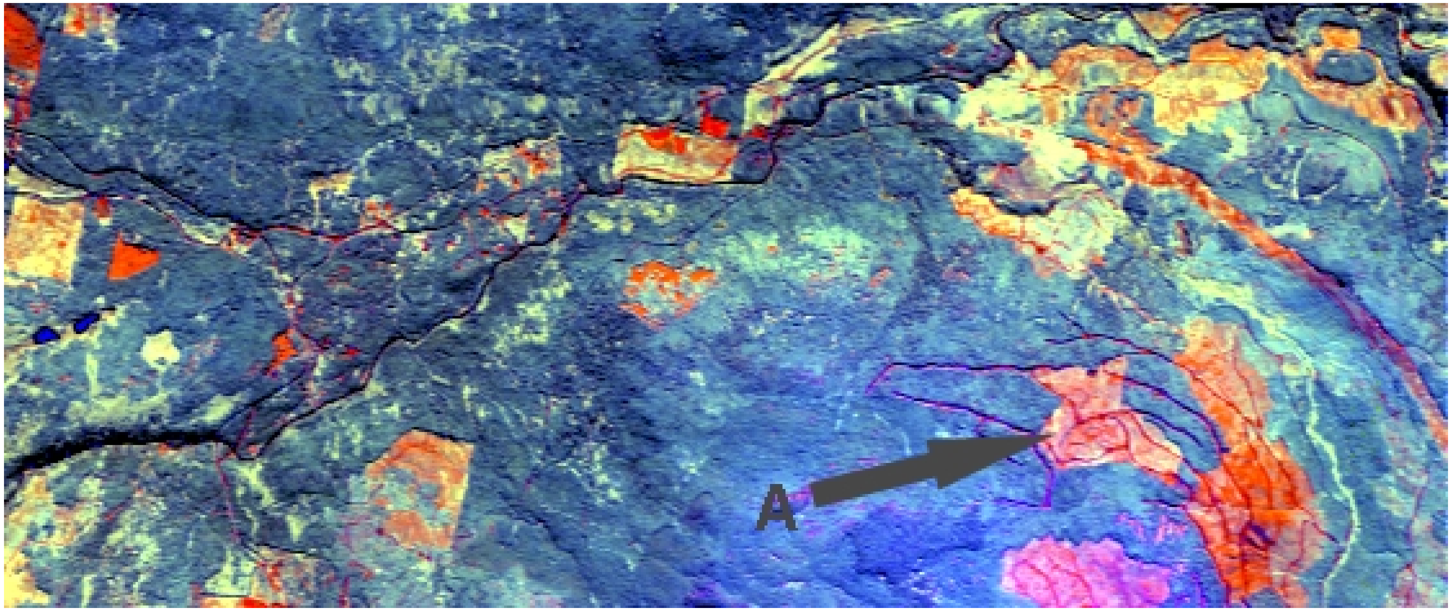


PCA Analysis (170 channels)



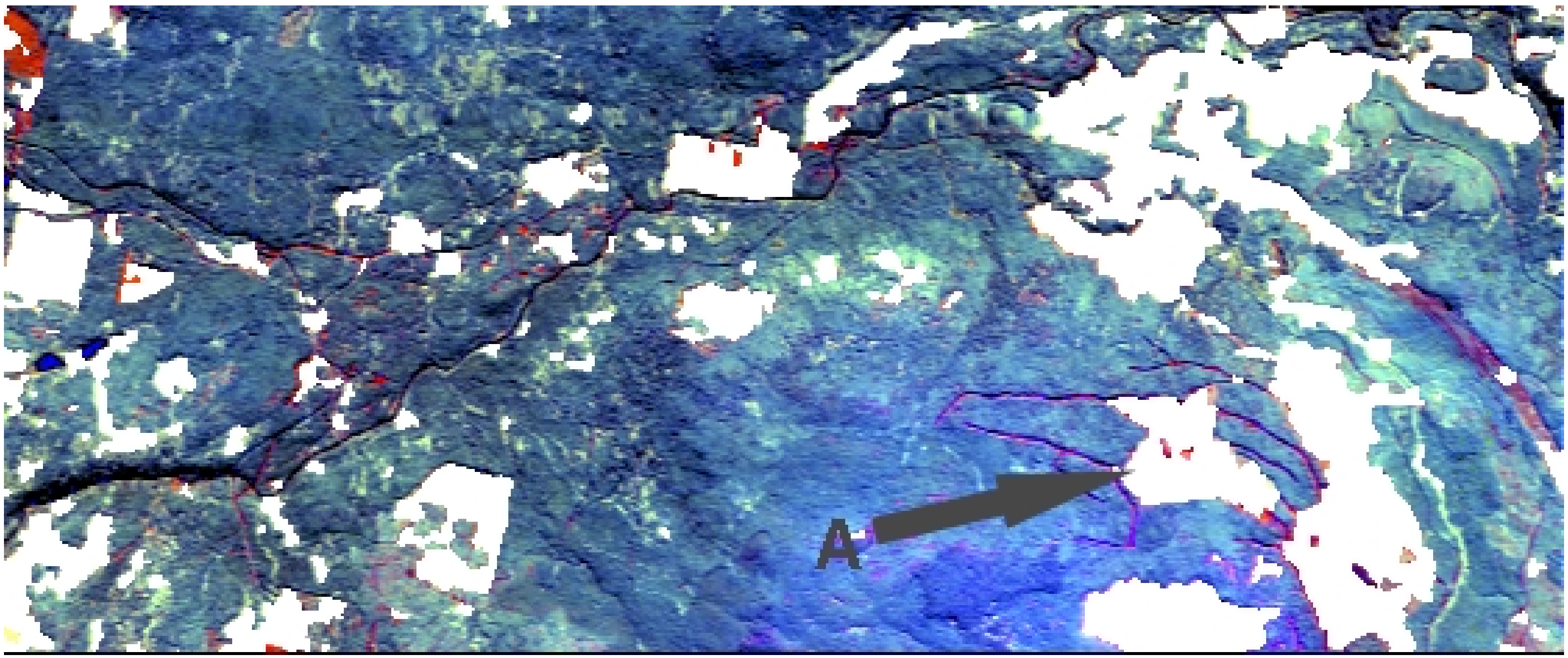
Principal component analysis (eigenvectors 1, 2 and 5) image computed using 170 channels of AVIRIS data from August, 1993. Clear-cuts appear as shades of blue, older vegetation appears as green, and gravel/civilization appears as red.

AVIRIS Band Moment Analysis Image



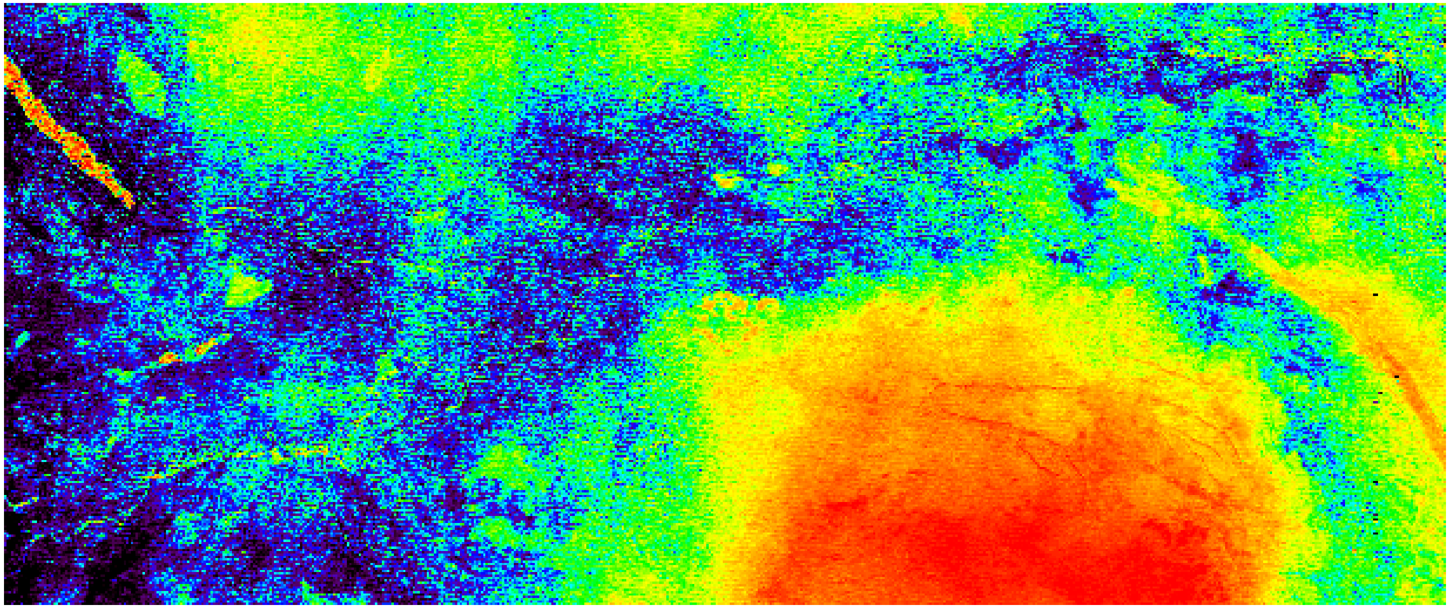
Band-moment reflectance image based on mean, standard deviation and skewness. Gravel and clear-cuts appear as shades of red and pink, with regeneration areas appearing as intermediate green/blue. Older growths appear as blue. Note the clear-cut labeled as “A” prior to segmentation.

Segmented AVIRIS BM Data



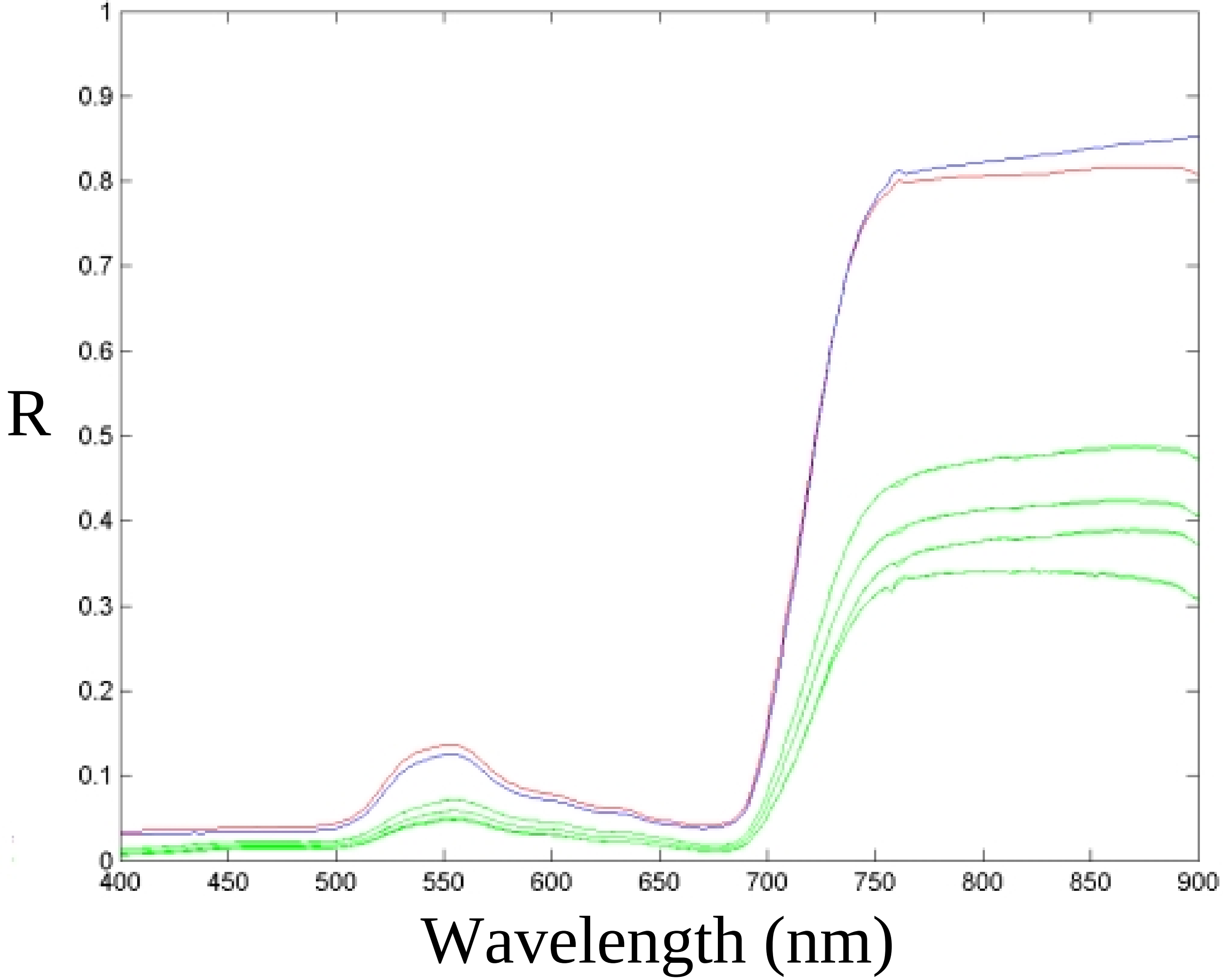
Major clear-cuts are correctly identified through the segmentation process on this ban-moment image (mean, standard deviation and kertosis). The segmented clear-cuts are shown in white. The clear -cut labeled as “A” is highlighted.

Atmospheric Water Vapour

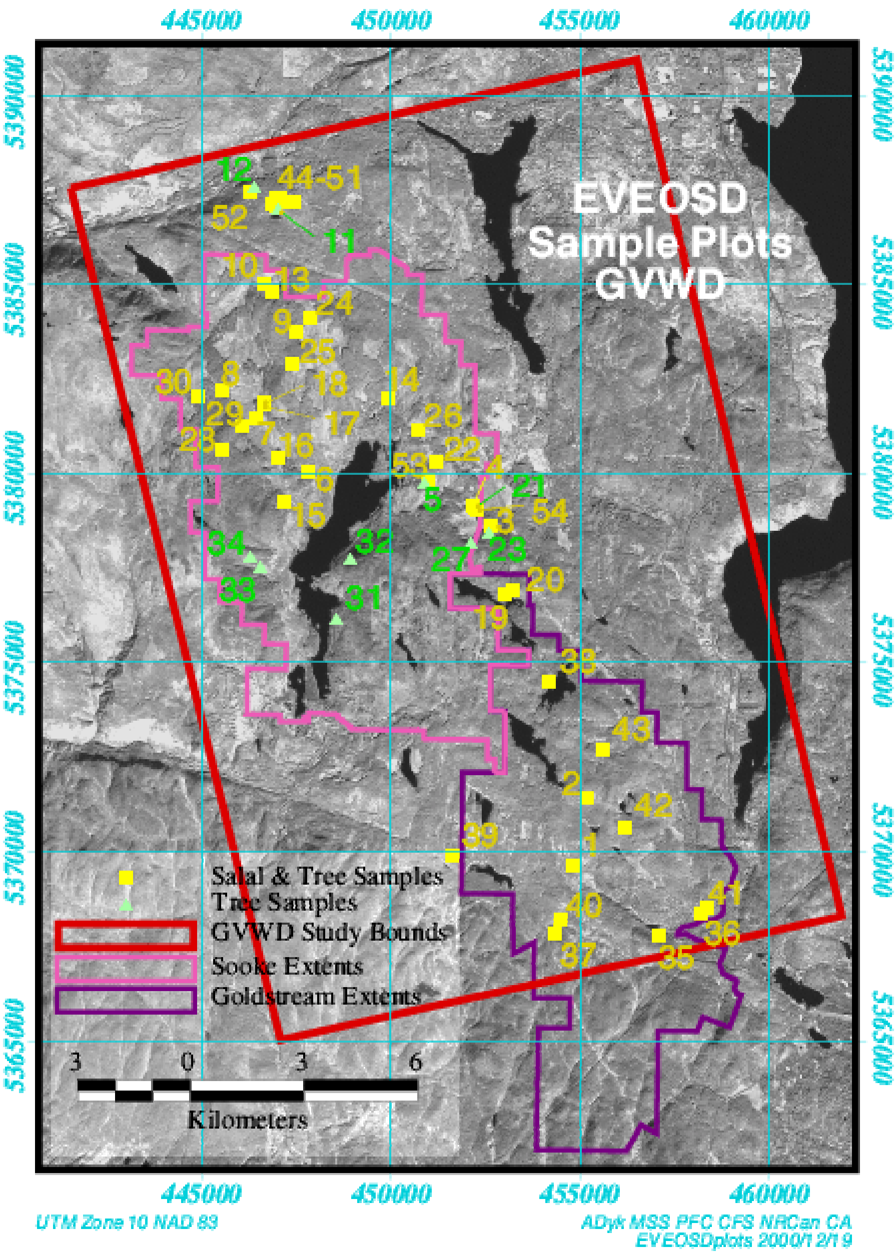


Density sliced AVIRIS image acquired over the Greater Victoria Water District in August, 1993 showing water vapour distribution in the atmosphere. Red denotes areas of highest water vapour distribution, with blue denoting areas of least concentration. Atmospheric absorption has been modeled as the ratio of 876 nm divided by 943 nm.

Reflectance of salal in shade (r) and sunlight (b) vs D. Fir spectra from stack (g)



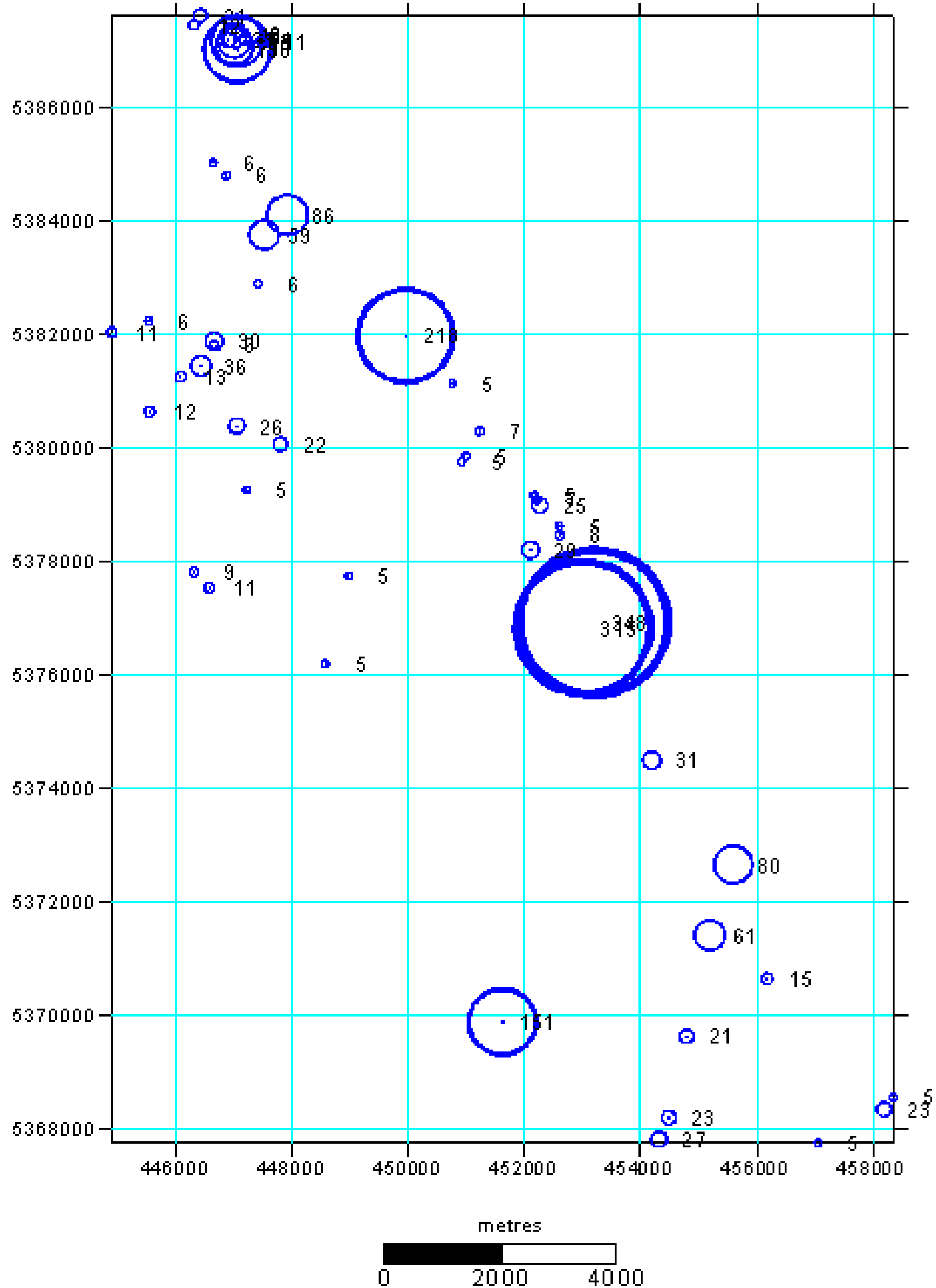
Sampling Locations in GVWD



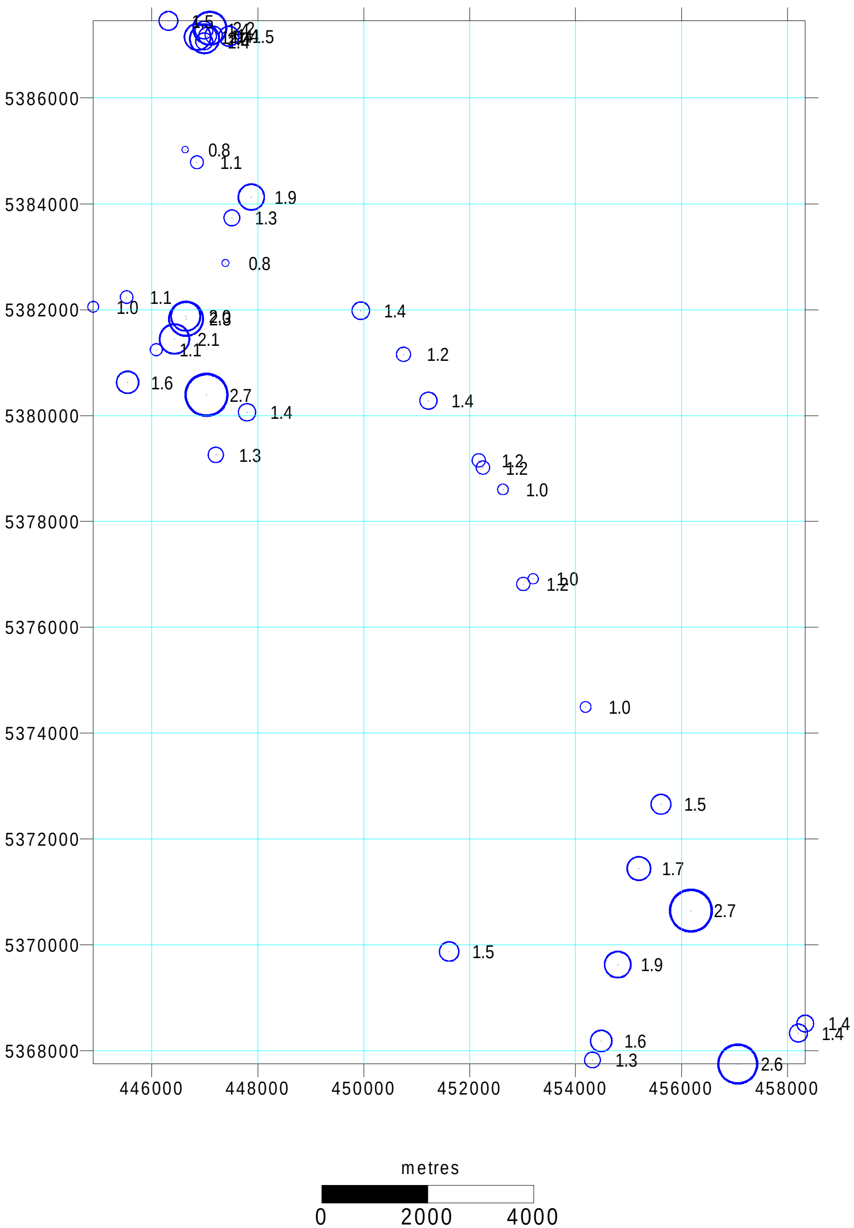
Foliar Sampling and Organic/Inorganic Analysis

- Tree tops
  - 540 Douglas Fir from 55 plots plus 50 of five other species
- Salal
  - 208 samples from 43 plots

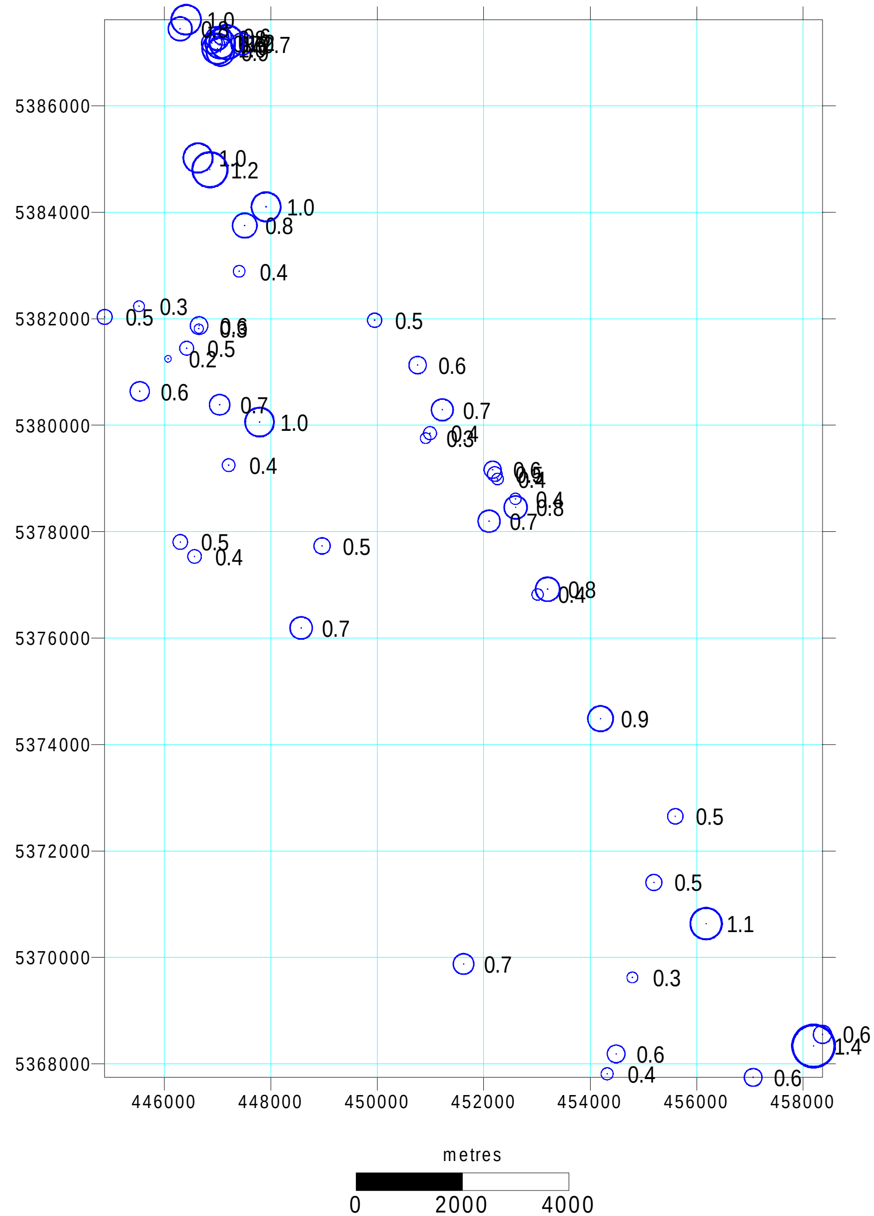
Arsenic (ppm) in ash of D. Fir Needles



CADMIUM (ppm) in ash of Salal Leaves



CADMIUM (ppm) in ash of Douglas-fir Needles



Summary

- Satellite hyperspectral data has potential for determination and mapping of chemical constituents in the forest canopy
  - Our efforts will use EO-1 data and newer AVIRIS data sets (due to be acquired over our test sites in 2001) in this effort
- Validation of hyperspectral observations of chemical constituents the canopy and ground will use field spectrometers and chemical analysis of foliar samples
- Integration of canopy reflectance models will assist in determination of BRDF effects to improve quantitative measurements.

Some Applications of Remote Sensing to Aquaculture

Gary Borstad
Borstad Associates Ltd.
Sidney BC

Gary@Borstad.com

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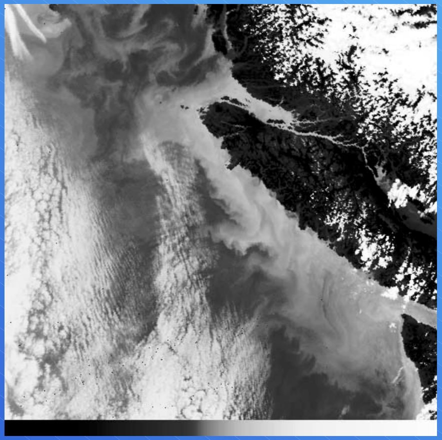

Some Practical Considerations for Remote Sensing of Coastal Zones

- Spatial Resolution (bays < inlets < estuaries < rocky shores)
- Temporal Scales (tides, weather - hrs or days)
- Immediacy (how soon is information needed?)
- Which part of electromagnetic spectrum is to be measured (UV, Visible, IR, microwave)
- Spectral Resolution (in VNIR intertidal vegetation requires narrow well placed bands)
- Dynamic Range (eg, shoreline vegetation and deep water have very different NIR signals)

Ways to look at a coastline

- Eyeballs
- Film + video cameras
- Video + GPS (aircraft and underwater)
- Multi-spectral video
- Airborne and Satellite Digital Systems
  - Imaging Spectrometers
  - Thermal Scanners
  - Laser Profilers
  - Fluorosensors
  - Synthetic Aperture Radar

Fast/cheap, Qualitative

more quantitative
precise geolocation
slower, more expensive

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Ocean parameters accessible via optical remote sensing

- Chlorophyll concentration (some class types?)
- Phytoplankton physiology? (via solar stimulated fluorescence)
- Suspended sediment concentration
- Slicks (oil, natural slicks)
- Near surface fish schools in shallow water
- Effluents (sewage, pulp mills, dyed discharges)
- Intertidal and shallow subtidal vegetation
- Sea surface termperature
- Shallow bathymetry in clear water
- Ocean features (fronts, inferred currents, drift of dye)
- Sea ice

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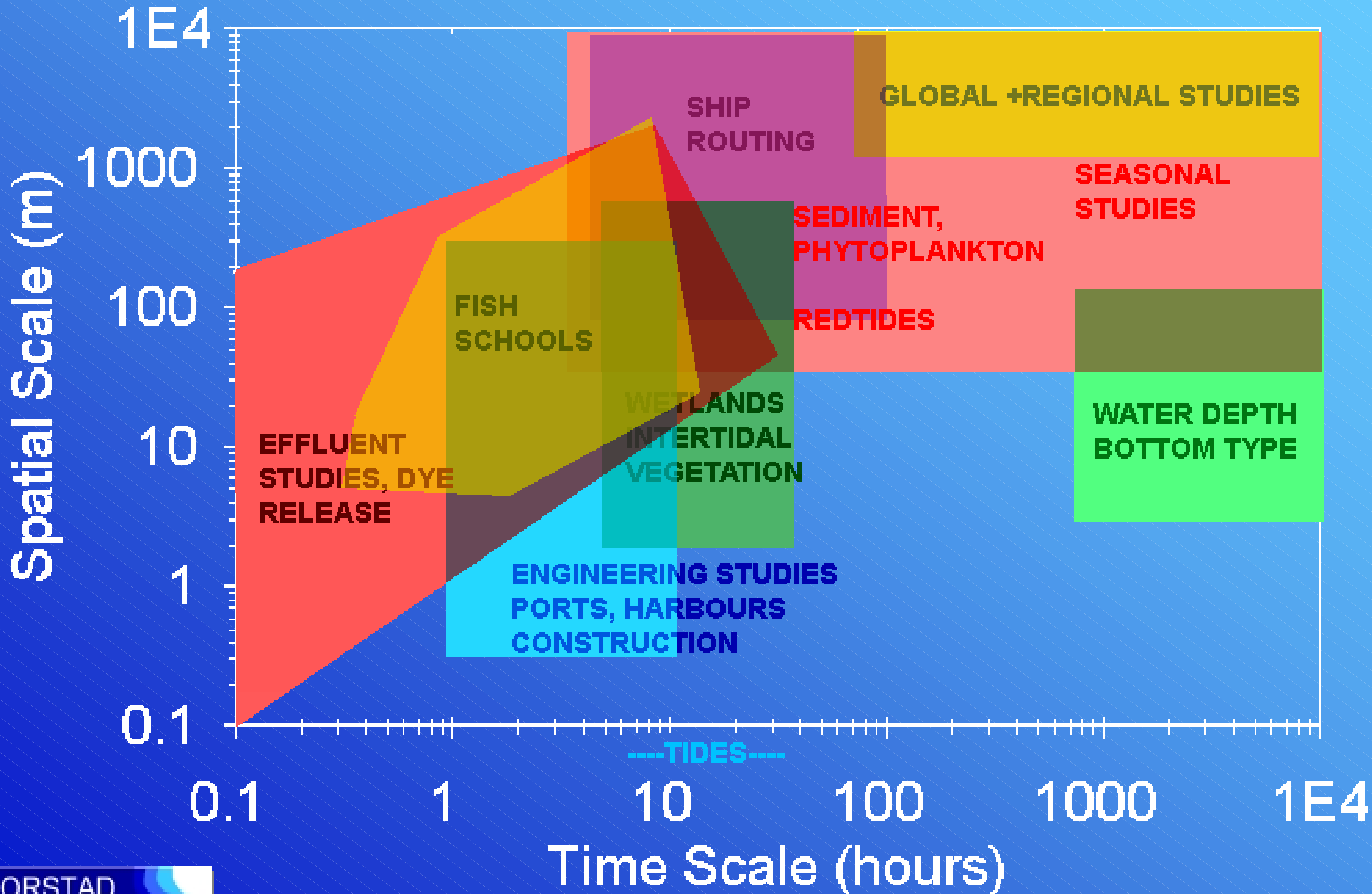
Time Space scales of some ocean phenomena



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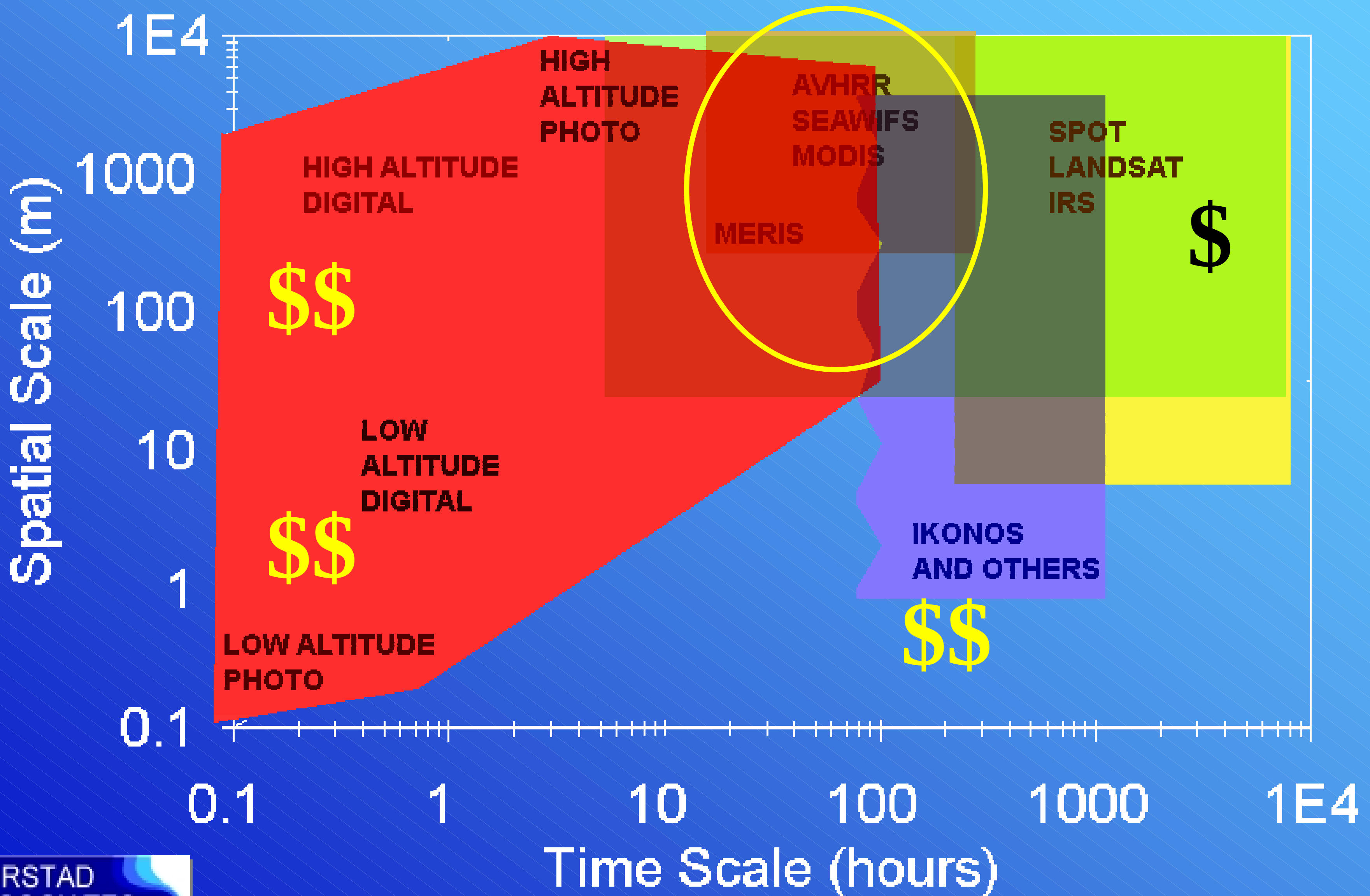
Time Space scales of some remote sensors



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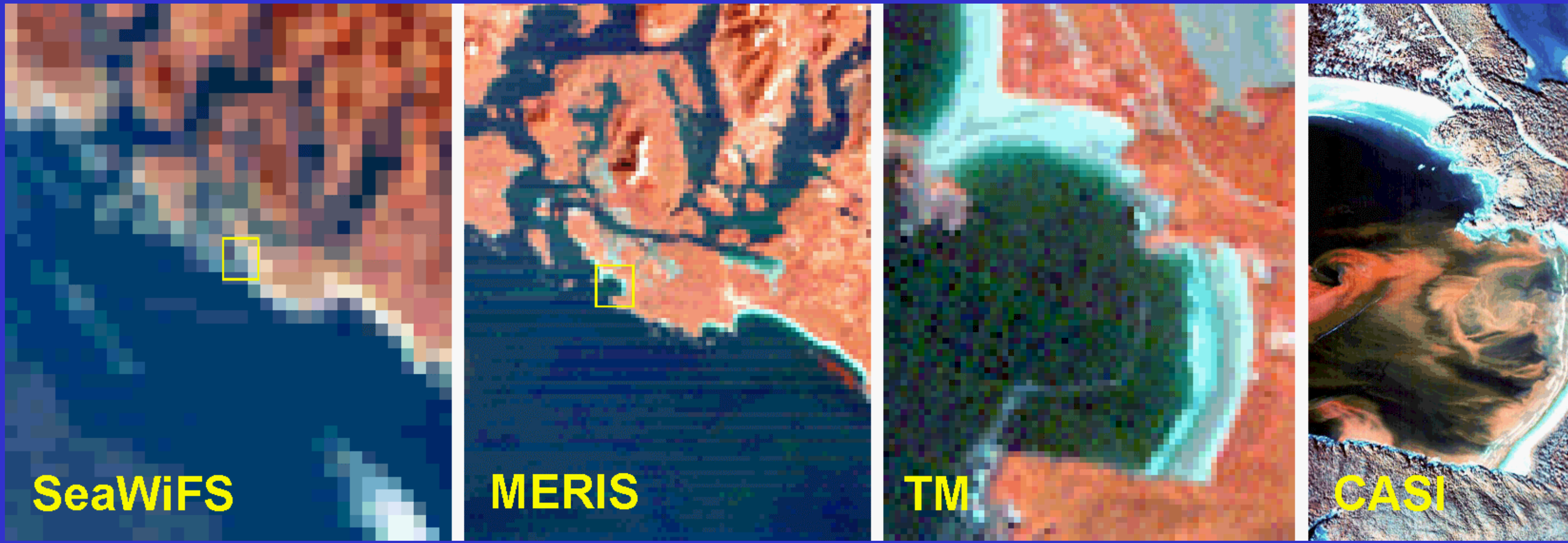
Spatial Resolution

1km | 300m | 30m | 3m



1978-86, 98-> | **2001 -** | **1982->** | **1990->**

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Background

The apparent colour of a water body is determined by

- water itself (absorbs red)
  - think tropical oceans
- phytoplankton (absorbs mostly blue)
  - think green duck pond
- Suspended Inorganic Materials (little absorption)
  - think glacier fed stream or lake
- Dissolved Organic Materials (absorbs blue)
  - think muskeg lakes or Tea

It is possible to interpret water colour and derive concentrations for these constituents

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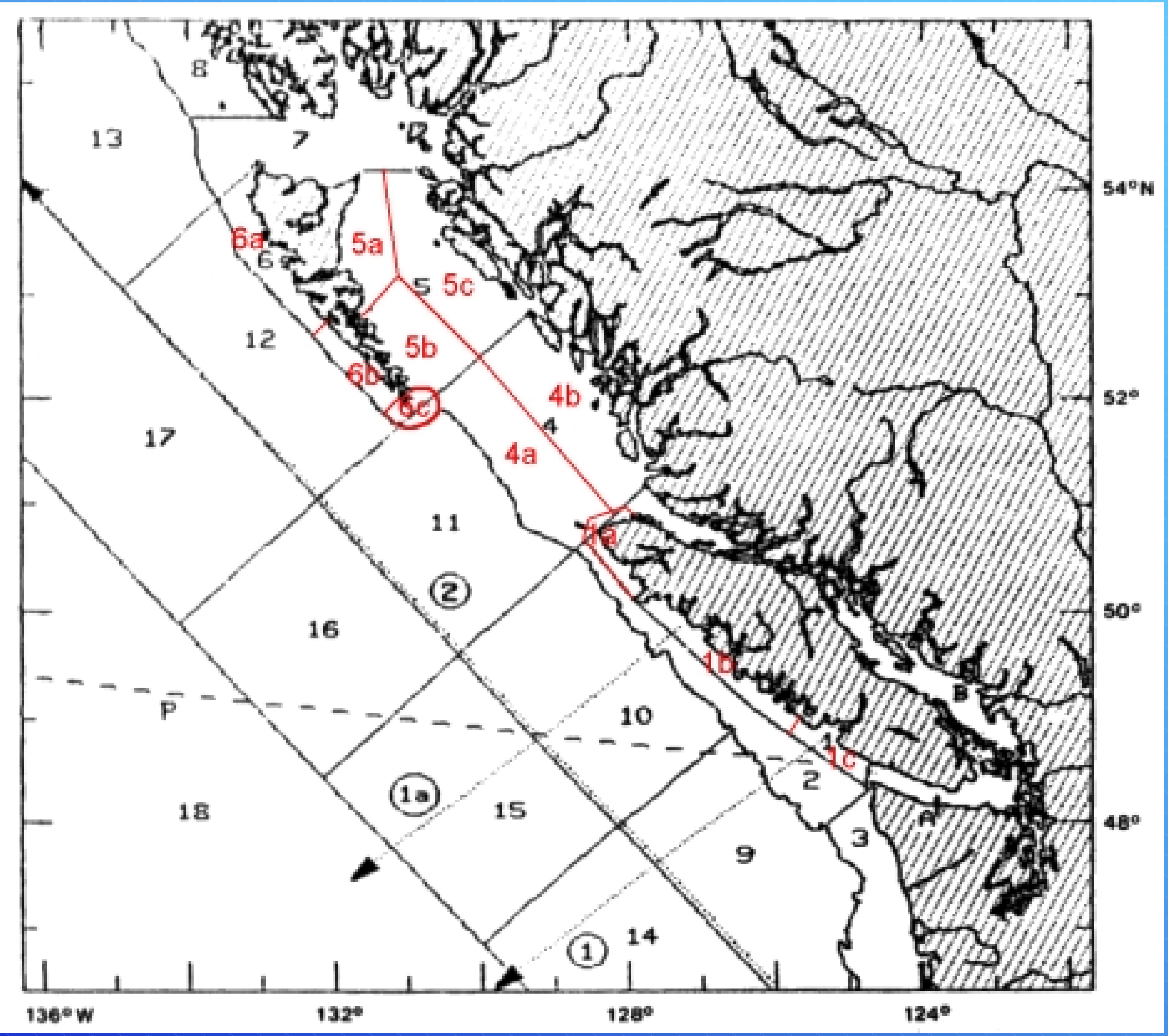
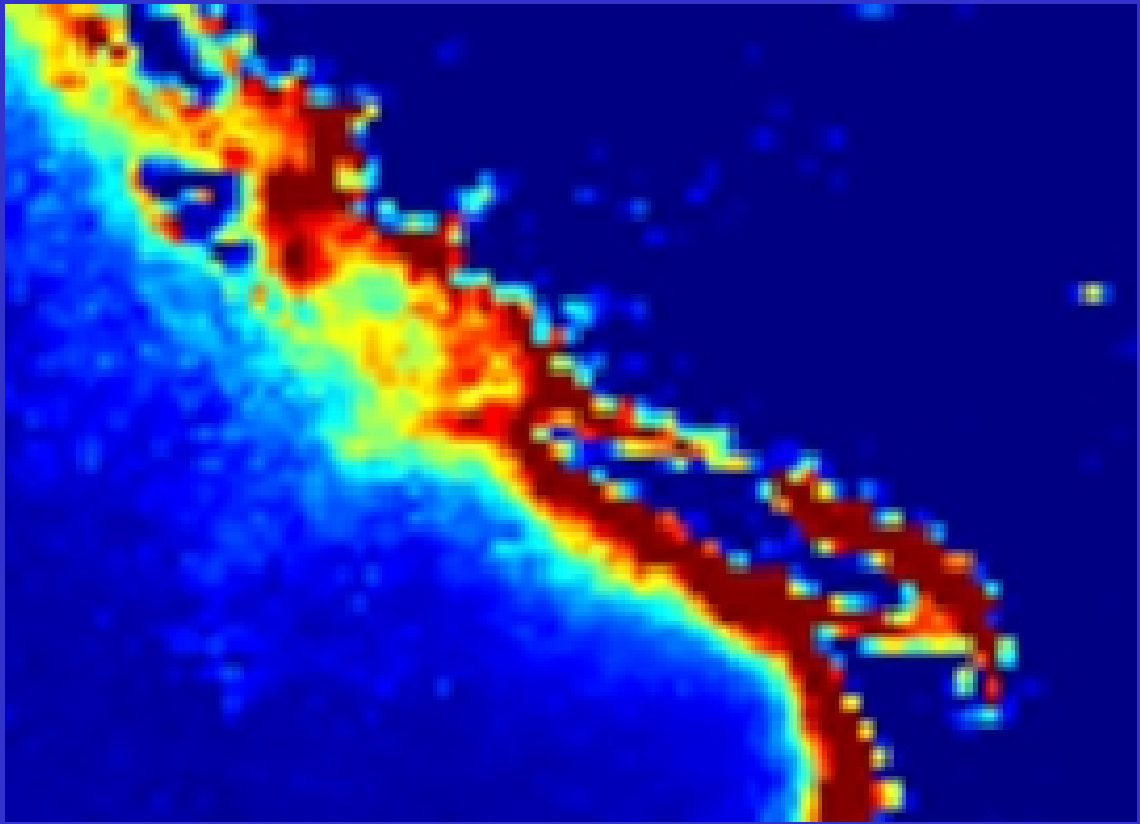
Seasonality of surface chlorophyll

- Analysis done for Parks Canada



AVERAGE CHLOROPHYLL CONCENTRATION

- 18 Km
- 1st Principal Component of 8 years CZCS data 1978-86



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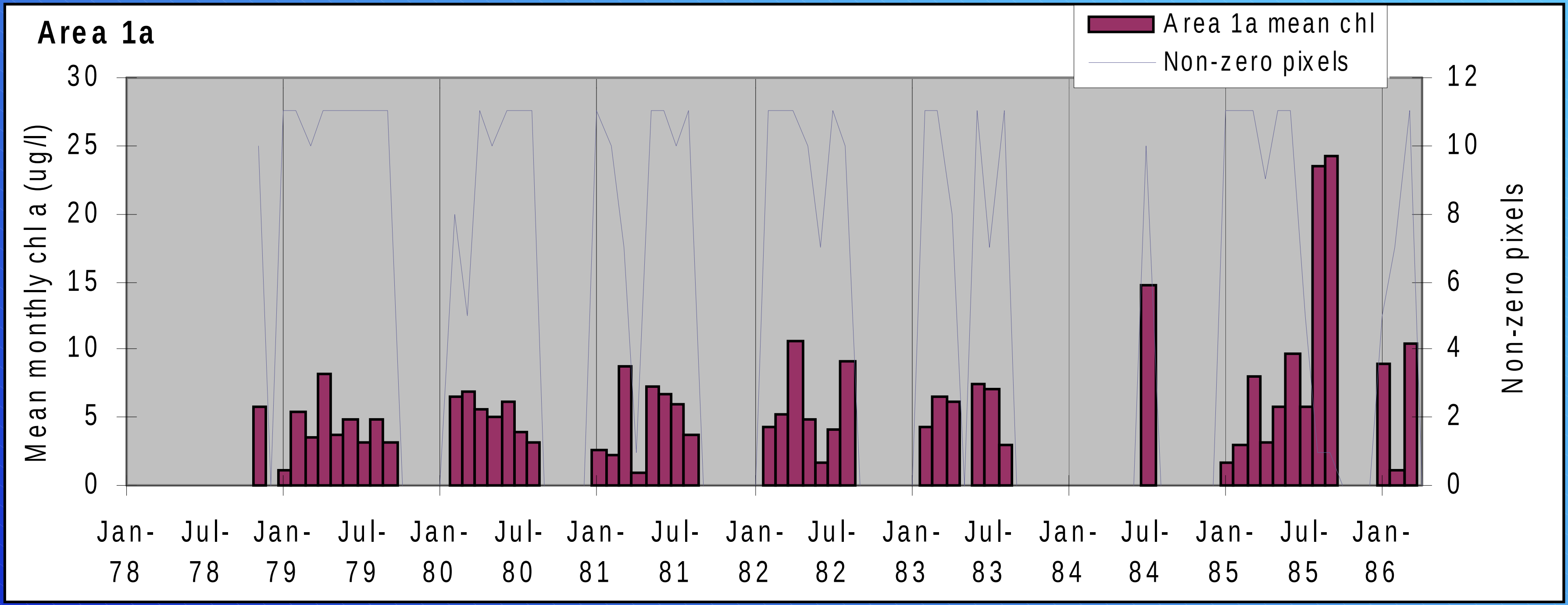
Seasonality and interannual variability of surface chlorophyll



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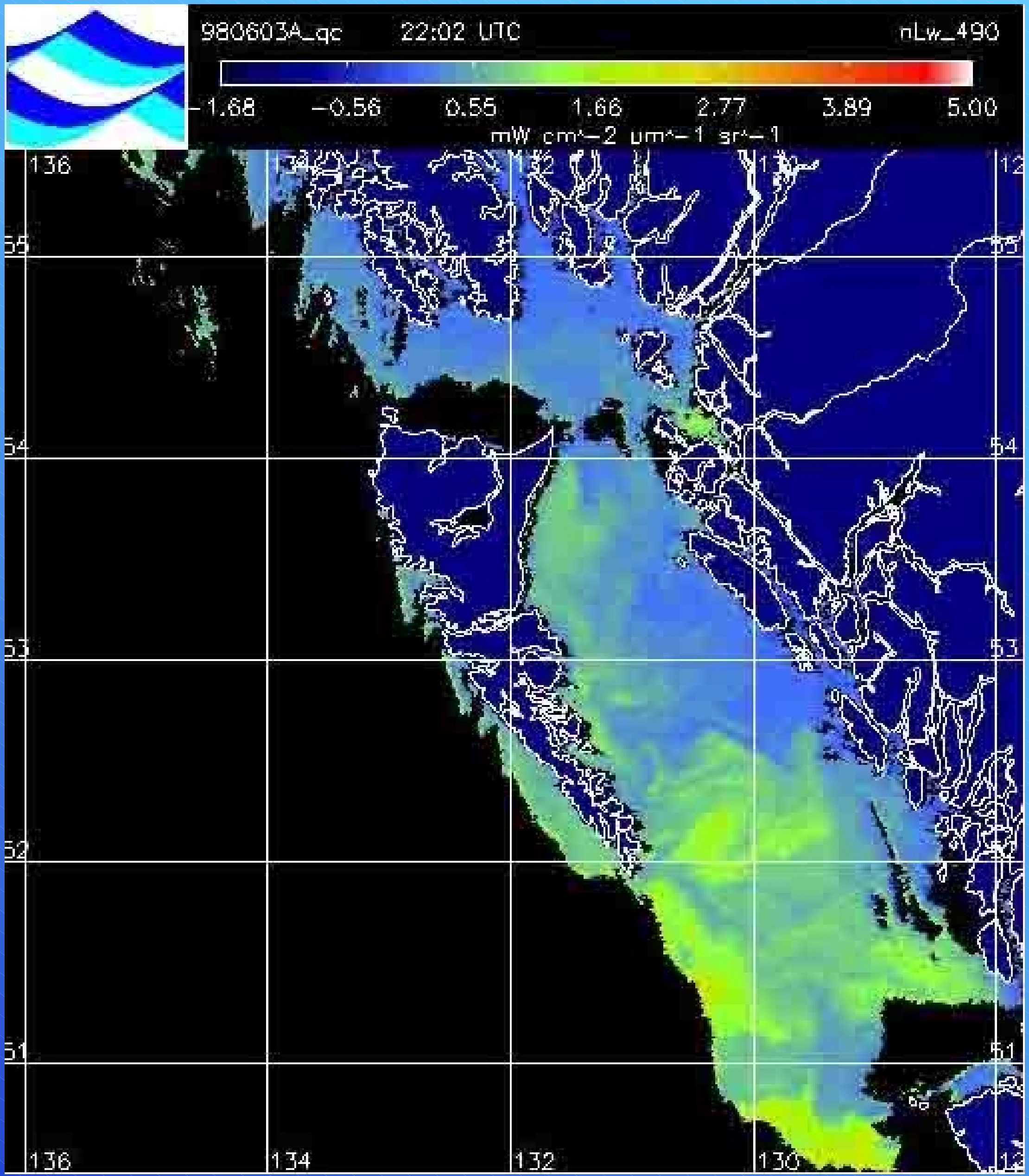
Plankton bloom sequence off Queen Charlotte Islands

- SeaWIFS imagery acquired by Jim Gower, IOS
- June 3, 1998



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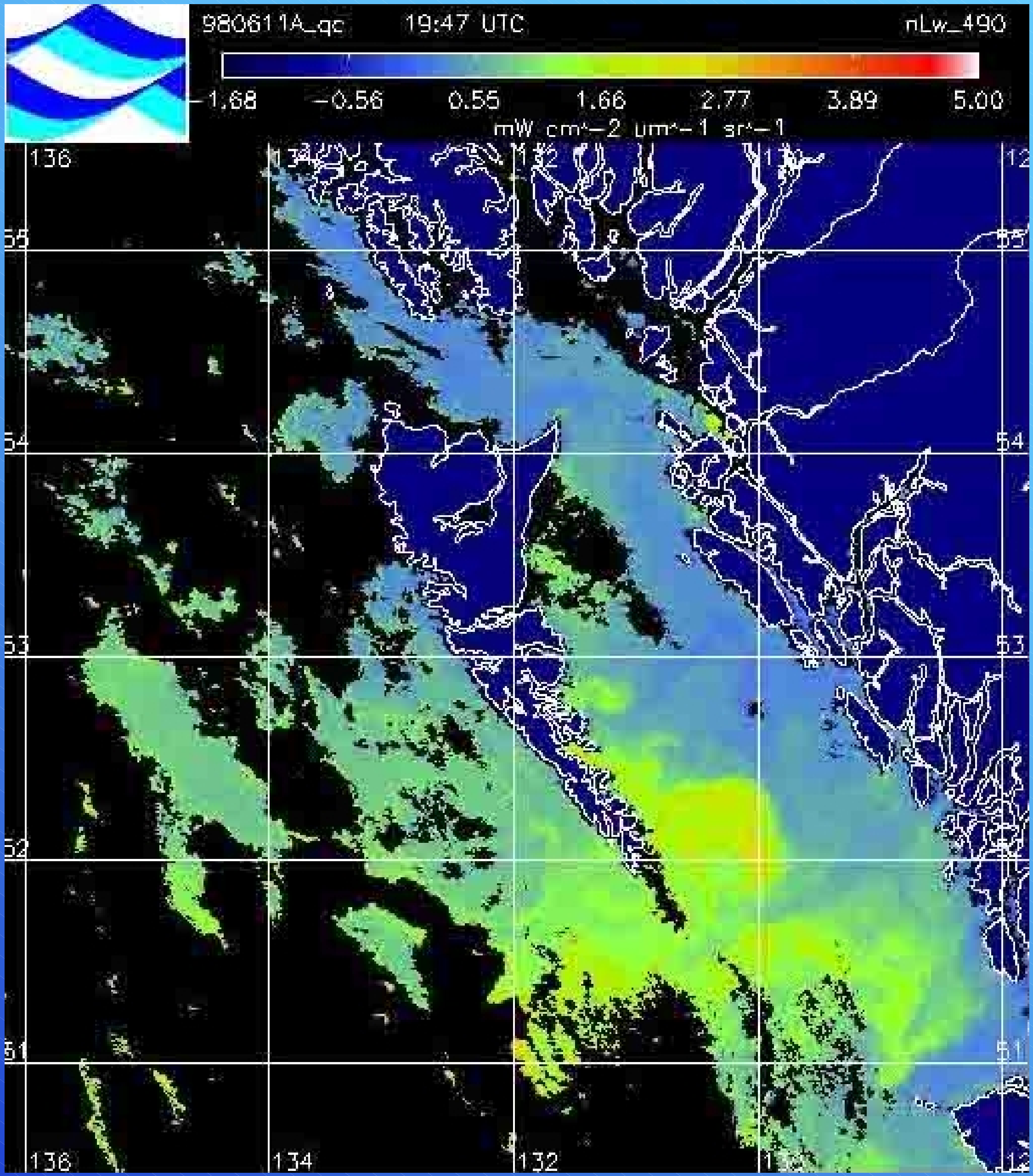
Courtesy Jim Gower, IOS

Plankton bloom sequence

- June 11, 1998



Courtesy Jim Gower, IOS

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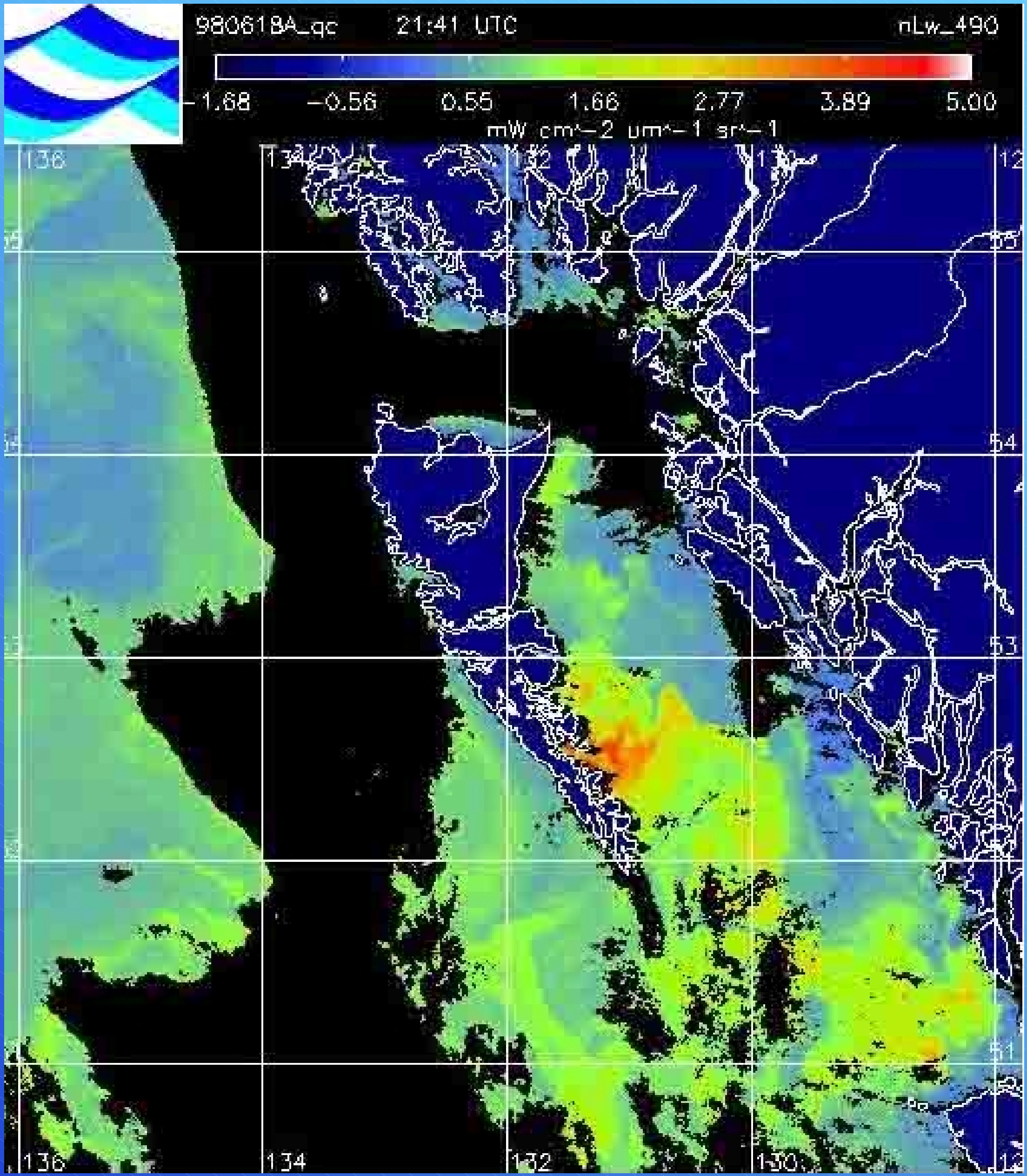
Plankton bloom sequence

- June 18, 1998



Courtesy Jim Gower, IOS

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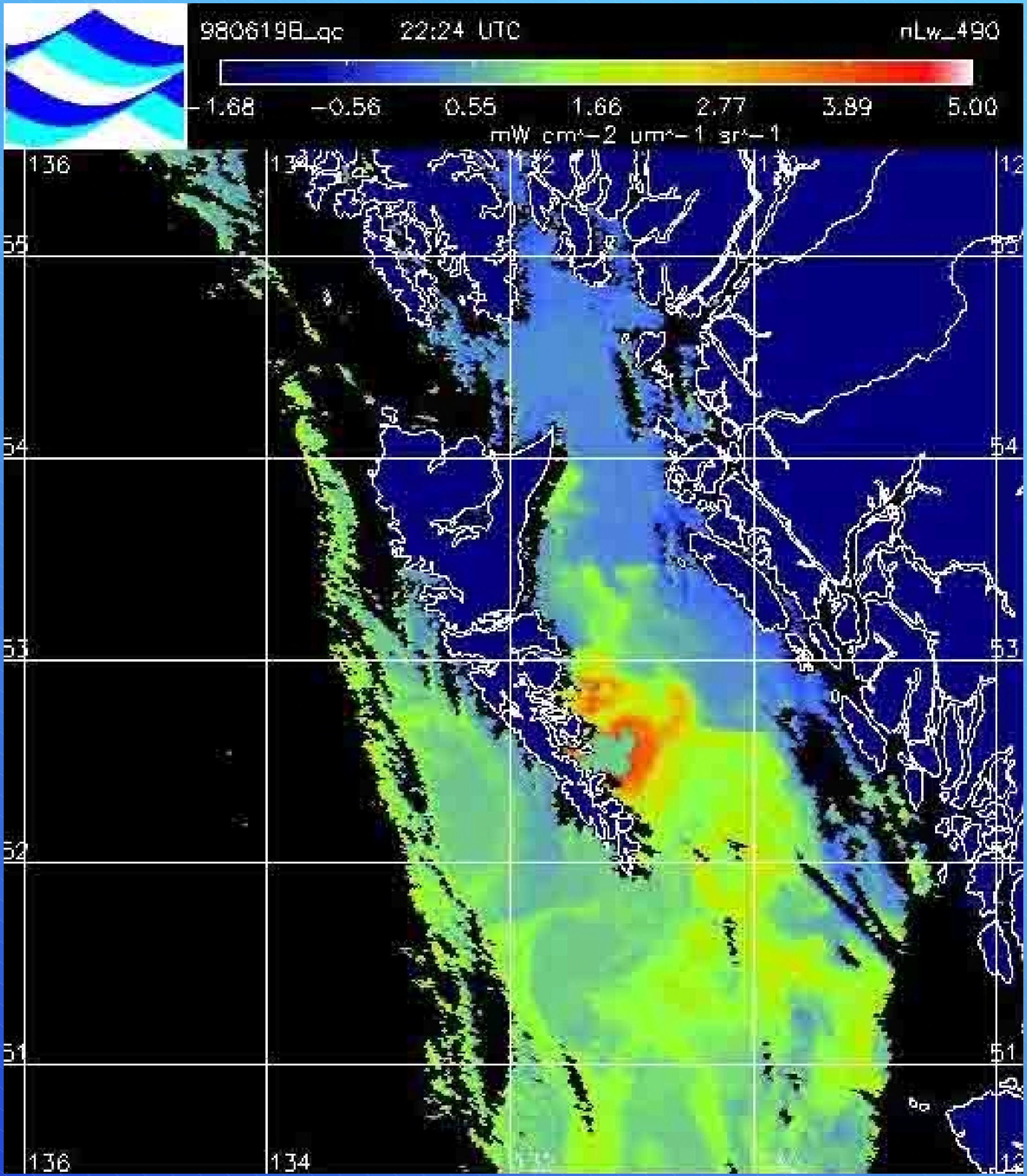
Plankton bloom sequence

- June 19, 1998



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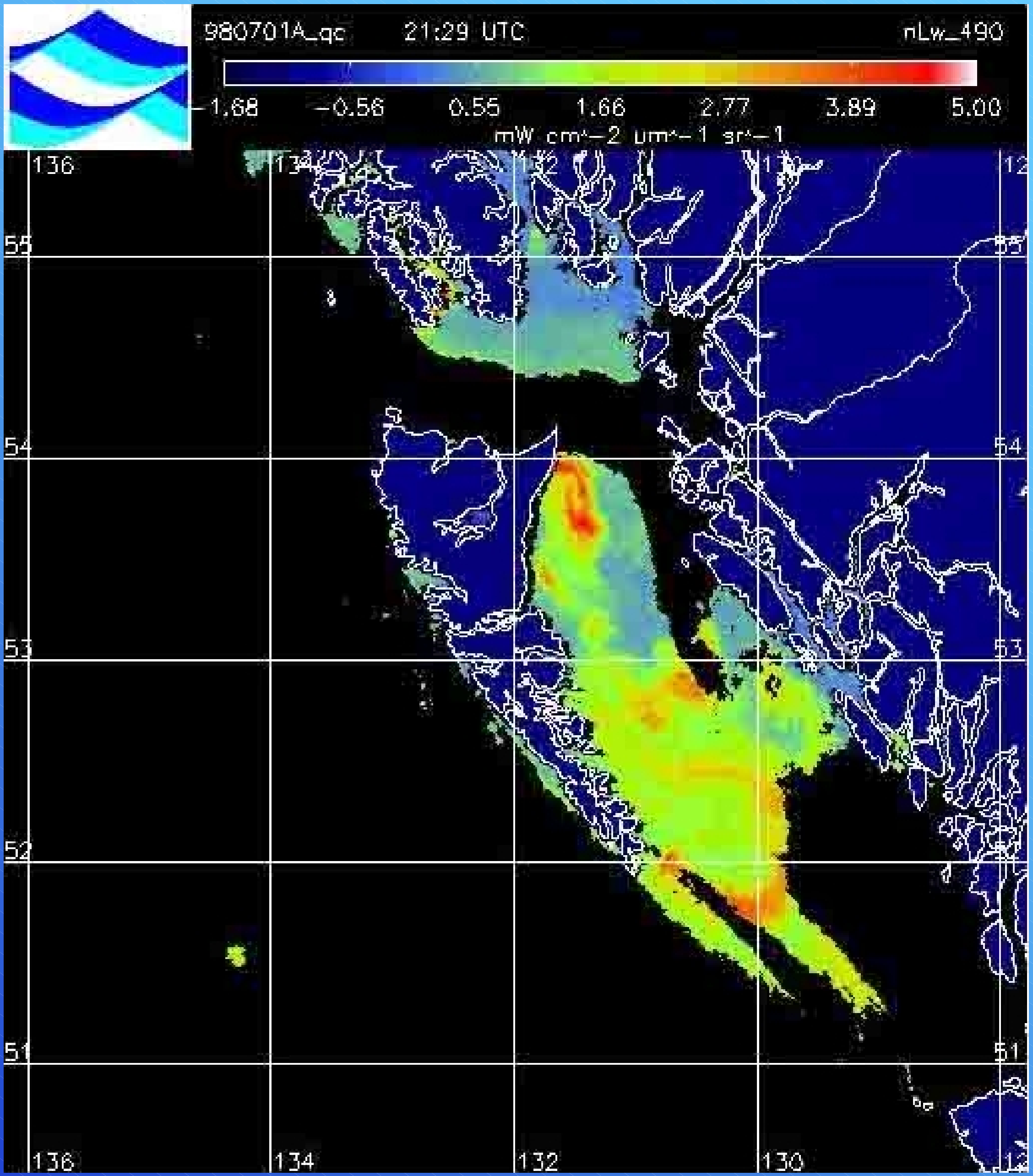
Courtesy Jim Gower, IOS

Plankton bloom sequence

- July 1, 1998



Courtesy Jim Gower, IOS

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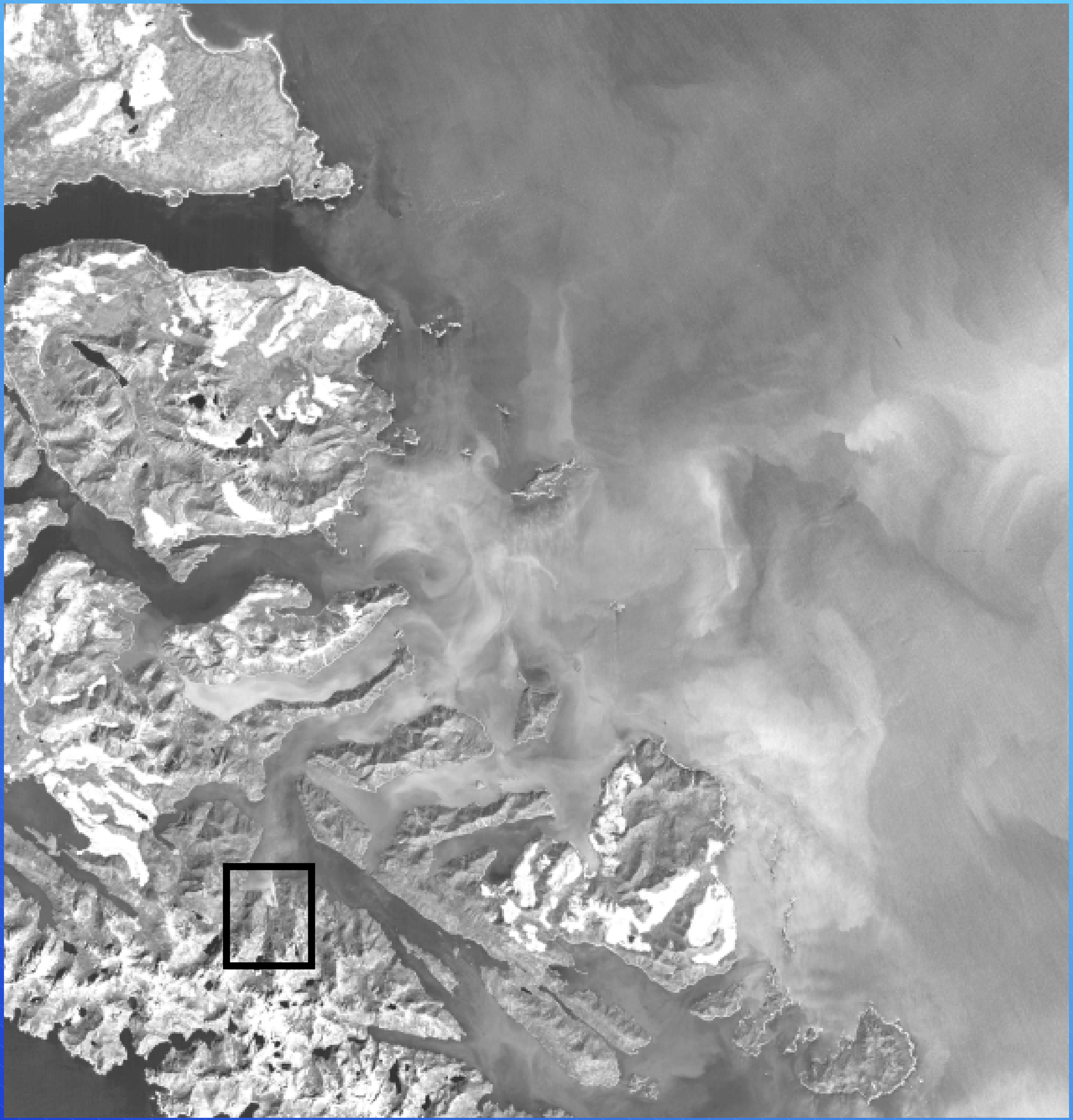
Gwaii Haanas Plankton Bloom

- SPOT full scene 60 km wide



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Courtesy Jim Gower, IOS

Gwaii Haanas Plankton Bloom

- SPOT full resolution (10 m)

Courtesy Jim Gower, IOS

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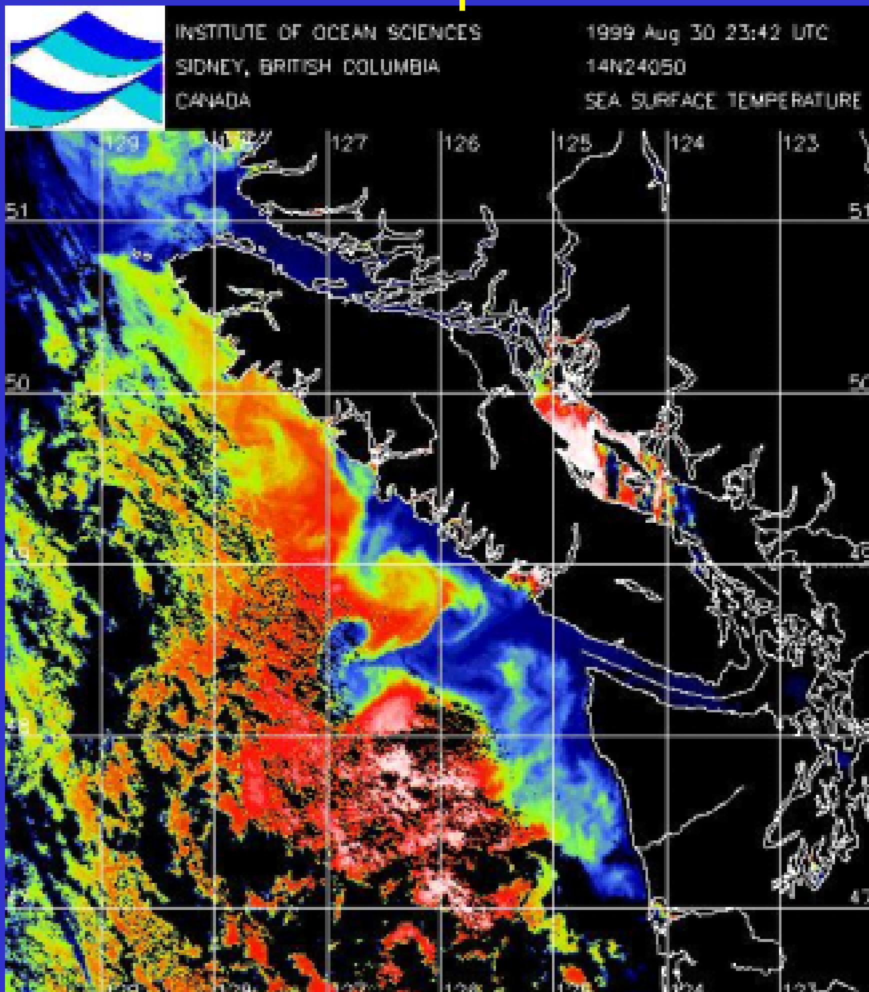
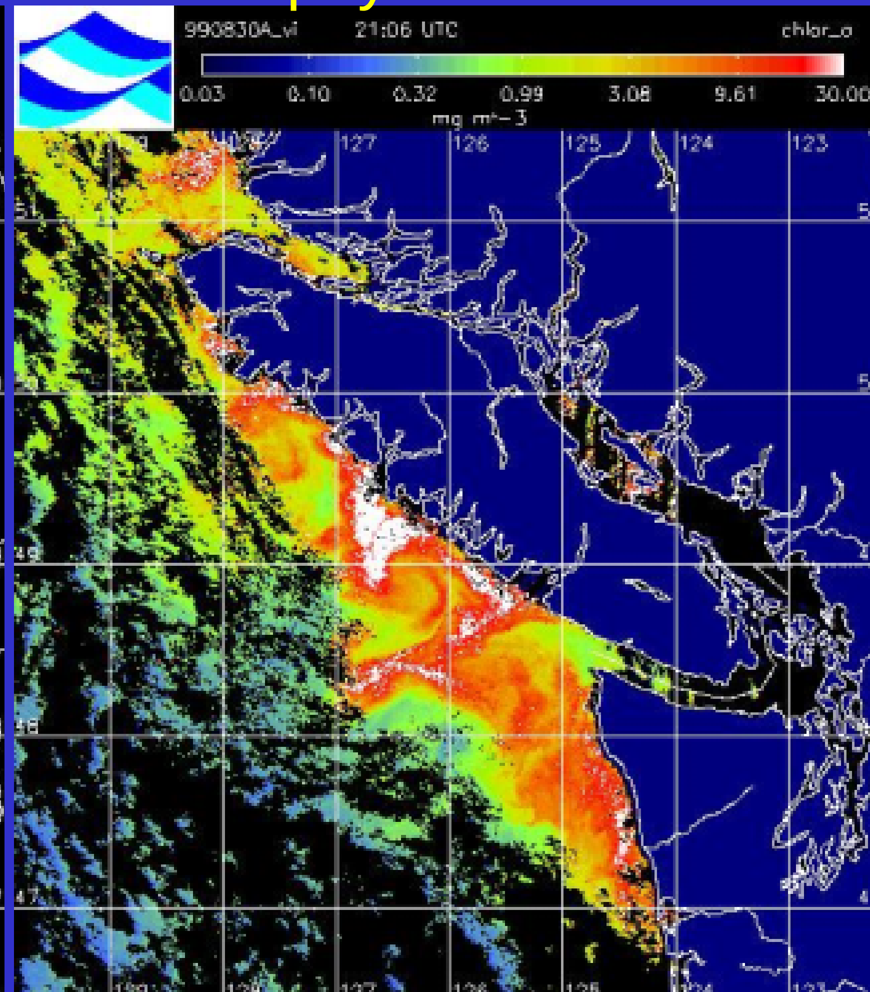
Monitoring coastal upwelling with satellites

Surface Temperature



Chlorophyll concentration



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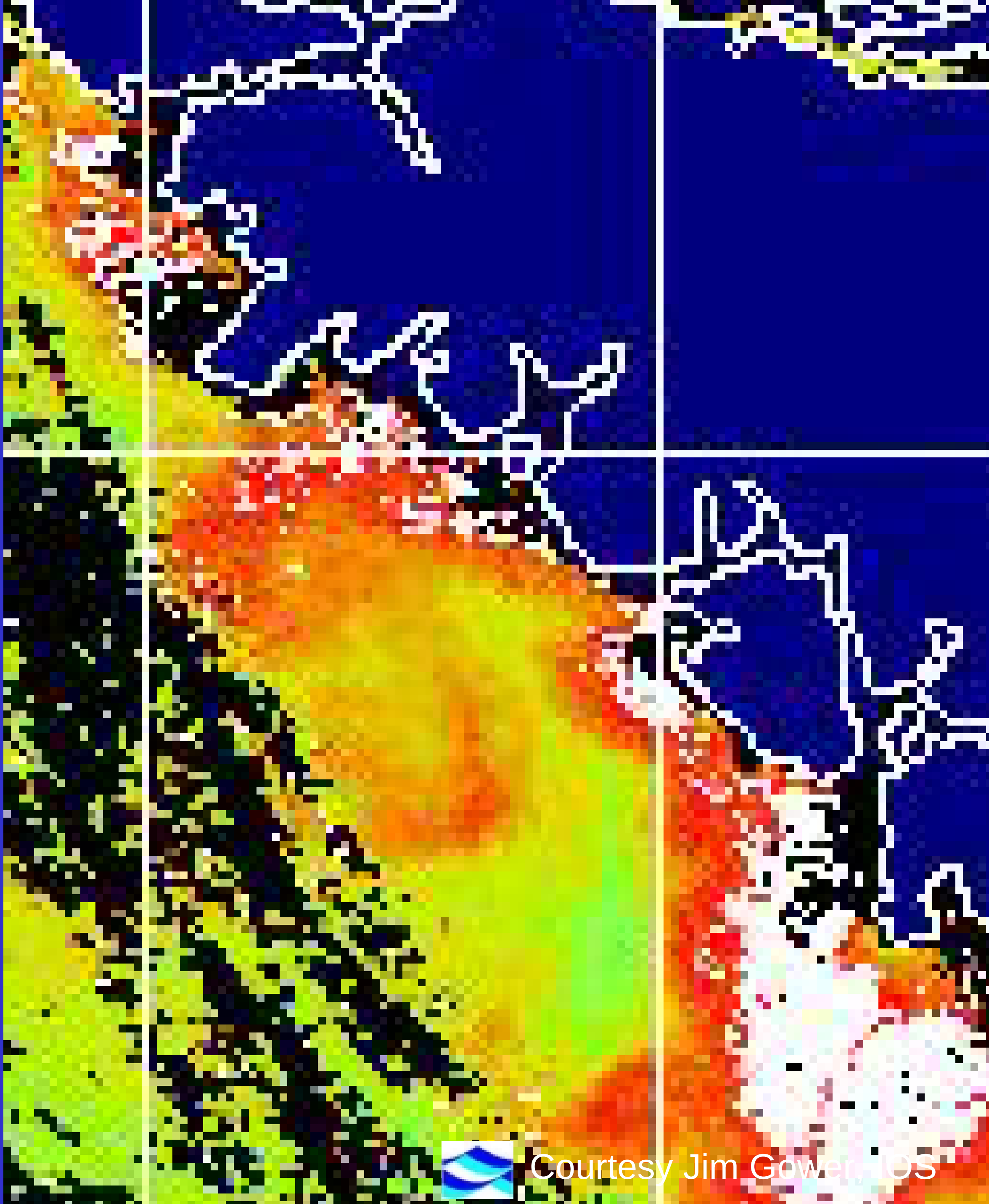
Courtesy Jim Gower, IOS

Chlorophyll concentration



Airborne multispectral

- CASI - a small digital system made in Canada

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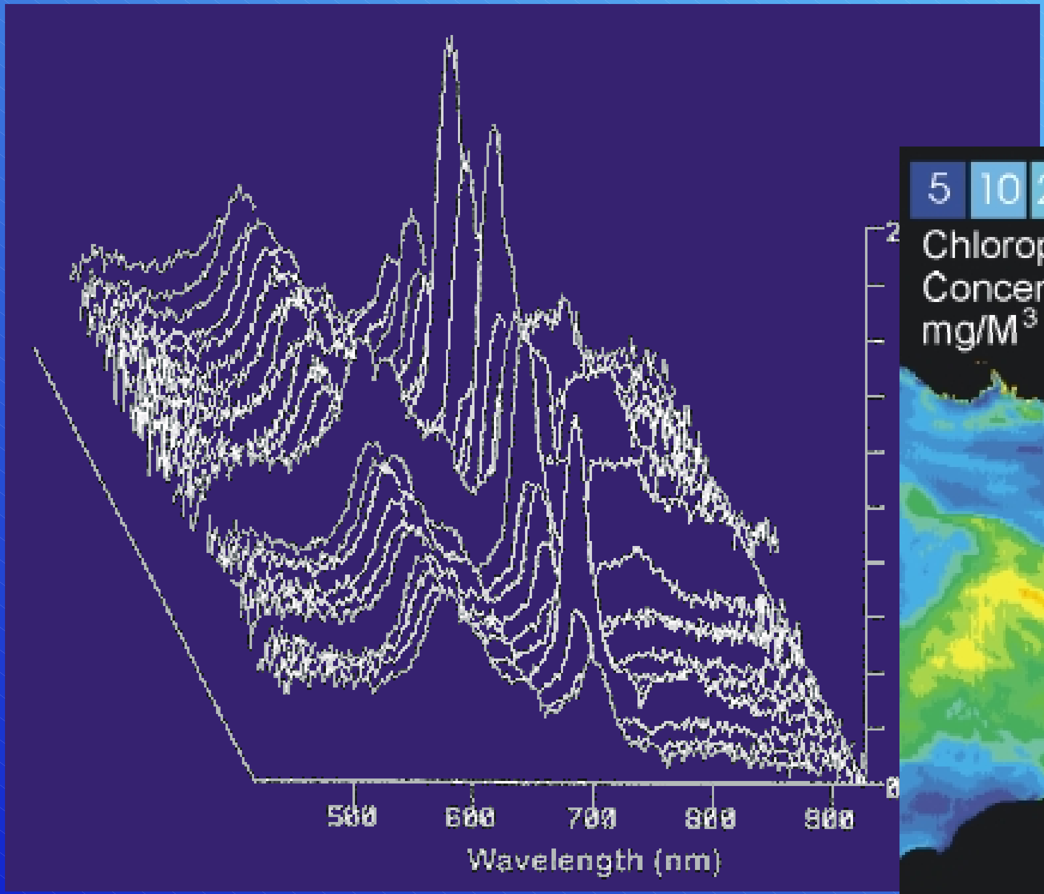
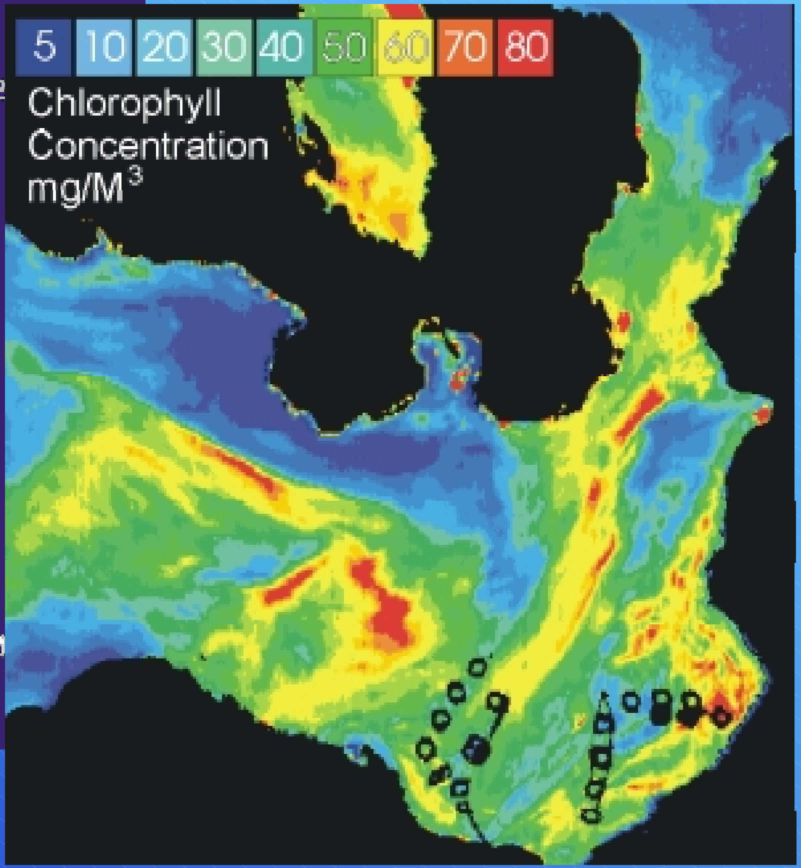
Plankton blooms from aircraft (CASI)





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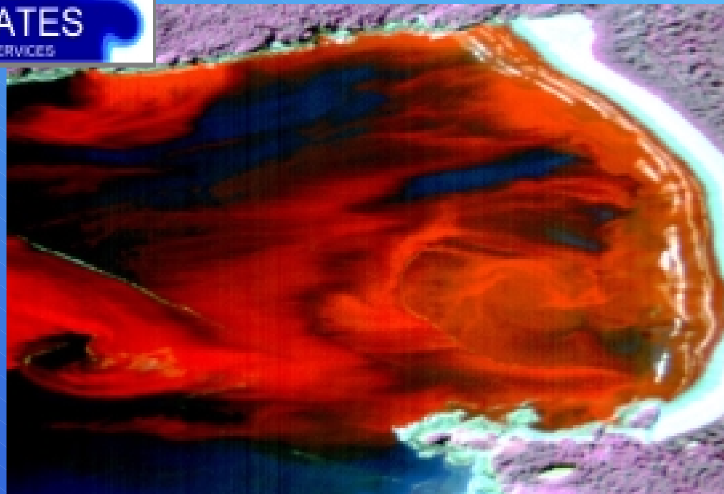
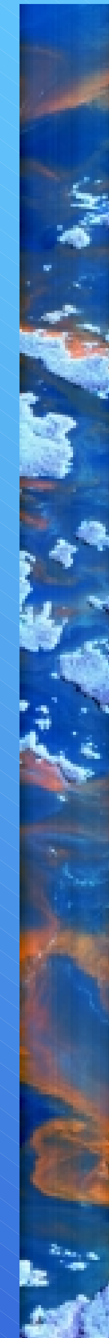
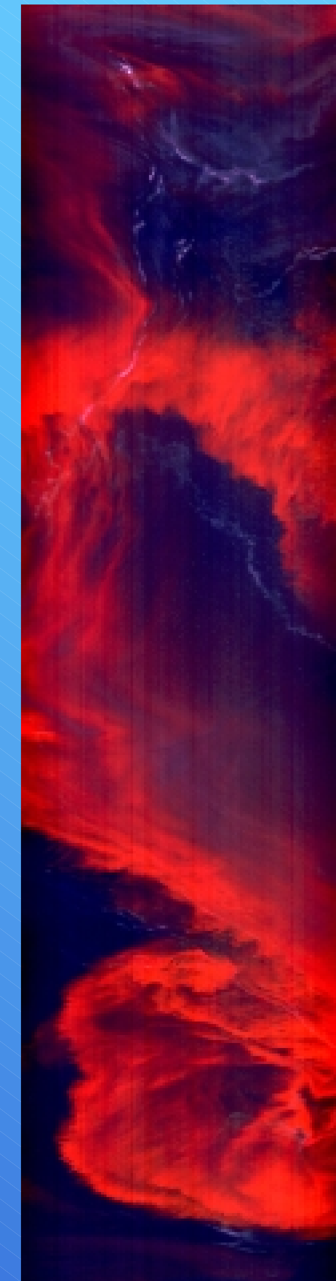


In September 1990 a massive red tide due to the non-toxic dinoflagellate *Gonyaulax spinifera* was reported along the southern half of the west coast of Vancouver Island, British Columbia.

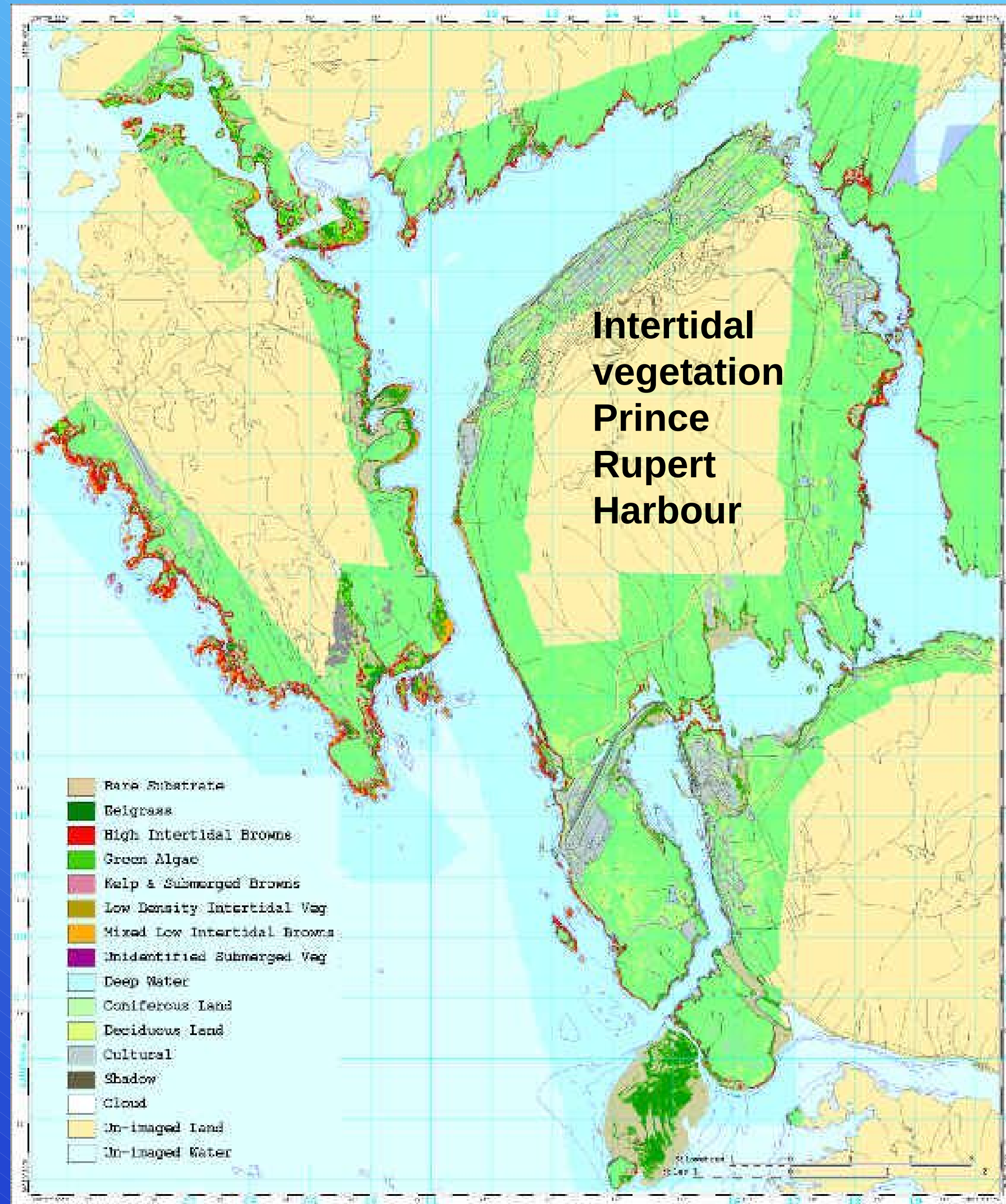
AERIAL MAPPING OF RED TIDES
TOFINO, BC 1990





A Map of Intertidal Vegetation from Aerial Remote Sensing

- Kelp and browns on outer coast
- eel grass in Venn Passage at north and on Flora Bank at south
- very little vegetation near pulp mill



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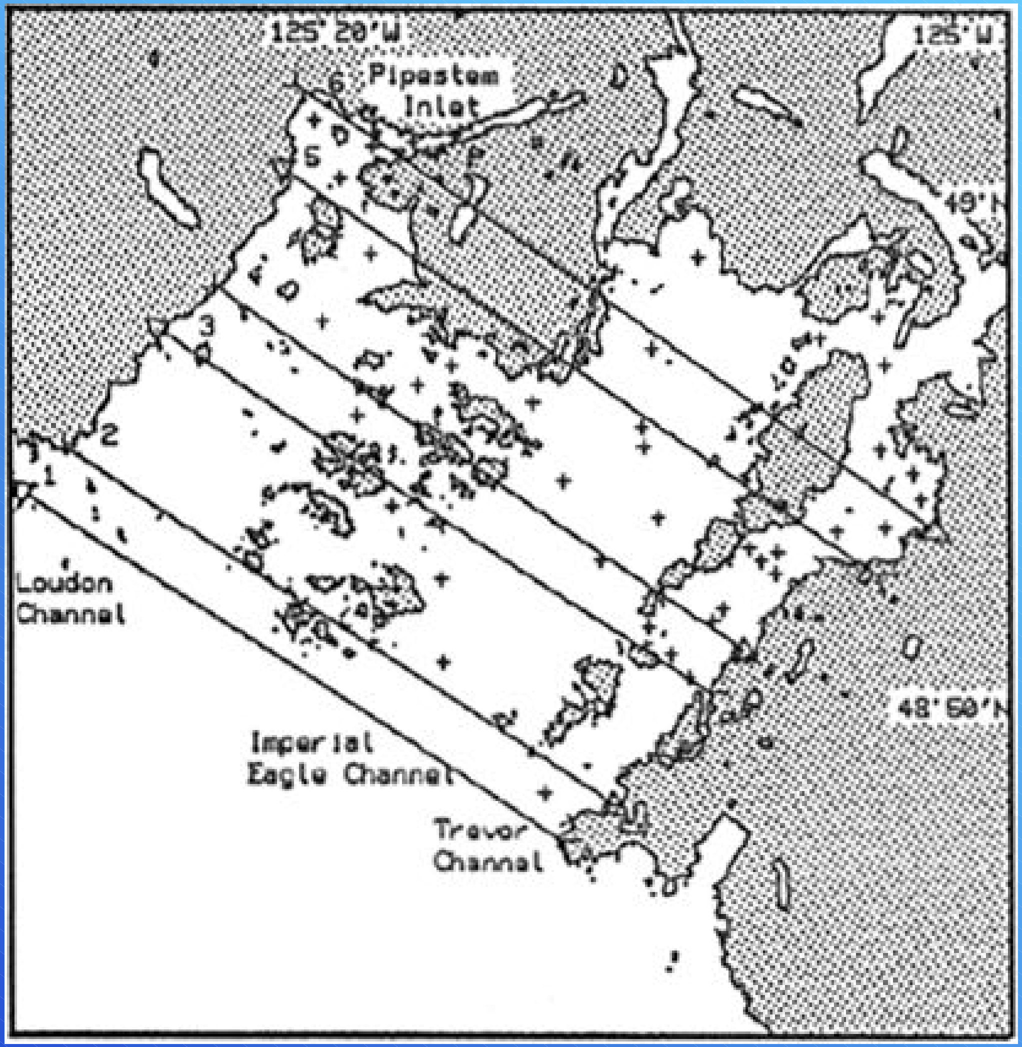
MAPPING SURFACE CHLOROPHYLL AND TEMPERATURE

Approximate location of aerial transects and of *in situ* samples



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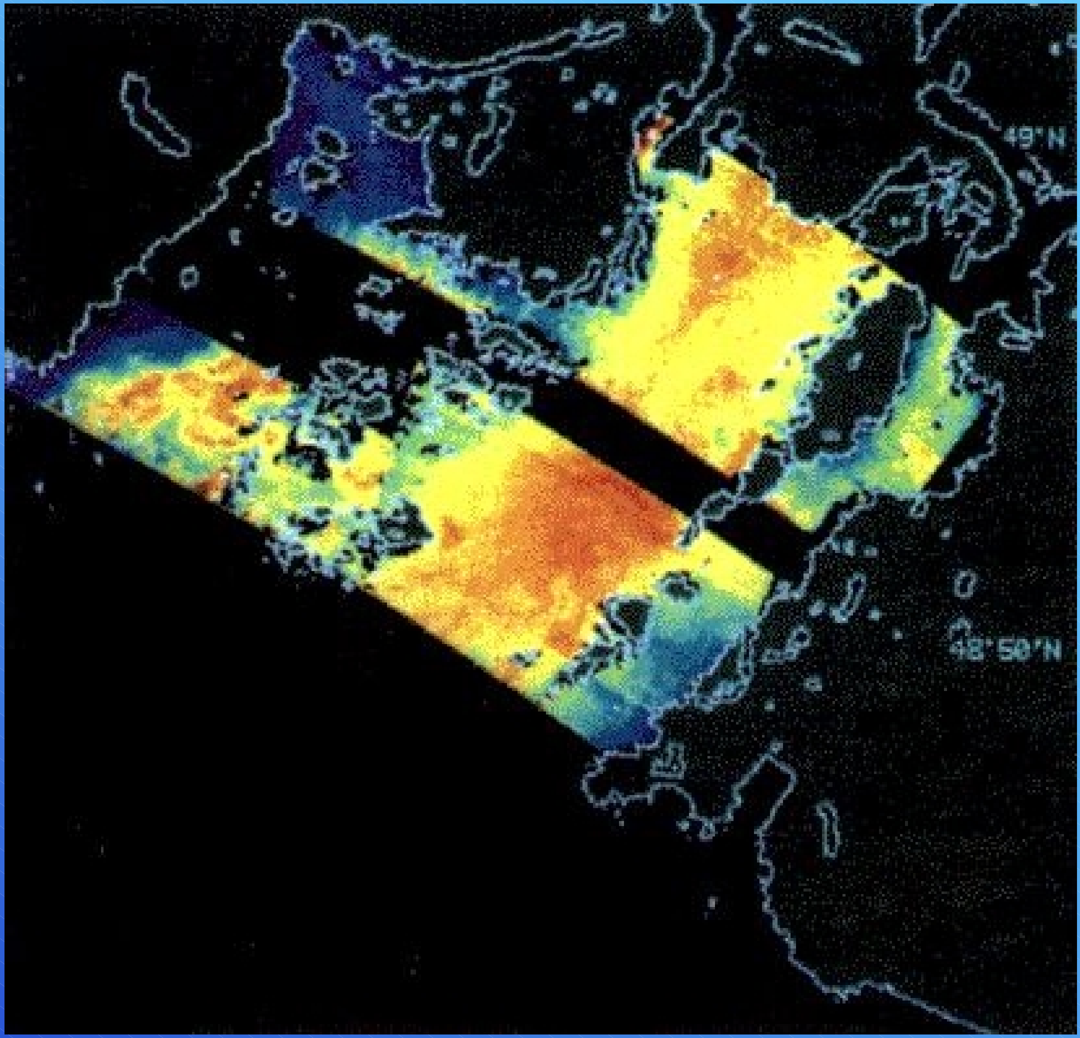
Surface Chlorophyll in Barkley Sound from Airborne Measurements of Solar Stimulated Fluorescence



Phytoplankton fluorescence
April 25, 1987

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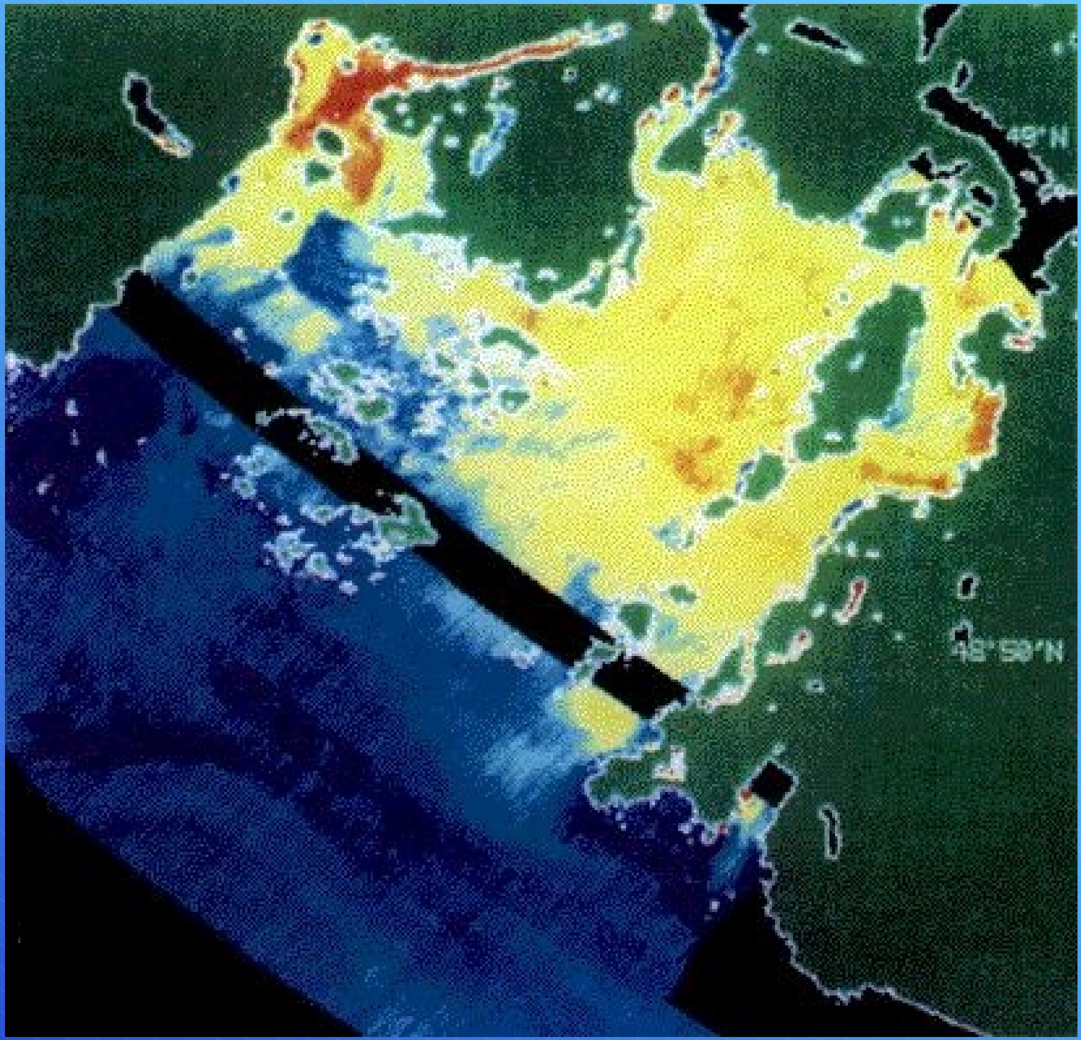
Surface Temperature in Barkley Sound from Airborne Measurements of Infra-Red Radiation

Surface temperature distribution

April 25, 1987.



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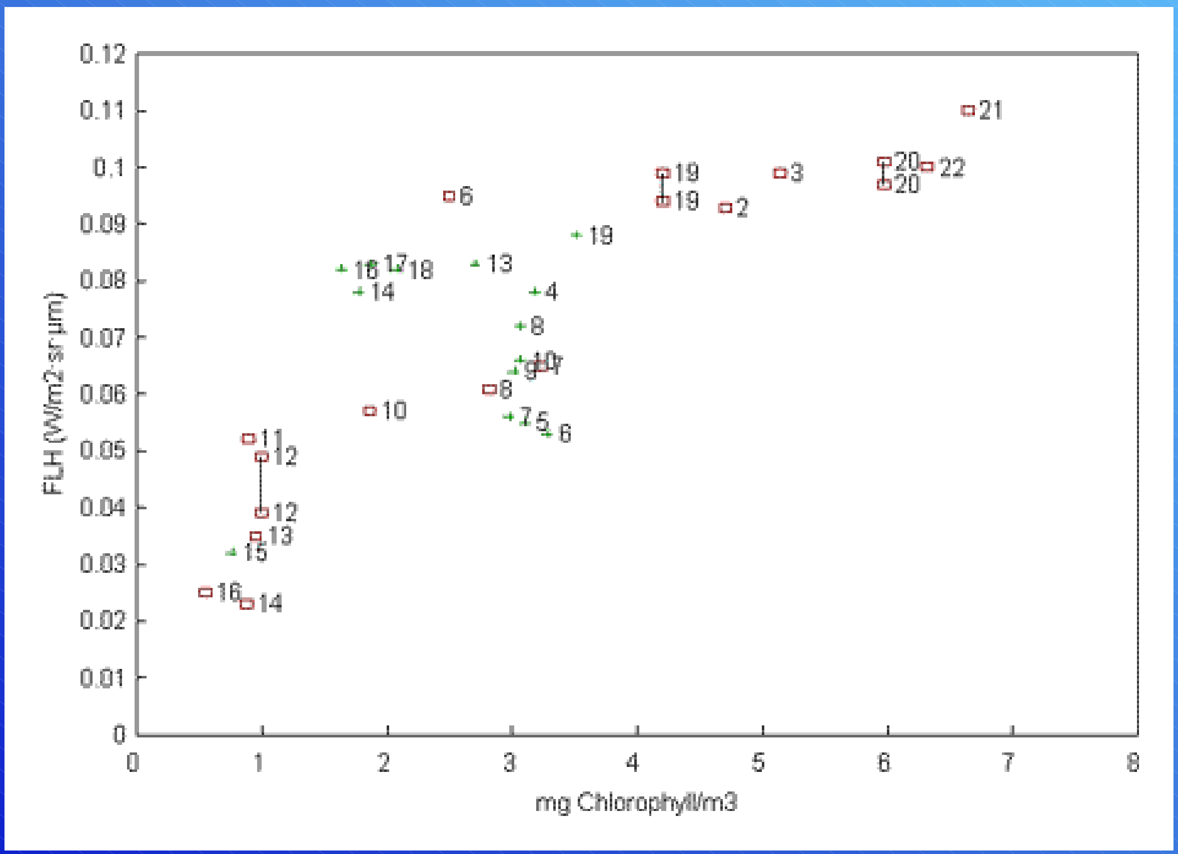
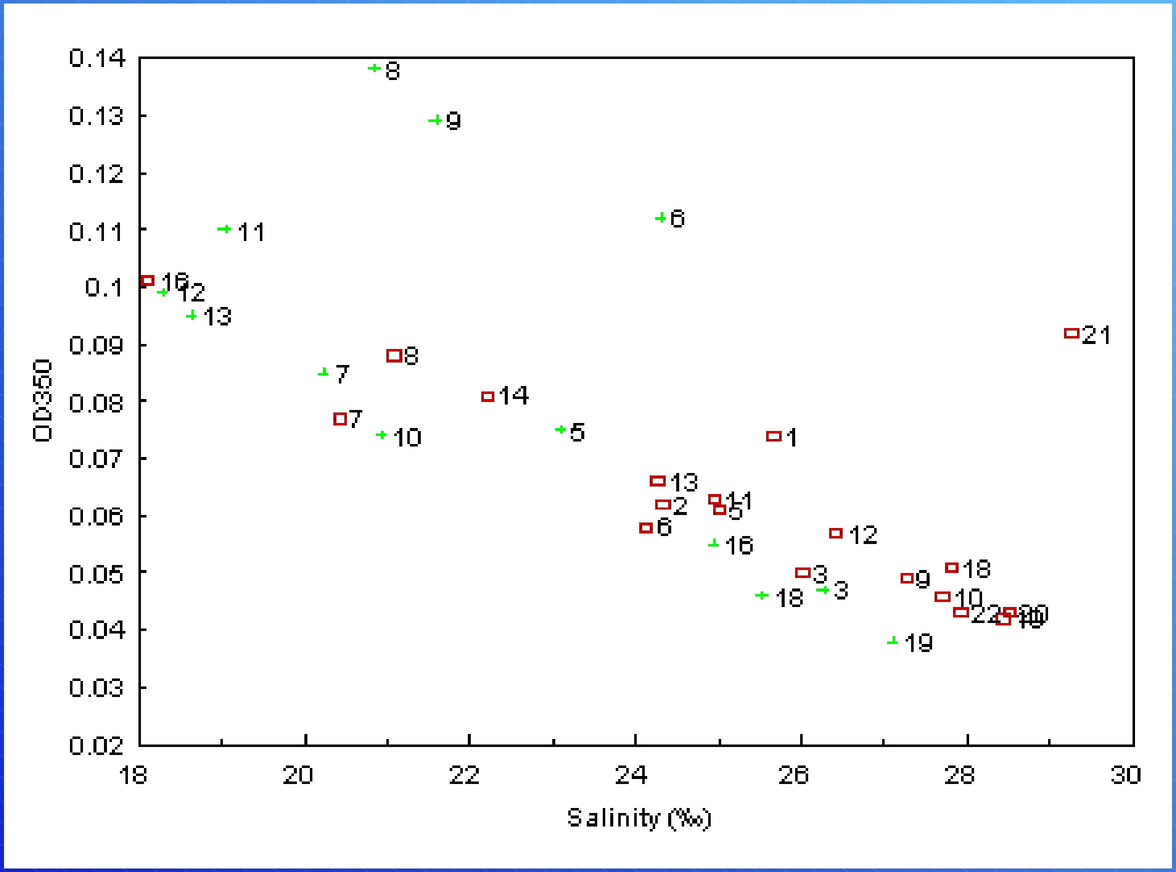
MAPPING SURFACE CHLOROPHYLL AND TEMPERATURE



Fluorescence Line Height and *in situ* **chlorophyll**

Squares represent April 24, crosses represent April 25.

Potential for Satellite Mapping of Surface Salinity from Measurements of Dissolved Organic Matter (DOM)



Optical density at 350 nm of filtered surface water *versus* **surface salinity**, illustrating that fresh water was a source of dissolved organic material in Barkley Sound.

The Future is here

-MERIS is an advanced Ocean Colour Imager to be launched this summer by the European Space Agency.

-MERIS will have the bands to quantitatively map Chlorophyll, Dissolved Organics, Suspended Inorganics and perhaps make some Phytoplankton species/type separation.

-MERIS will have 300 m spatial resolution-enough to approach the coast and map into inlets

-Borstad Associates, DFO and DoE are beginning a project this summer and we are looking for participants in the aquaculture industry.

Marine Biogeochemistry of Cadmium

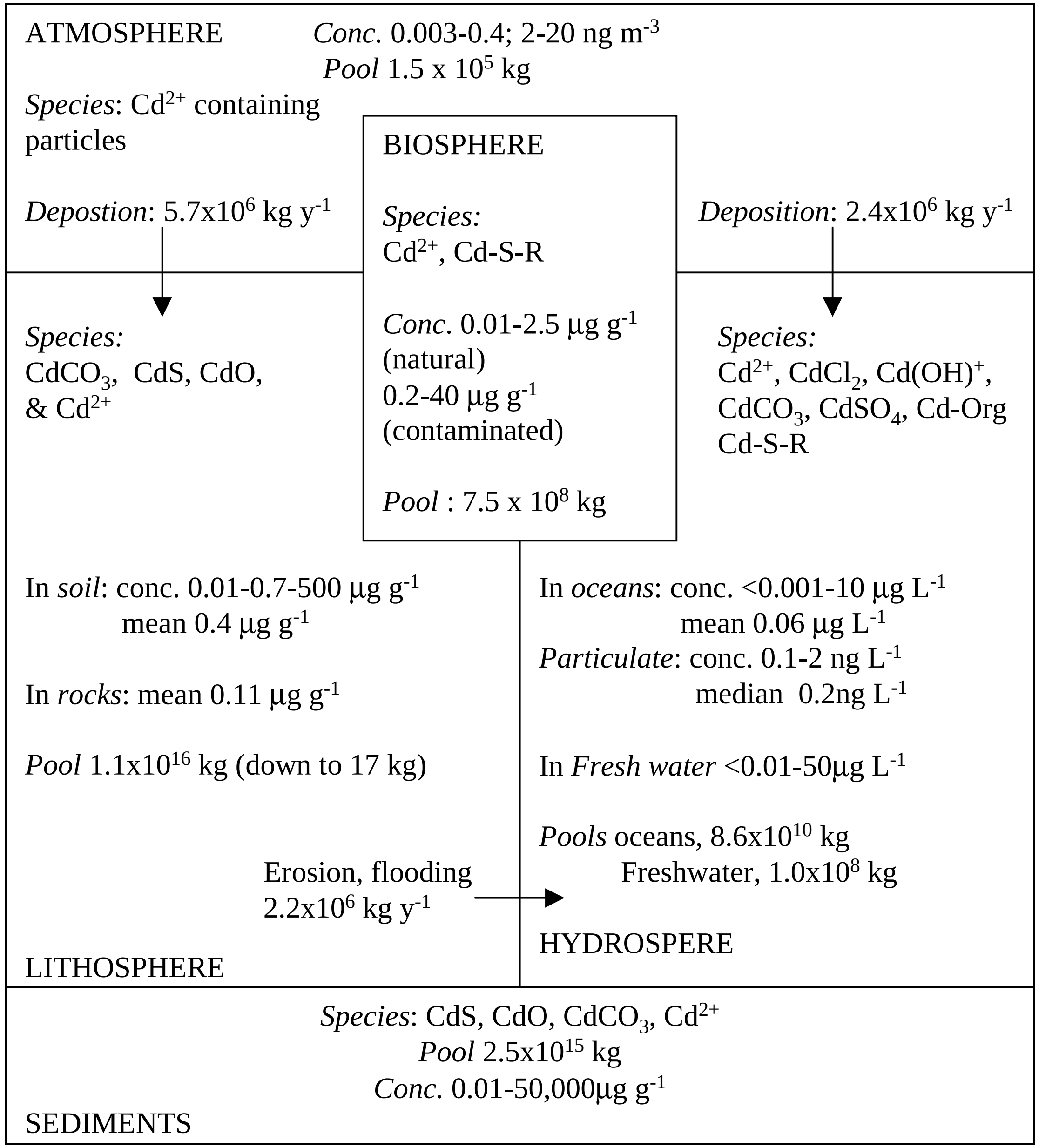
Sabrina Crispo

IOS Oyster Workshop

March 7th, 2001

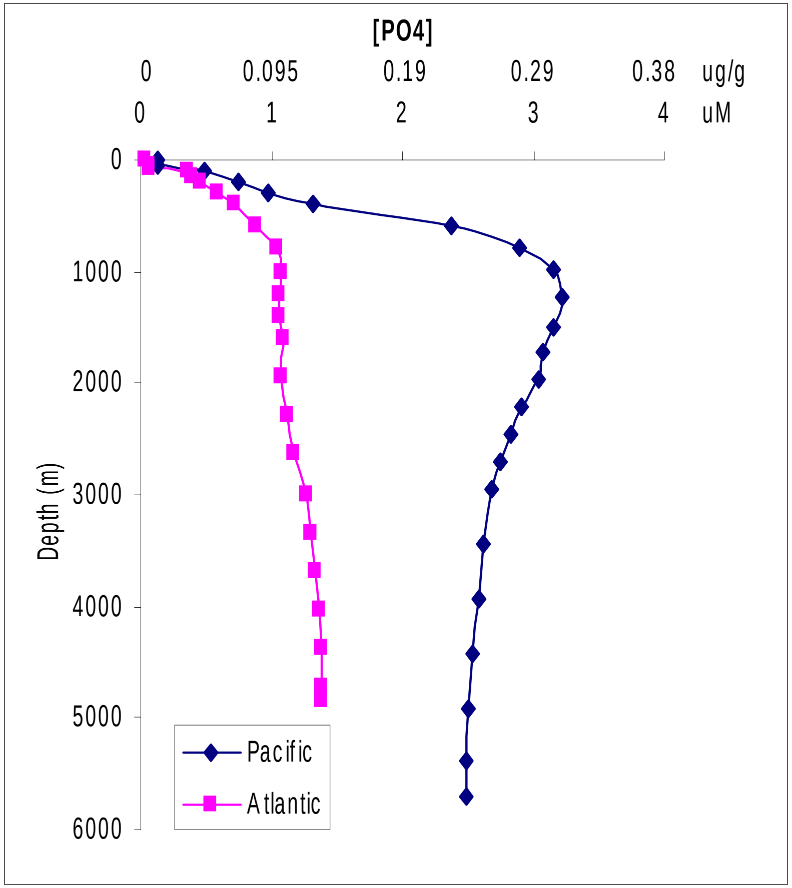
Outline

- Cadmium Cycling
  - Depth Profiles
  - Speciation
  - Ocean Conveyor
- Relationship to Phosphate
  - Deviations



Fergusson, JE. 1990. “The Heavy Elements: Chemistry, Environmental Impact and Health Effects.”

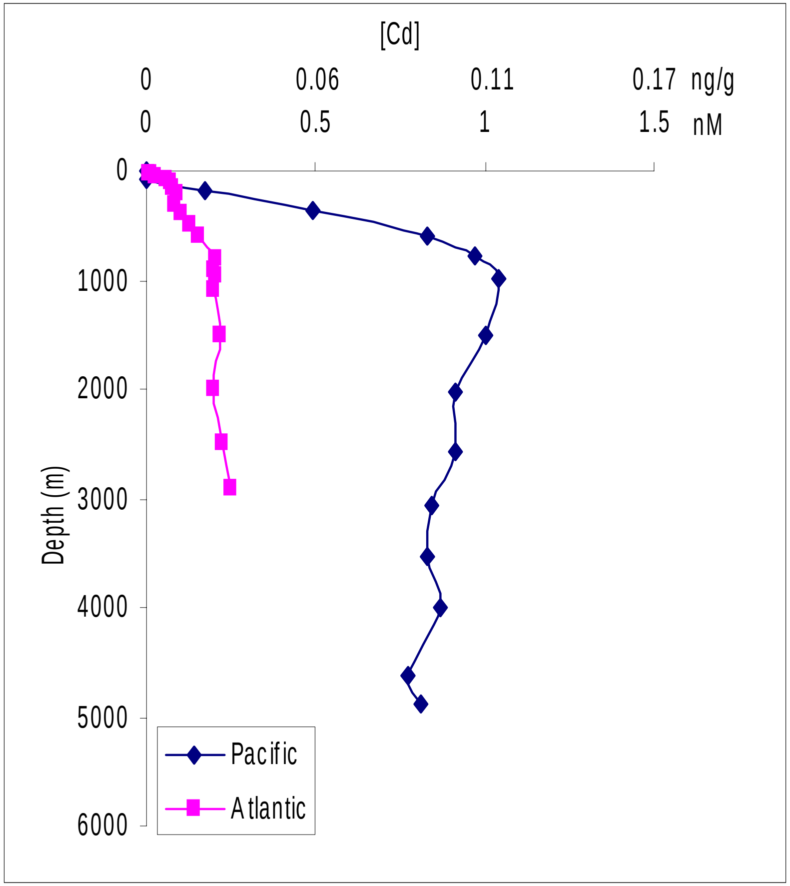
Dissolved Profile



Source eWOCE Atlas

Pacific = Cruise 18DD9403/1, Station W043

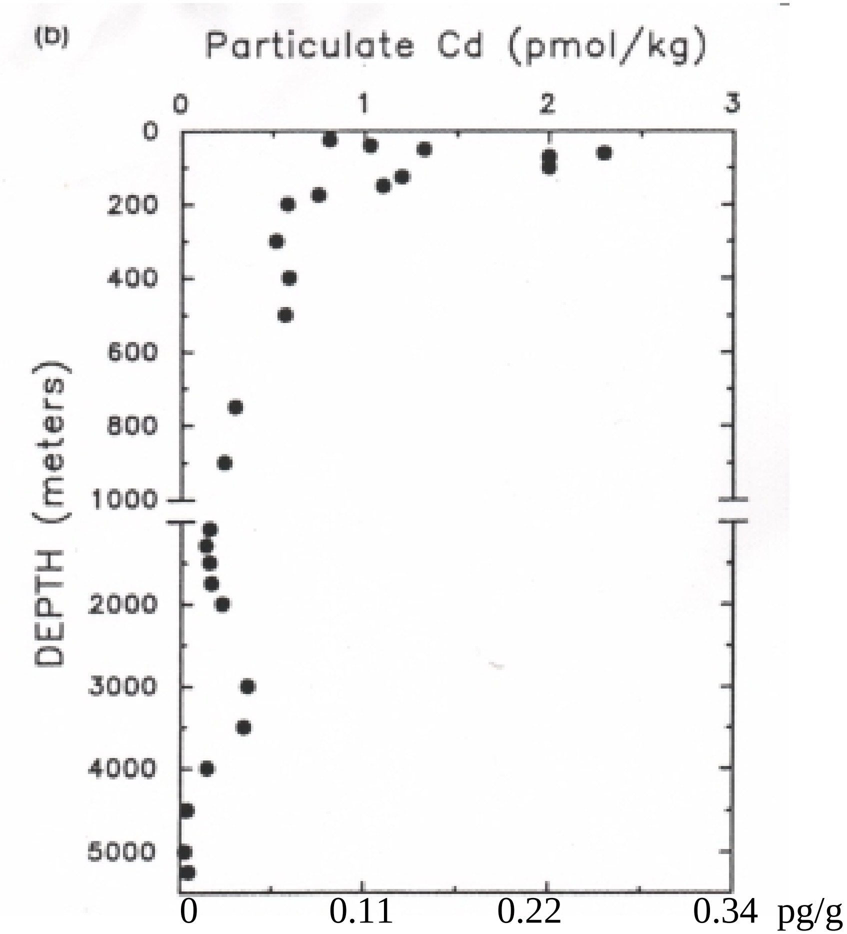
Atlantic = Cruise 32OC202/1, Station 50



Bruland, KW. 1980. Earth Planet. Sci. Lett. 47, 176-198.

Martin, JH, Fitzwater, SE, Gordon, RM, Hunter, C N, and Tanner, S J. 1993.. Deep-Sea Res., 40:115-134.

Particulate Profile



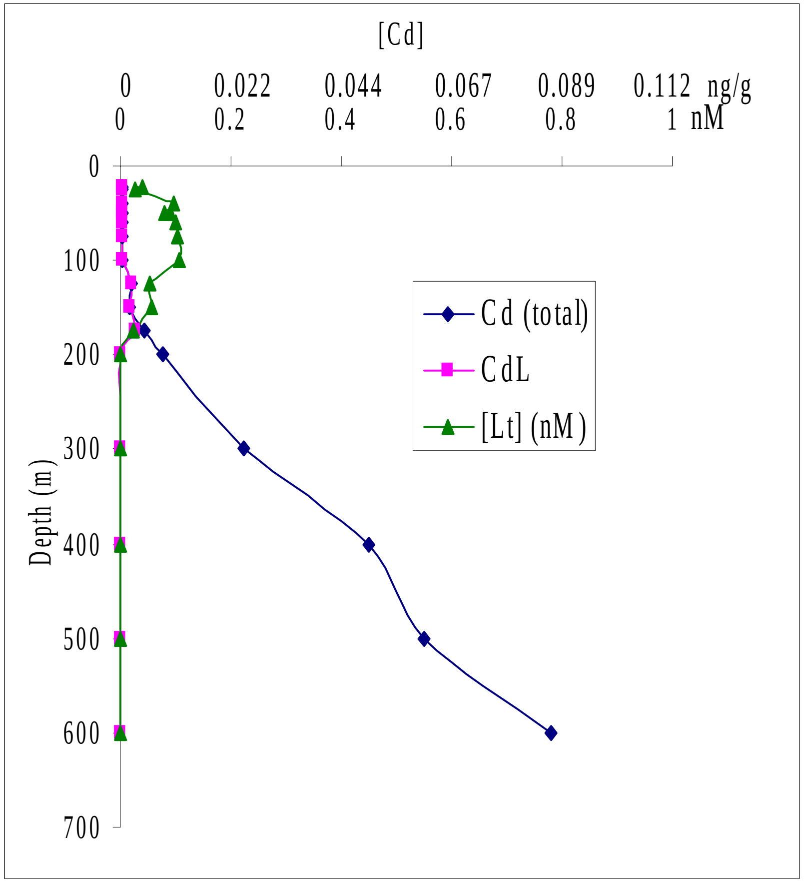
- Max at chlorophyll maximum
- Fractionation between particulate and dissolved phases:
  - Surface: 65% dissolved
  - Depth: 99.98% dissolved

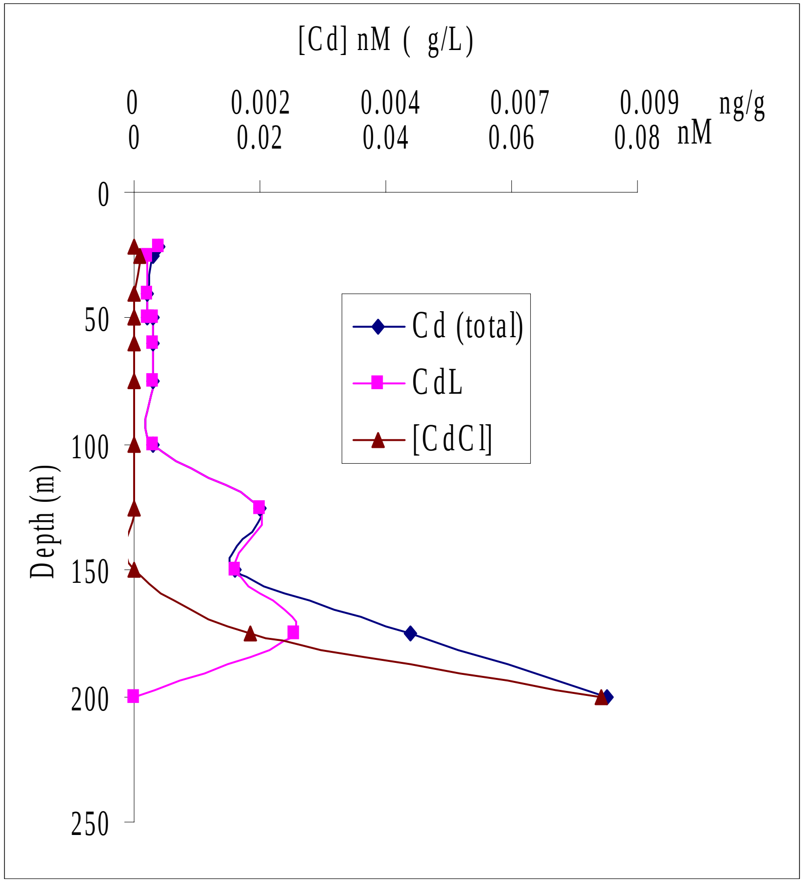
Bruland, KW, KJ Orians, JP Cowen. 1994. Geochimica et Cosmochimica Acta. 58(15) 3171-3182.

Speciation

- In ocean, speciation is important
- In surface, Cd_{diss} bound to organic ligands
  - – 70% bound in strong complex(es)
  - – not biologically available?
- At depth, chloride complexes dominate (no important organic ligands)
  - – 99% complexed

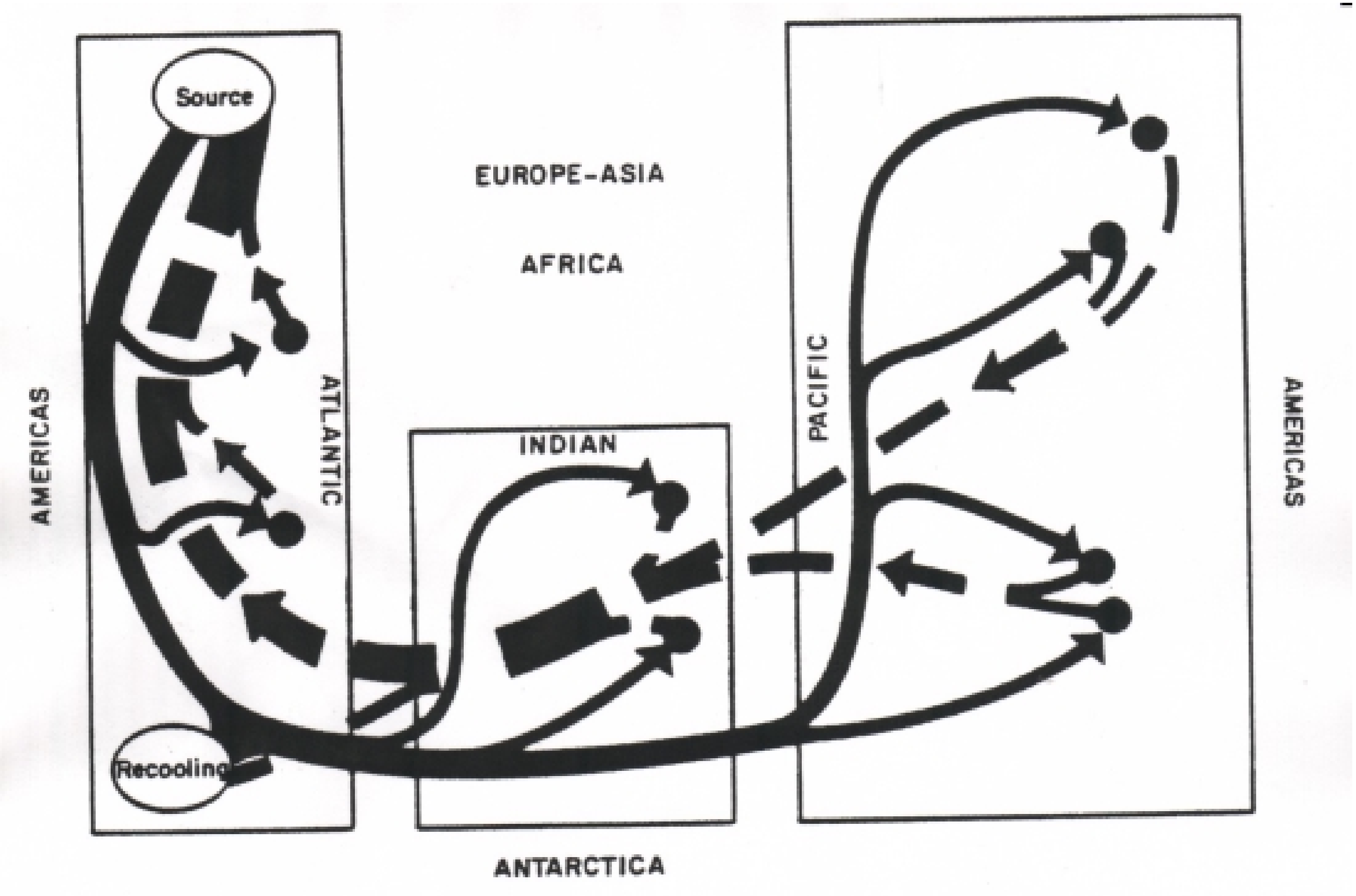
Speciation (cont.)





Bruland KW. 1992.Complexation of Cadmium by Natural Organic Ligands in the Central North Pacific. L&O, 37(5), 1008-1017

Ocean Conveyor



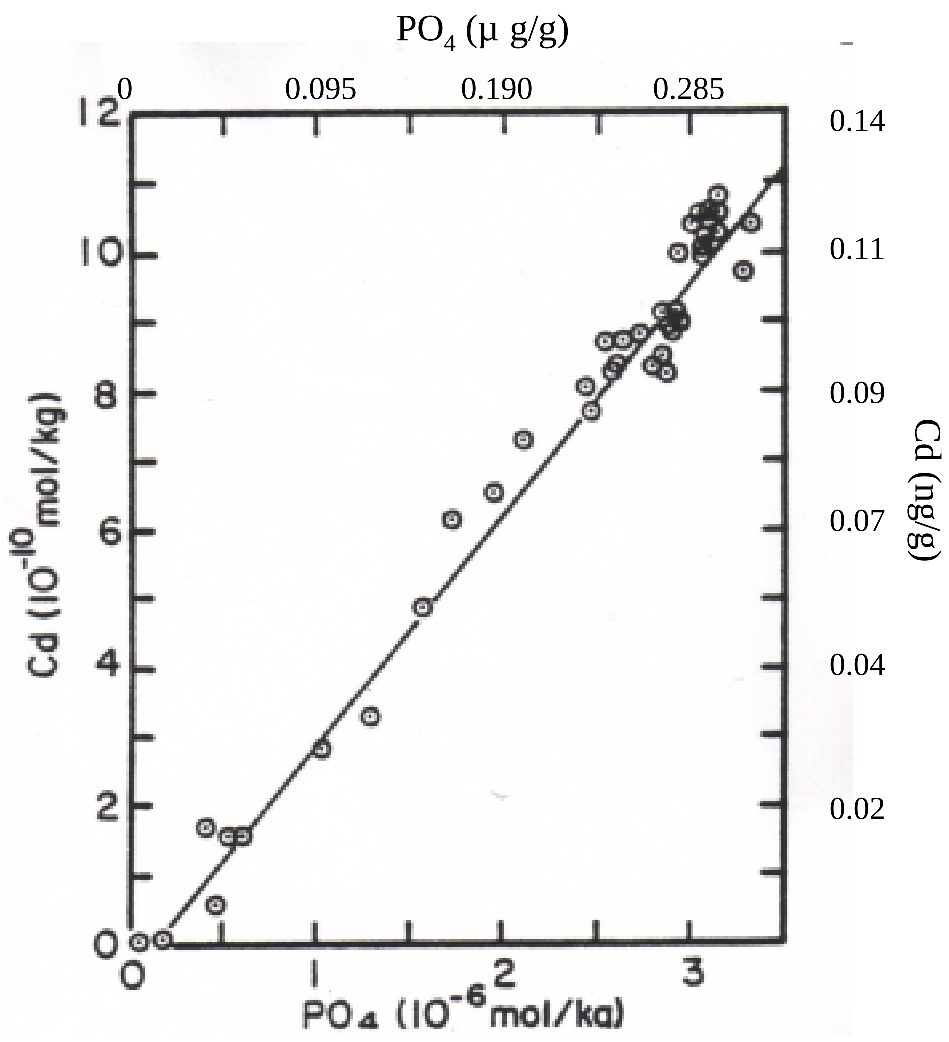
Source: *Tracers in the Sea*, WS Broecker and TH Peng, 1982 p 34.

Residence Time

$$\tau = \frac{Concentration}{Rate\ of\ Removal\ or\ Addition}$$

- Cd (Deep Ocean): 60,000 years
- Deep Ocean Circulation: 800-1000 years

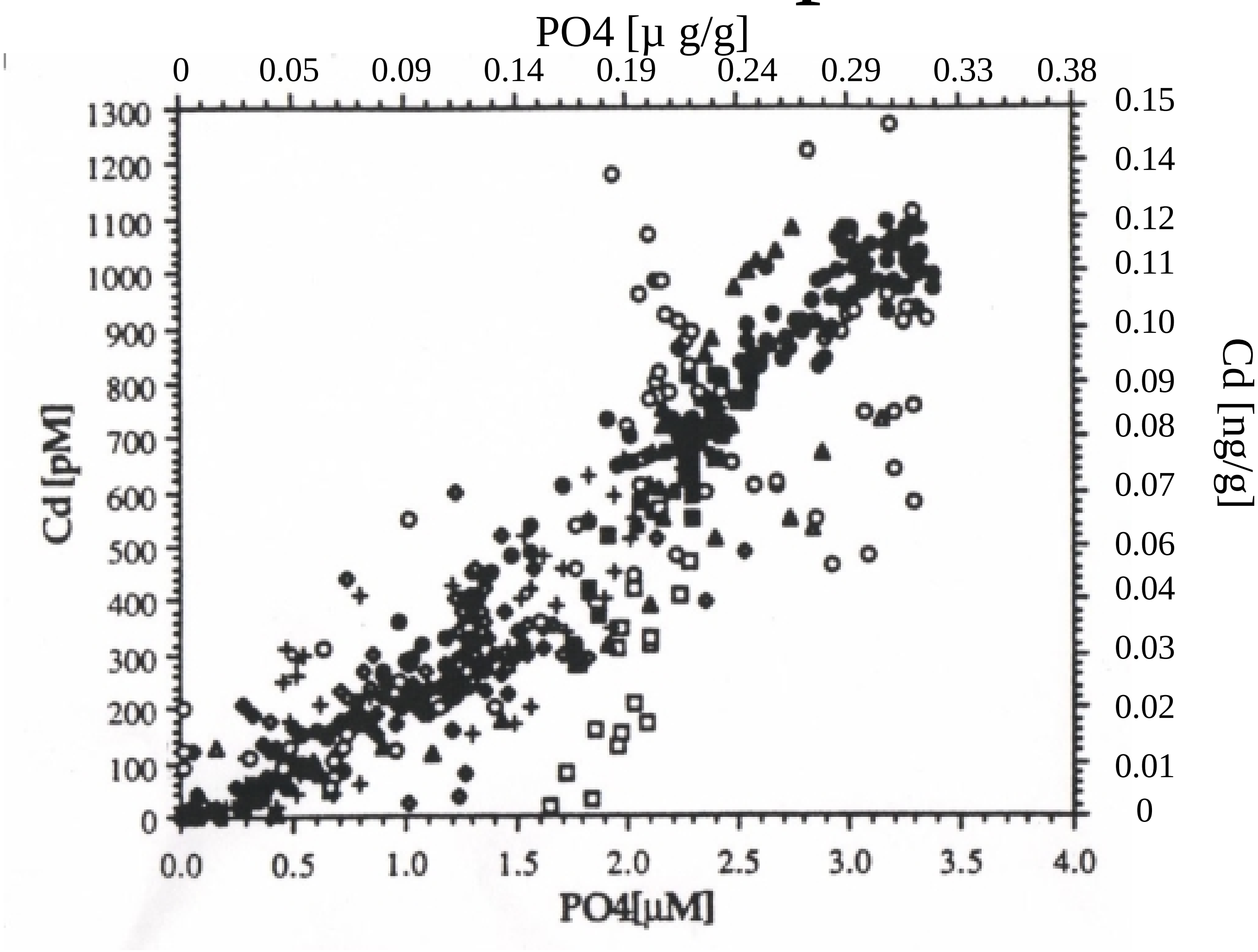
Phosphate –Cadmium Relation



Bruland KW, GA Knauer, JH Martin. 1978. Limnology and Oceanography. 23, 618-625.

- $Cd/PO_4 \approx 0.3x10^{-3}$
- Northern Pacific

Little more complicated…



De Baar et al.1994. Marine Chemistry, 46, 261-281

Also…

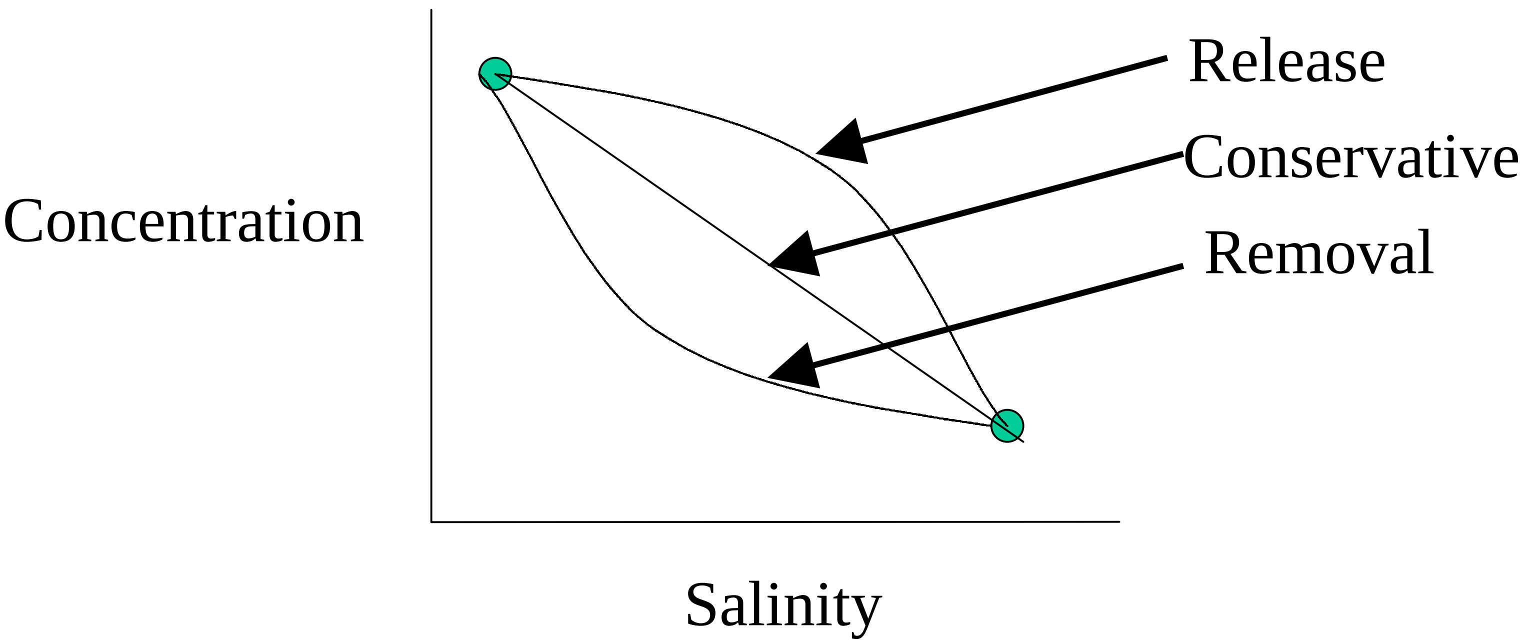
- Deviations occur in:
  - Surface water
  - Estuaries
  - Upwelling areas

Surface Water

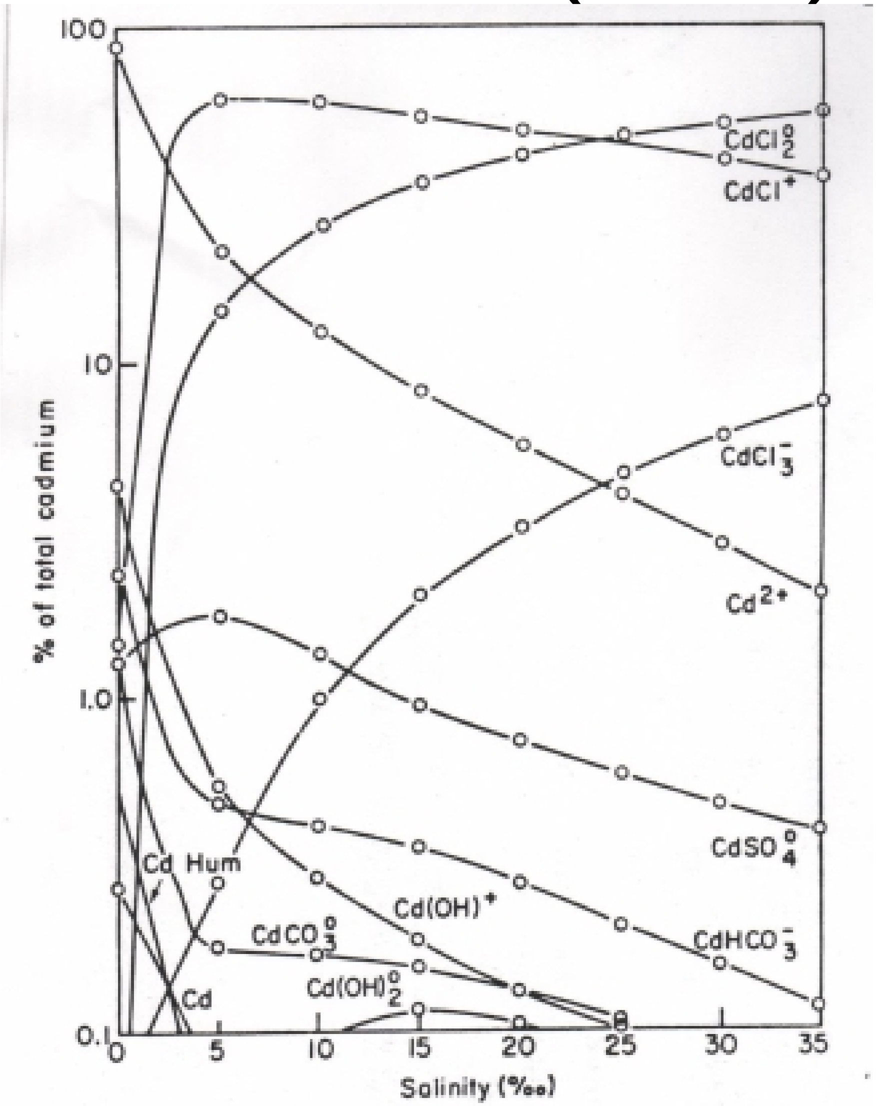
- Ratio Cd/PO_4 usually lower ($0.1x10^{-3}$)
  - Preferential uptake of Cd
  - Faster regeneration of PO_4
- Amount of Cd taken up
  - vary inversely with $P(CO_2)$ and [Zn]
- Deviates in Fe-depleted areas

Estuaries

- Mixing behavior



Estuaries (cont)



MantouraRFC, A Dickson, JP Riley. 1978. Estuarine Coastal Mar. Sci. 6, 387-408.

Estuaries (cont)

- Reports of all three behaviors
  - Rhine estuary (Removal)
  - Britannia Creek (Conservative)
  - Aber-Wrac`h estuary (Release)
- Phosphate usually removed in estuary
  - Reacts with iron oxyhydroxides
- Sources of cadmium and phosphate different in estuary

Britannia Creek

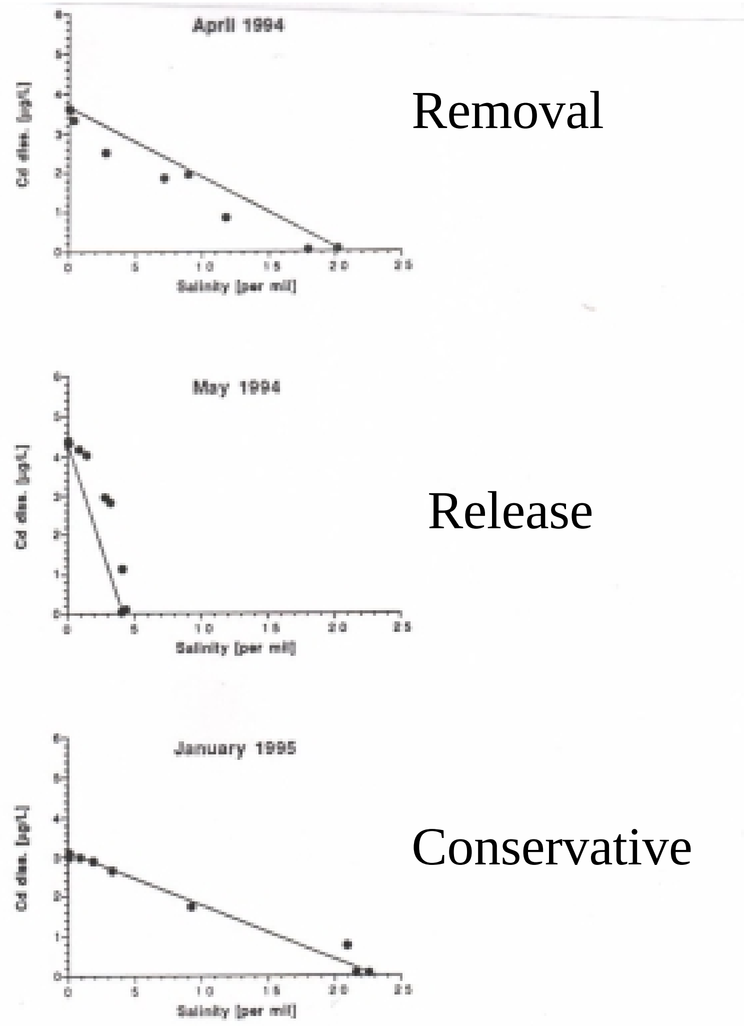


Figure 2.2. Dissolved Cd in three transects collected in April and May 1994 and in January 1995. Also shown is the conservative mixing line.

Chretien, ARN. 1997. PhD thesis. University of British Columbia.

Upwelling Areas

Area	[Cd] nM	Ratio
California[a]	0.6-0.8 (0.067-0.09 μ g/L)	~0.36×10^{-3}
Cal/Mexico border[b]	0.2 (0.022 μ g/L)	-
Vancouver Island[c]	0.8 (0.09 μ g/L)	~0.4×10^{-3}

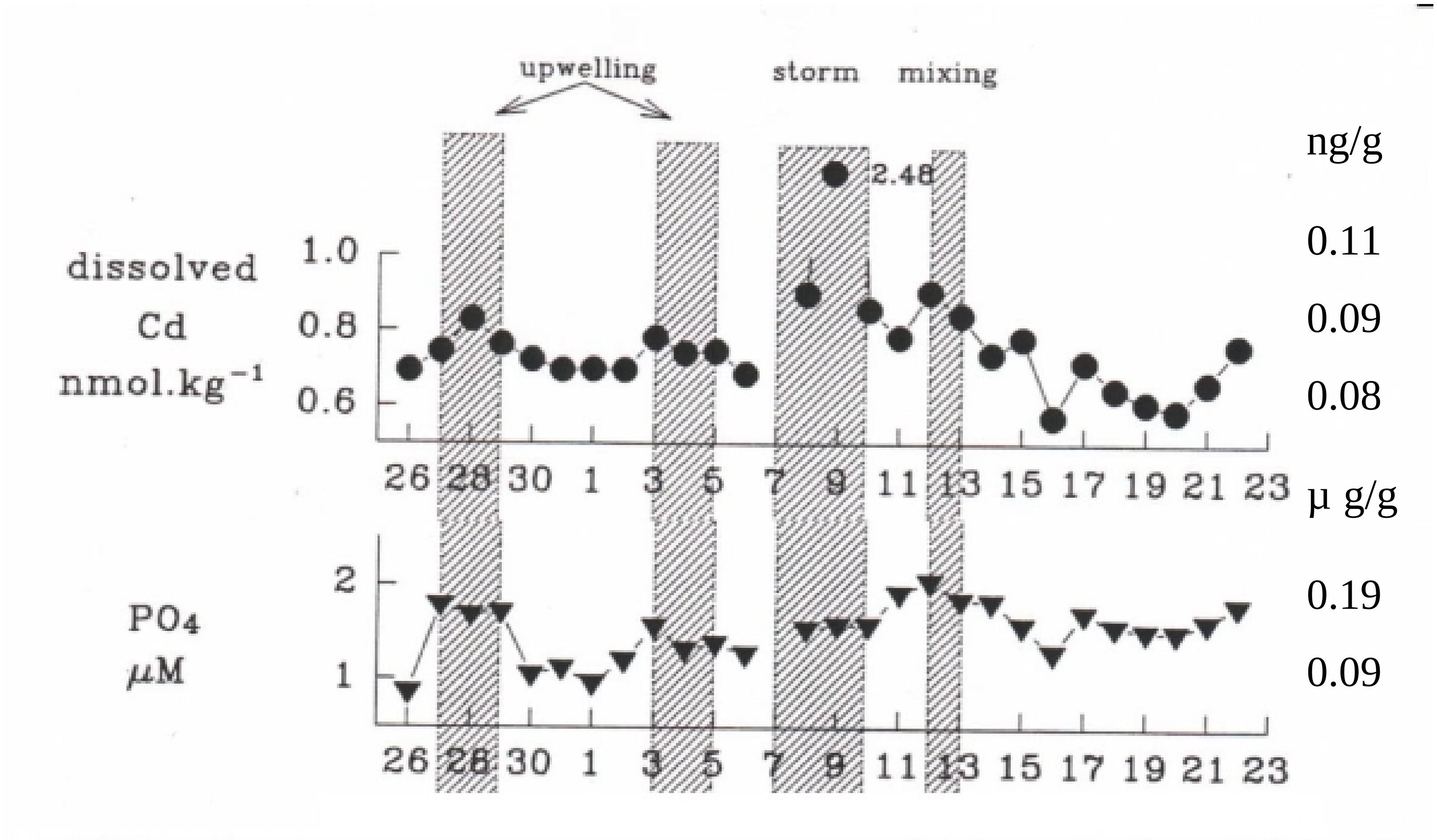
- Cd/PO_4 anomalies occur
  - High chlorophyll
  - Preferential PO_4 uptake
  - High Zn, Mn concentrations

[a]van Geen A. 1996. J. of Geophysical Research. **101** C2 (3489-3507)

[b]Segovia-Zavala JA et al. 1998. Estuarine, Coastal and Shelf Science. **46** (475-481)

[c] Del Carmen Lares Reyes M.L. 1995. PhD thesis. University of British Columbia.

Upwelling



Del Carmen Lares Reyes M.L. 1995. PhD thesis. University of British Columbia.

Concentrations in Area

	[Cd] µ g/g
West Vancouver Labs	0.045-0.065[a]
Bamfield Inlet	0.055-0.065[a]
Saanich Inlet	0.075
Amphitrite Point	0.07[a]

[a] Del Carmen Lares Reyes M.L. 1995. PhD thesis. University of British Columbia.

Summary

- Cadmium varies linearly with phosphate in deep ocean
  - Similar cycling
- Deviations occur in surface water, estuaries and upwelling regions
- Upwelled water may be more toxic due to lower complexation

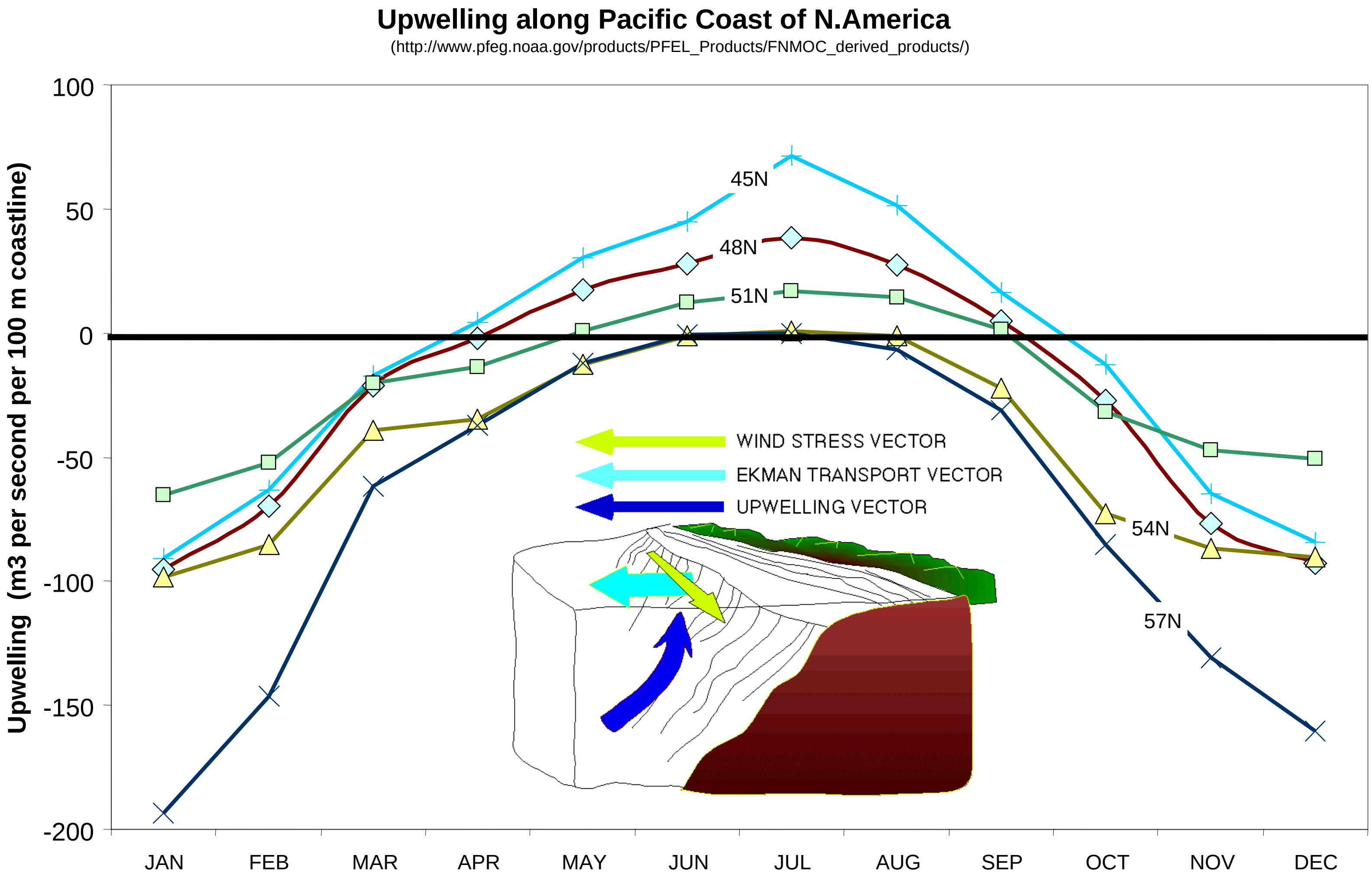
Nutrient supply along the Northeast Pacific margin

Frank Whitney, Fisheries and Oceans Canada

Abstract

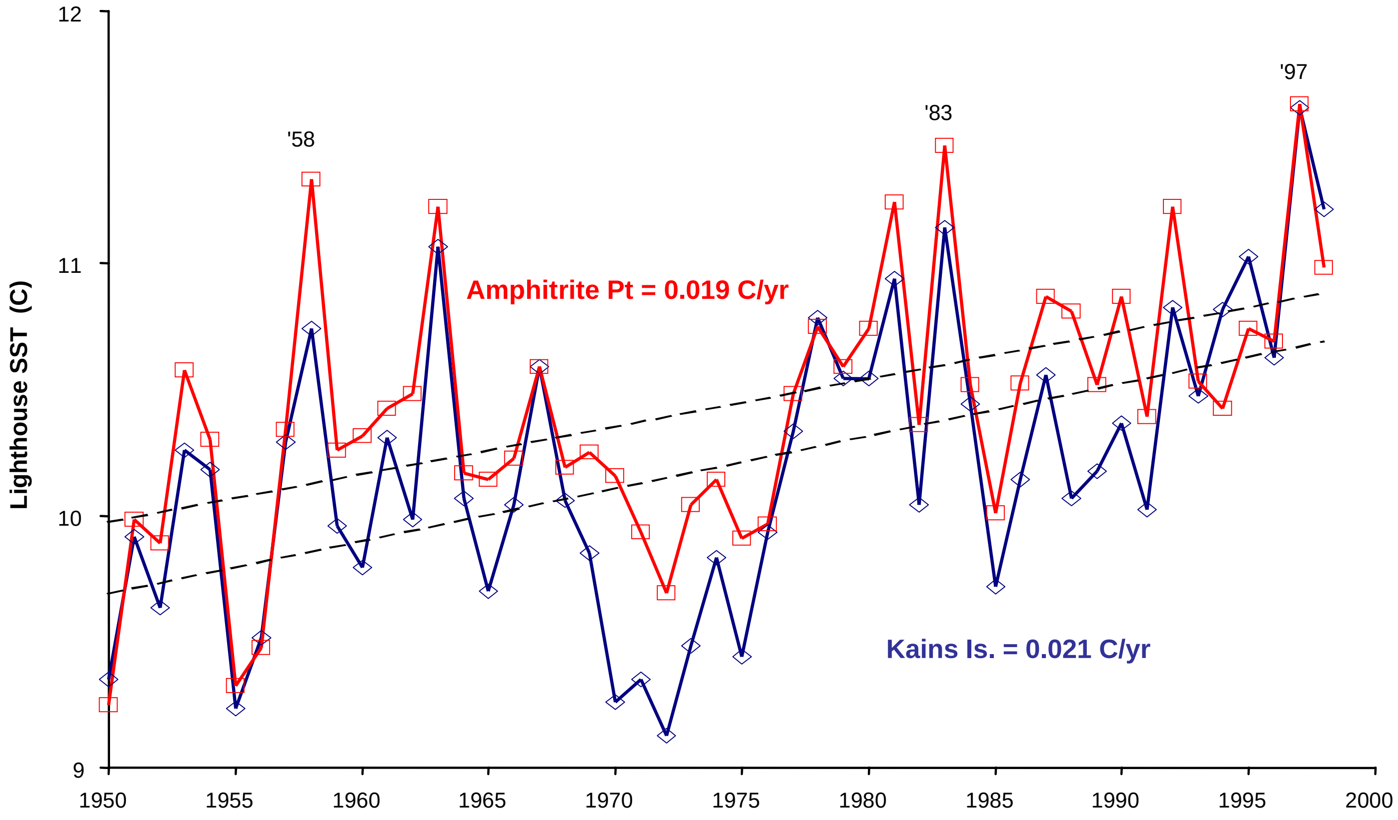
Nutrient supply to the southern B.C. coast is governed largely by winter mixing which fuels the spring bloom, summer upwelling which enriches the exposed coast, and other processes such as tidal mixing, river discharge and katabatic winds which dominate fjords and inland basins. My data shows that ocean stratification has altered nutrient supply to outer coastal waters in recent decades. The 1990s was an abnormally warm decade. Upper ocean warming was observed throughout the region, causing an increase in the stratification of the upper ocean. Strong stratification reduces nutrient supply from the deep ocean to the surface where it can support phytoplankton growth.

Since the chemistry of phosphate and cadmium are closely affiliated in open ocean, nutrient dynamics can be used to infer cadmium sources. Upwelled waters will be relatively rich in Cd, as they are in nutrients.

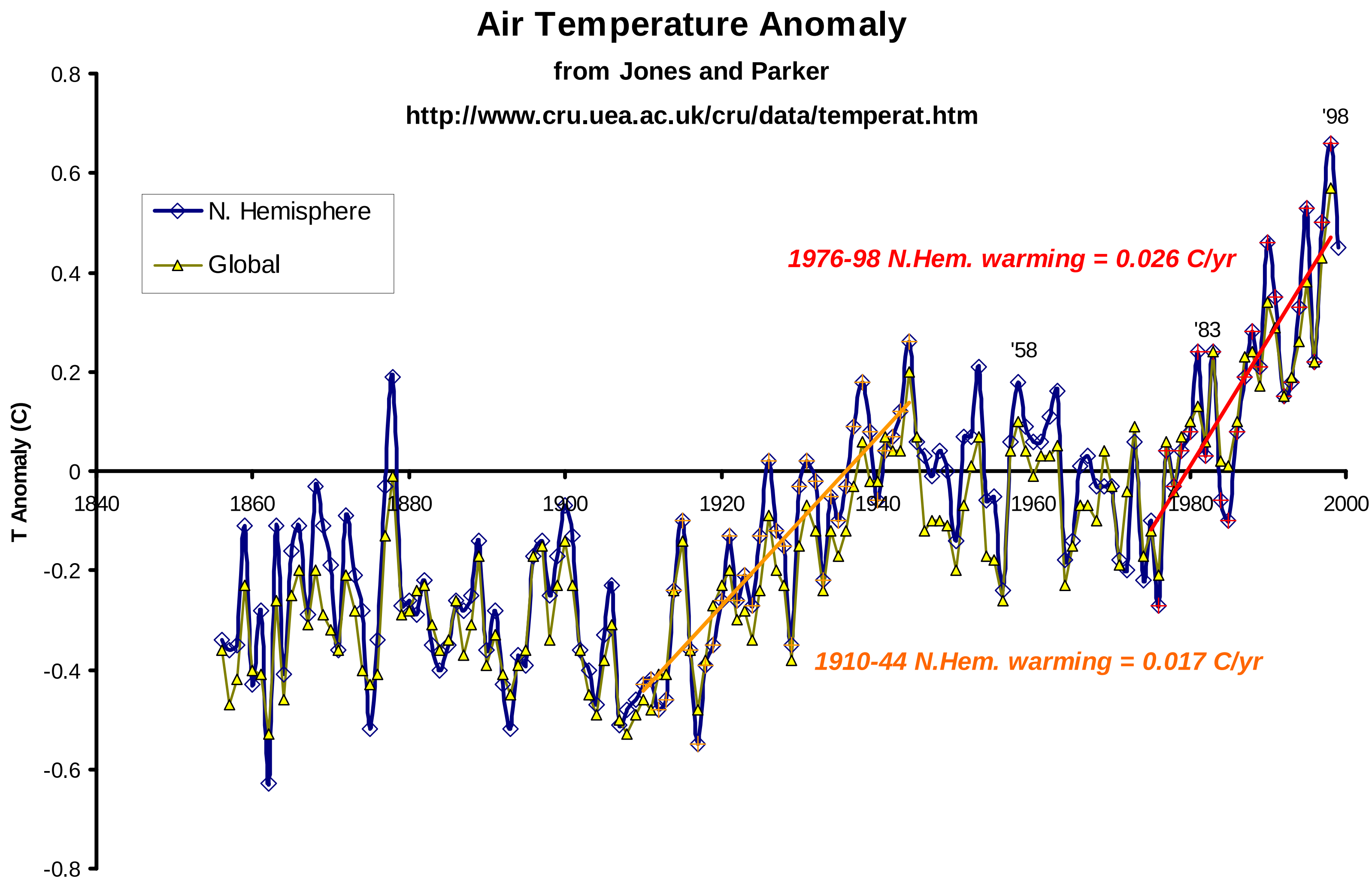


Summer upwelling supplies waters from 200 to 400 m depth onto the continental shelf along the coast of Vancouver Island. By 54 N (north end of the Queen Charlotte Islands), wind driven upwelling stops being an important process.

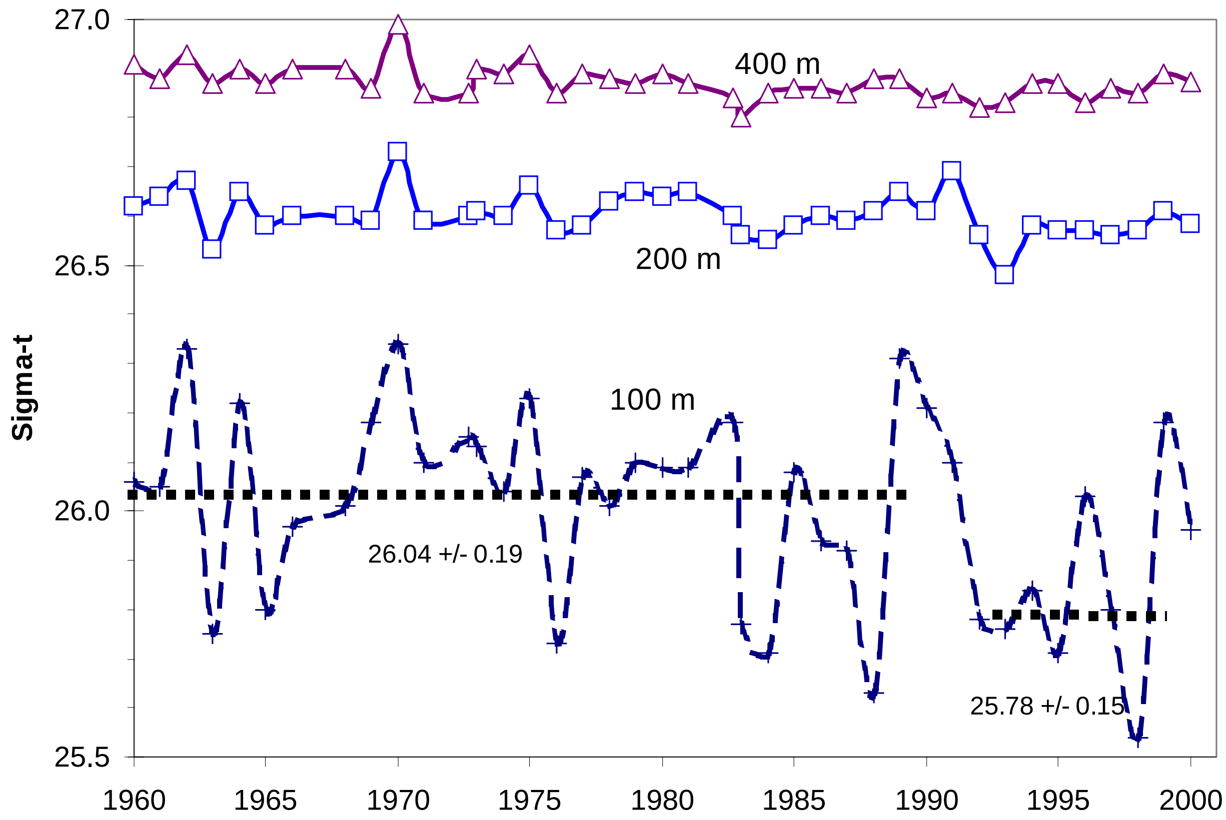
Winds supply the energy and stratification, the resistance to upwelling. Stratification is strengthened by warming and freshening of surface waters.



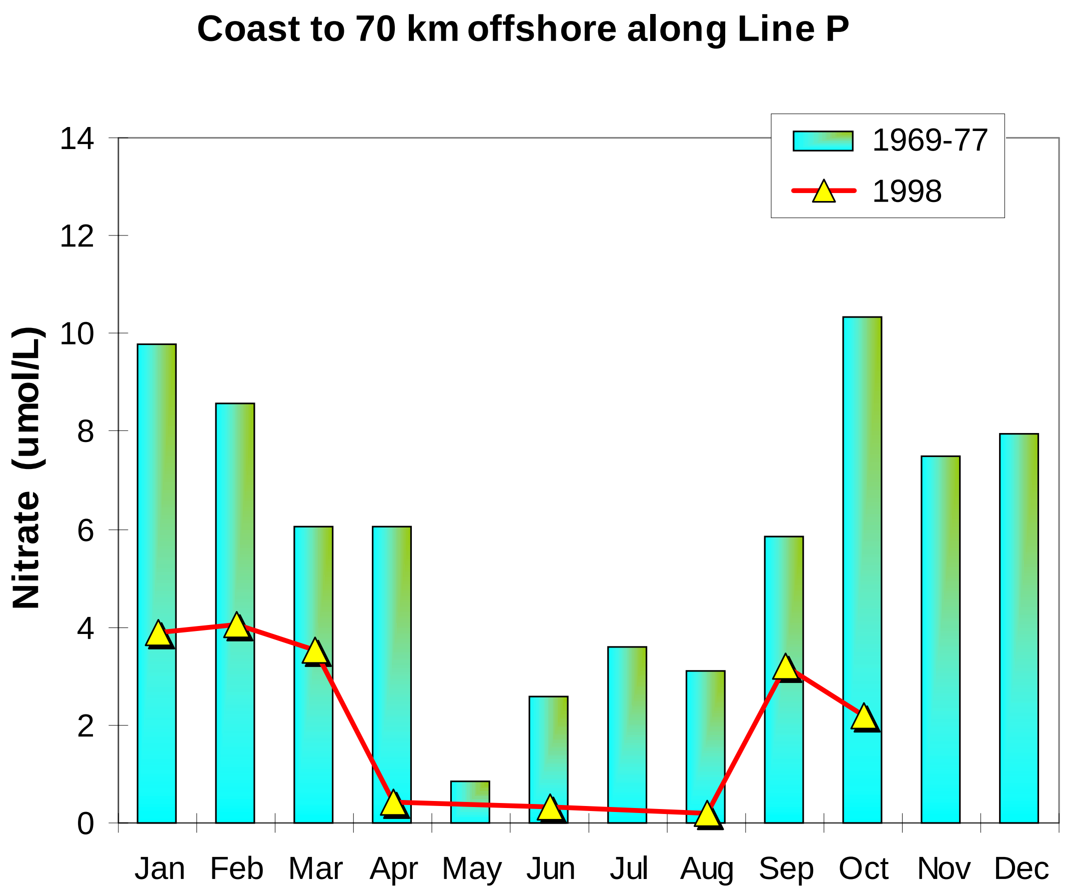
Coastal lighthouses provide a good example of the warming trend that is being seen in B.C. waters. A warming rate of 0.02 C/yr is similar to that being observed in the atmosphere, globally.



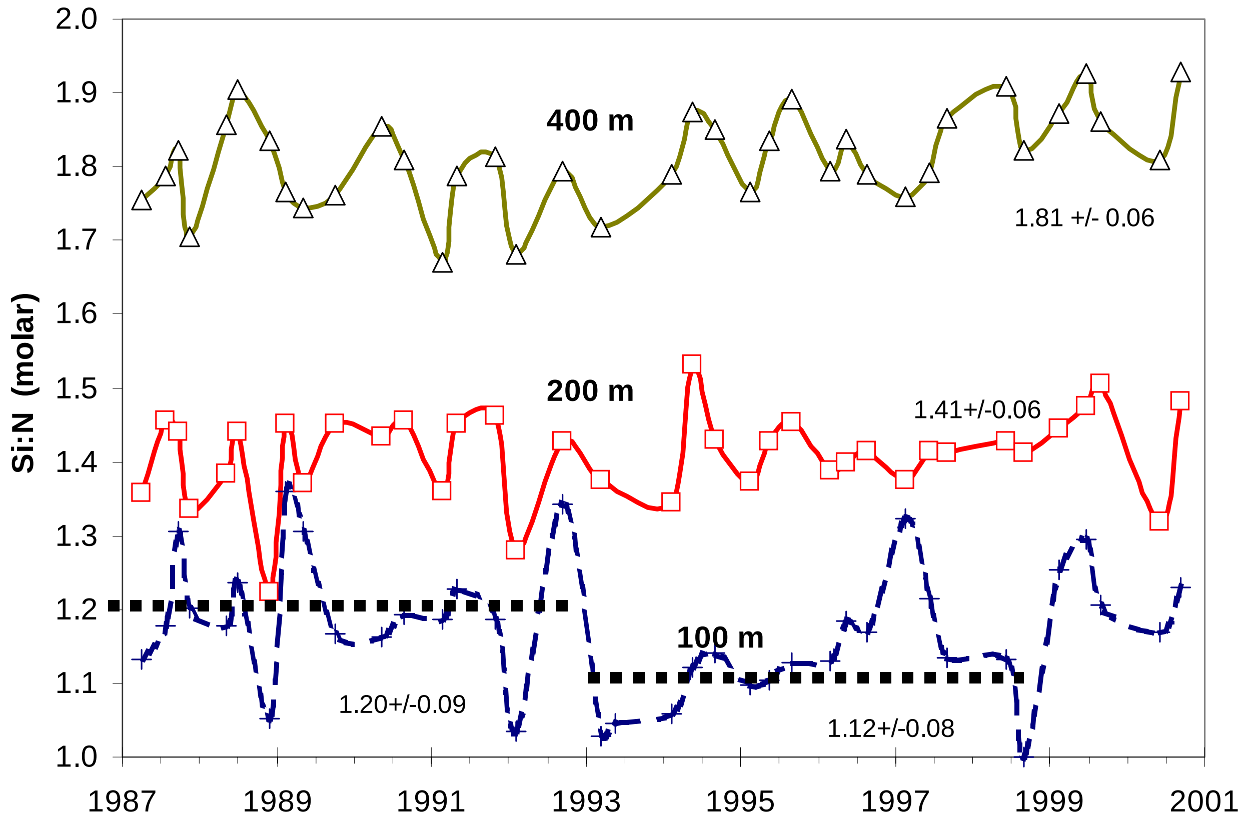
Air Temperature Anomaly
from Jones and Parker
http://www.cru.uea.ac.uk/cru/data/temperat.htm
N. Hemisphere
Global
1976-98 N.Hem. warming = 0.026 C/yr
1910-44 N.Hem. warming = 0.017 C/yr
'98
'83
'58
T Anomaly (C)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1840
1860
1880
1900
1920
1940
1960
1980
2000



At a station near the coast of southern B.C., we see that stratification increased through most of the 1990s due to warming of the upper ocean. The density of shallow waters decreased, whereas there was little change in that at 200 m.



1998 was an extreme example of the impact of a warm event (El Niño) on the supply of nutrients to the upper ocean. Strong stratification through the winter reduced the amount of nitrate available for spring growth in April and suppressed upwelling throughout the summer in southern B.C.

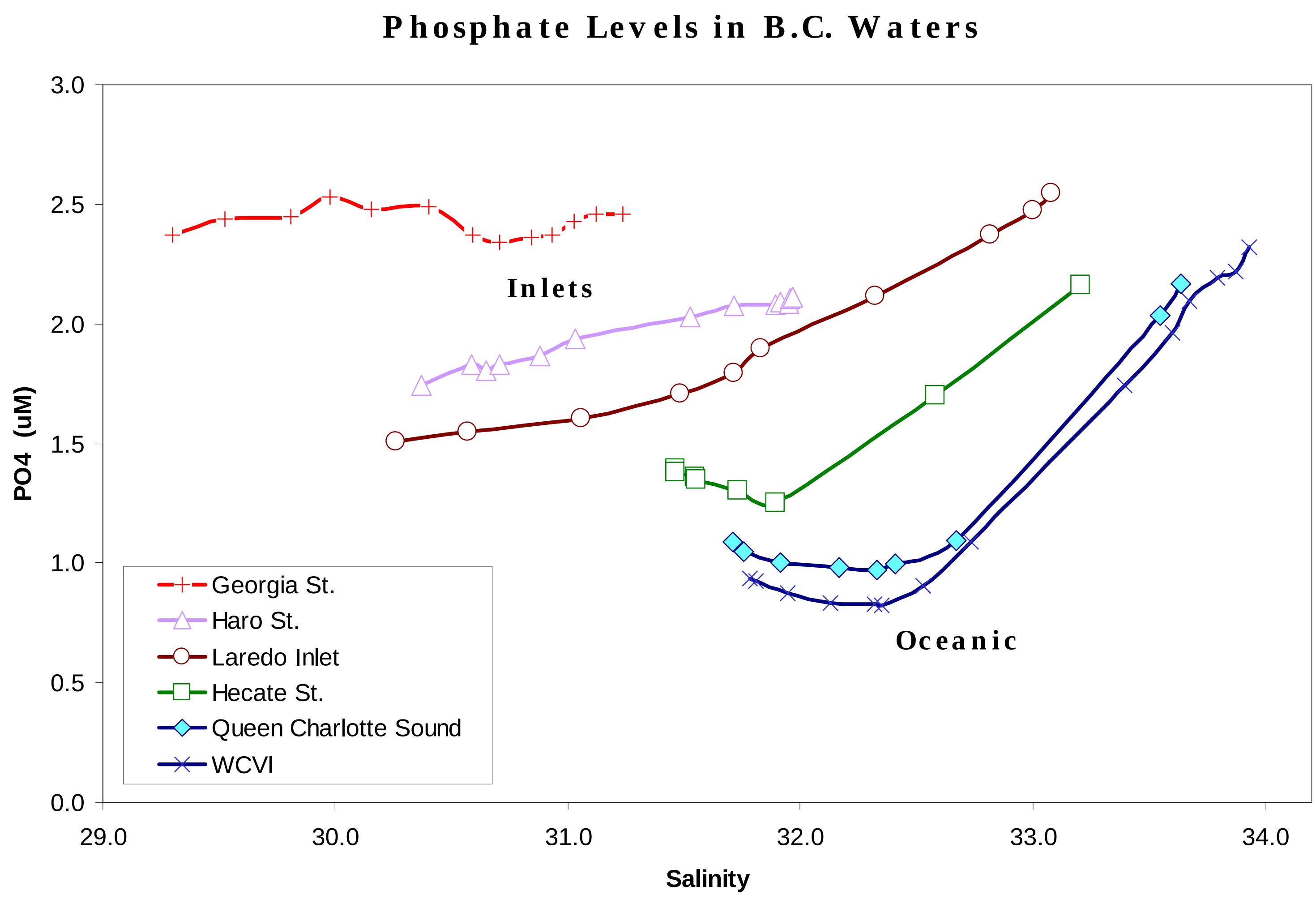


A second process reduces nutrient supply to the B.C. coast during warm periods. Southern ocean waters have lower nutrient levels, and relatively less silicate per unit nitrate than do Gulf of Alaska waters. Through the mid-1990s, these southern waters affected the quality of waters that were upwelled on the coast. A low Si to NO_3 ratio can lead to silicate depletion and to changes in the phytoplankton species which feed higher trophic levels.

Nitrate and silicate are the nutrients we most commonly see limiting phytoplankton growth. However, since Cd and phosphate covary in oceanic waters, we should also be aware of how this nutrient is distributed. In oceanic water, Bruland (1980) showed that there was a tight correlation between these two:

$$Cd\ (nmol/kg) = 0.347\ PO_4\ (umol/kg) - 0.068$$

Metals tend to be more particle reactive than do nutrients. Therefore, we cannot be sure that Cd acts like PO_4 in coastal waters where particles are more abundant.



Inlets and basins have higher concentrations of phosphate than oceanic waters. Georgia Strait has high concentrations from top to bottom, whereas surface waters off the West Coast of Vancouver Island have relatively low levels. It is evident that inlets are efficient nutrient (and metals) traps.

During 1995, the B.C. Ministry of Environment, Lands and Parks conducted a review of Saanich Inlet waters and sediments. One interesting result was that the sediments of the Saanich Inlet basin are often above 2 ug Cd/L, even though water levels are low. This is likely the result of the efficient way in which biological processes strip nutrients and metals from seawater and transport them to depth.

Sediments in Saanich are anoxic because they are rich in organic matter. Such conditions will immobilize Cd, whereas phosphate is released into bottom waters as bacteria decompose organics. Such processes should result in Cd and phosphate behaving somewhat differently in coastal waters.

Summary

Upwelling is an important means by which nutrients (and Cd) are transported to the upper ocean along the west coast of North America. For several months each summer, upwelling brings waters from depths as great as 400 m onto the continental shelf. This process becomes weaker to the north.

Phosphate and cadmium behave alike in the open ocean. We can assume that phosphate measurements in outer coastal waters will provide a good estimate of Cd supply. It appears, therefore, that there is a large reservoir capable of continuously supplying Cd to the outer coast.

This may not be true in inland waters where anoxic waters and sediments can remove metals such as cadmium from seawater. In these regions, sediments may prove to be a more important source of Cd.

In recent decades, a warming trend has increased the stratification of B.C. waters. This has resulted in a reduced winter and summer nutrient supply in southern B.C through the mid 1990s.

MUSSELS AS INDICATORS OF Cd IN UPWELLING REGIMES

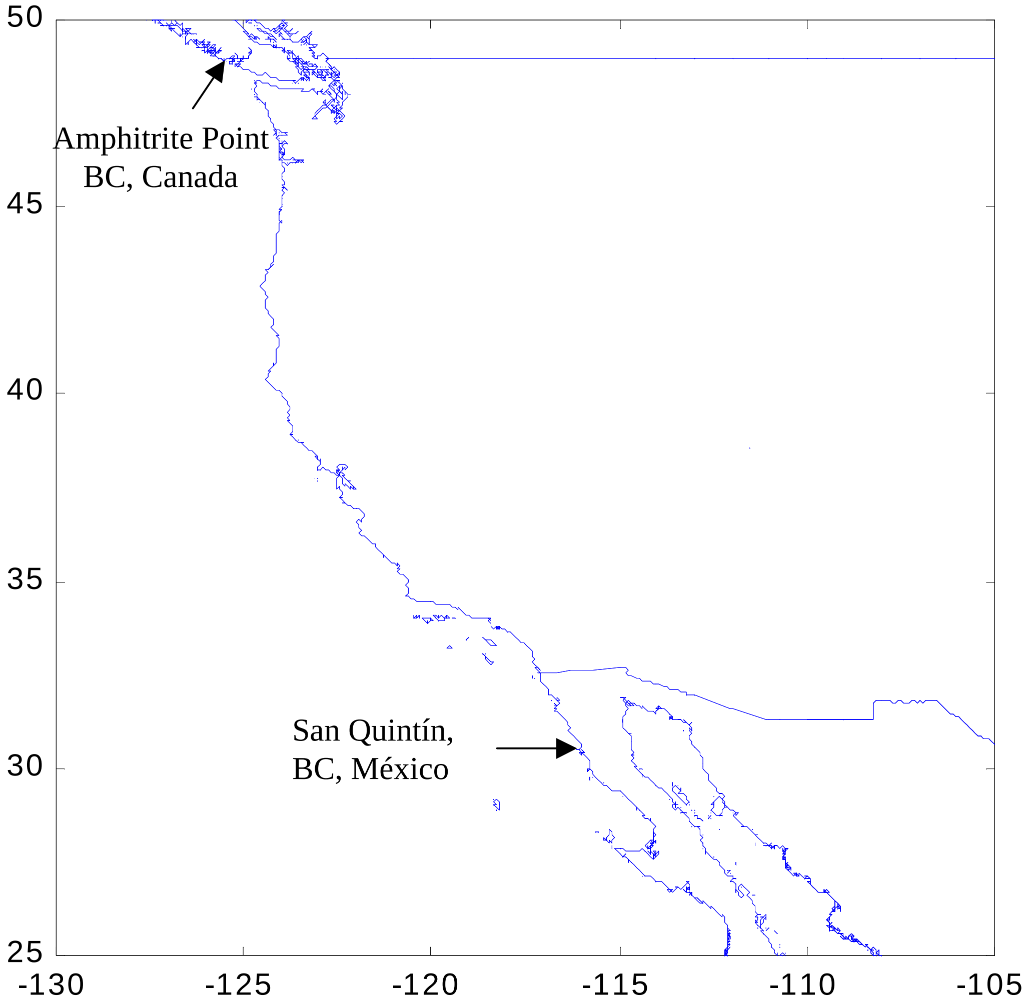
M. Lucila Lares

Departamento de Ecología

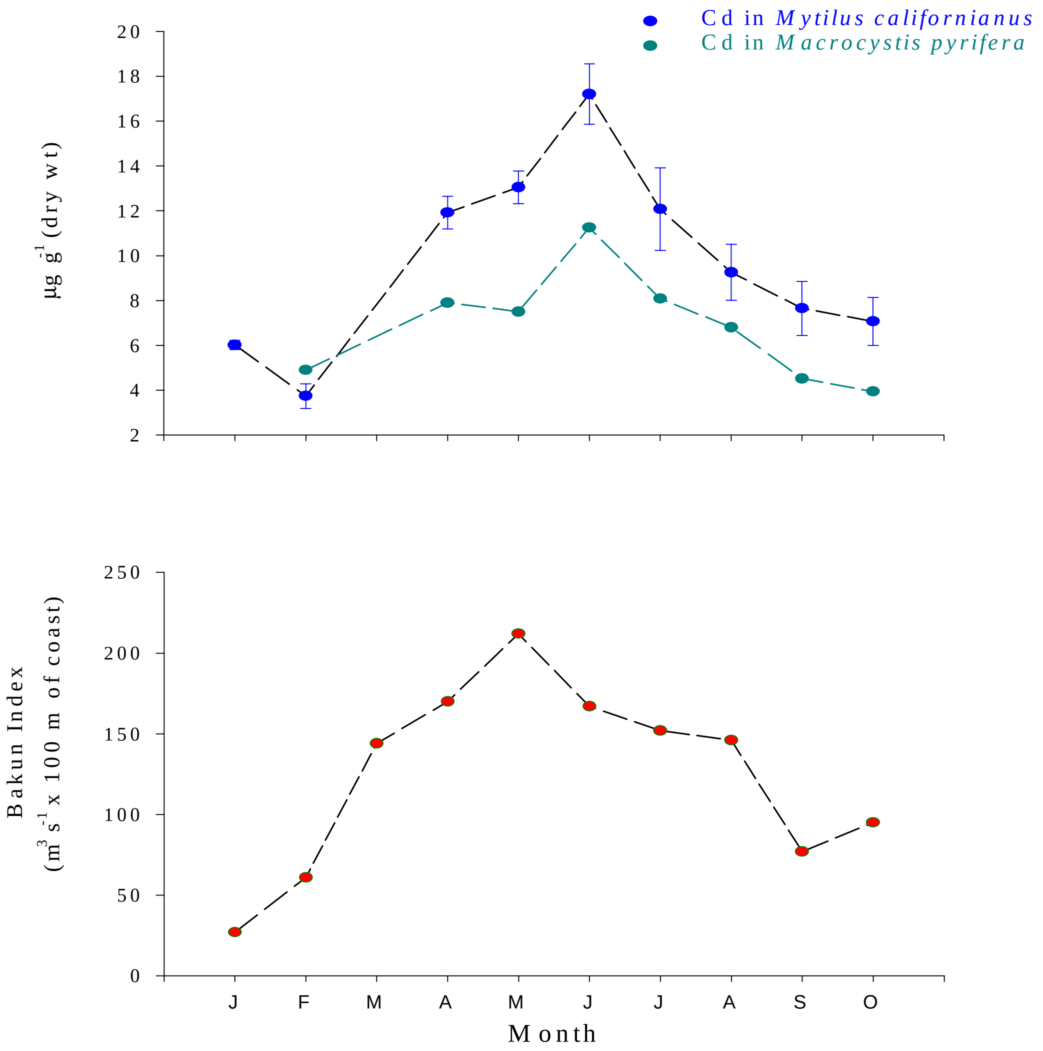
Centro de Investigación Científica y de Educación Superior de Ensenada

OUTLINE

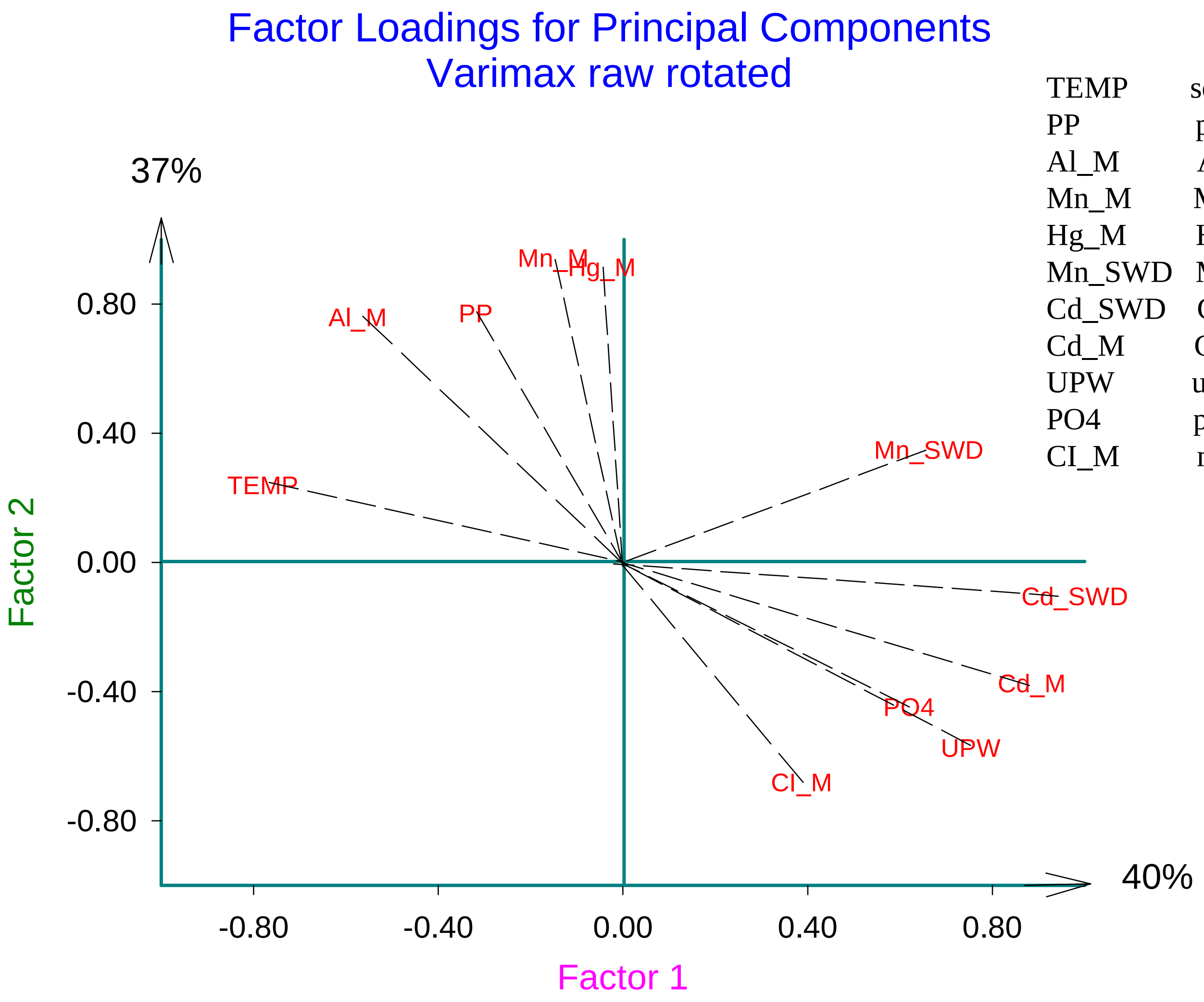
- Baja California results
- Amphitrite Point results
- Difference in Cd depuration kinetics of *M. californianus* and *M. trossulus*
- Levels of Cd in Baja California related to upwelling
- Cd in *Crassostrea gigas* of Baja California


50
45
40
35
30
25
-130
-125
-120
-115
-110
-105
Amphitrite Point
BC, Canada
San Quintín,
BC, México

Monthly variabililty of Cd in an upwelling region of Baja California, México



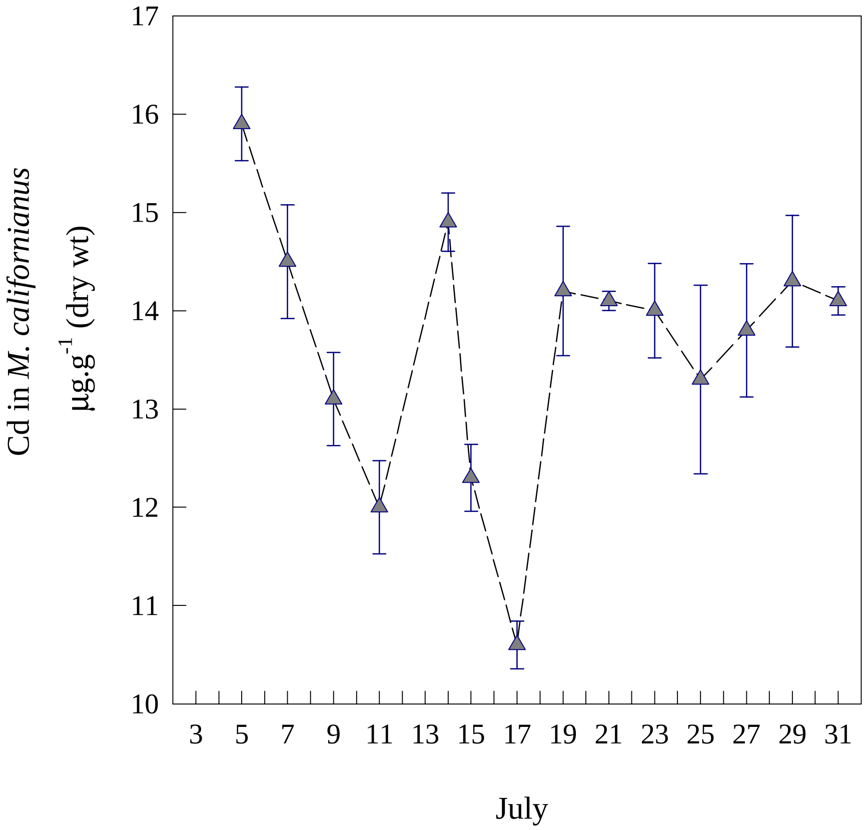
PCA for the study on the monthly variability of trace metals in Baja California mussels



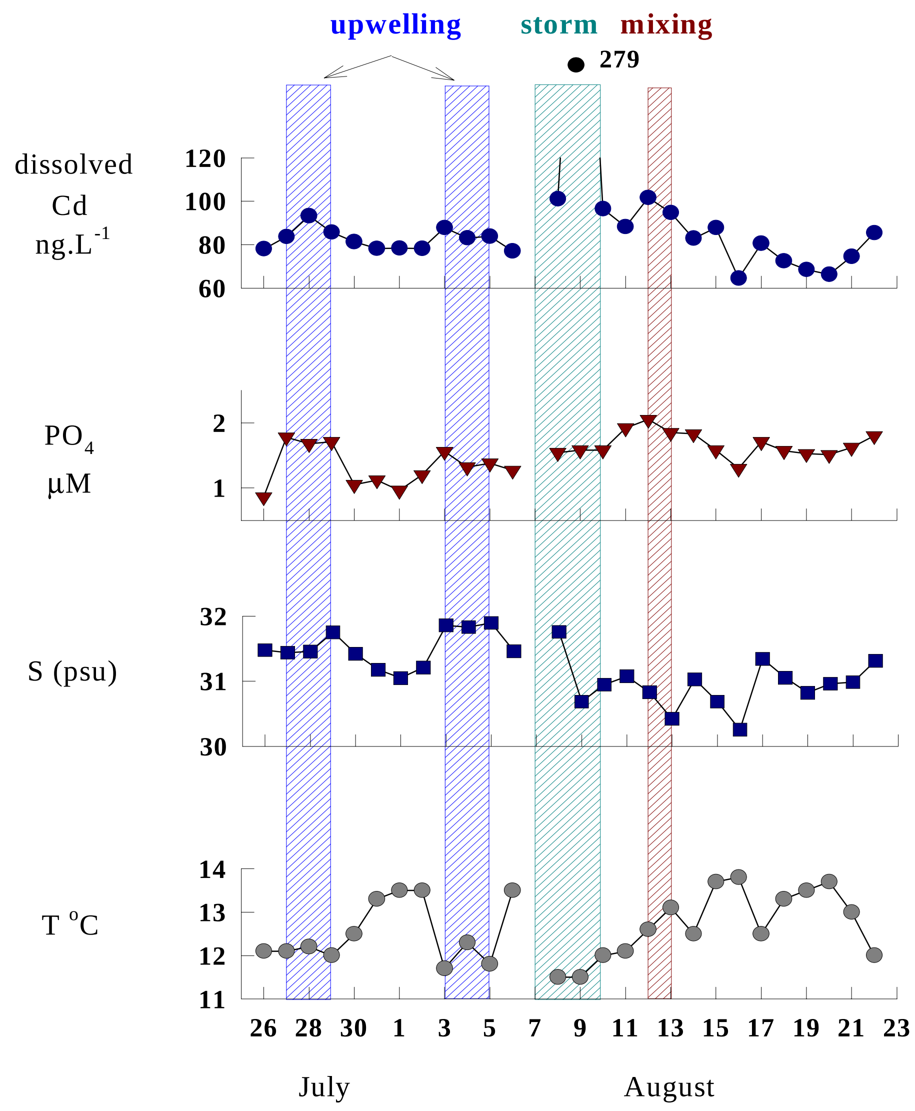
TEMP	seawater temperature
PP	pluvial precipitation
Al_M	Al conc. in mussels
Mn_M	Mn conc. in mussels
Hg_M	Hg conc. in mussels
Mn_SWD	Mn conc. in seaweeds
Cd_SWD	Cd conc. in seaweeds
Cd_M	Cd conc. in mussels
UPW	upwelling index
PO4	phosphate
CI_M	mussel's condition index

Short-term variability during upwelling season

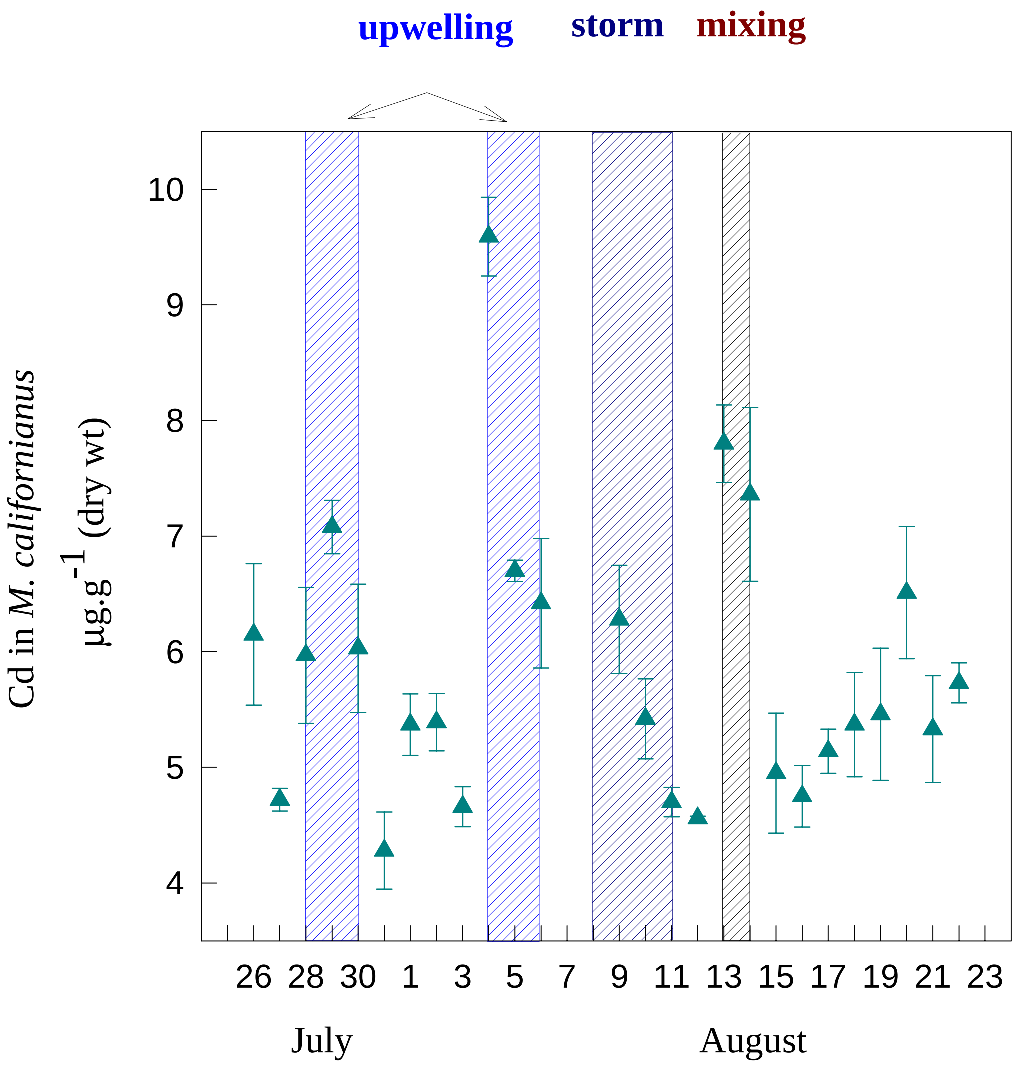
in Baja California



Amphitrite Point



Amphitrite Point



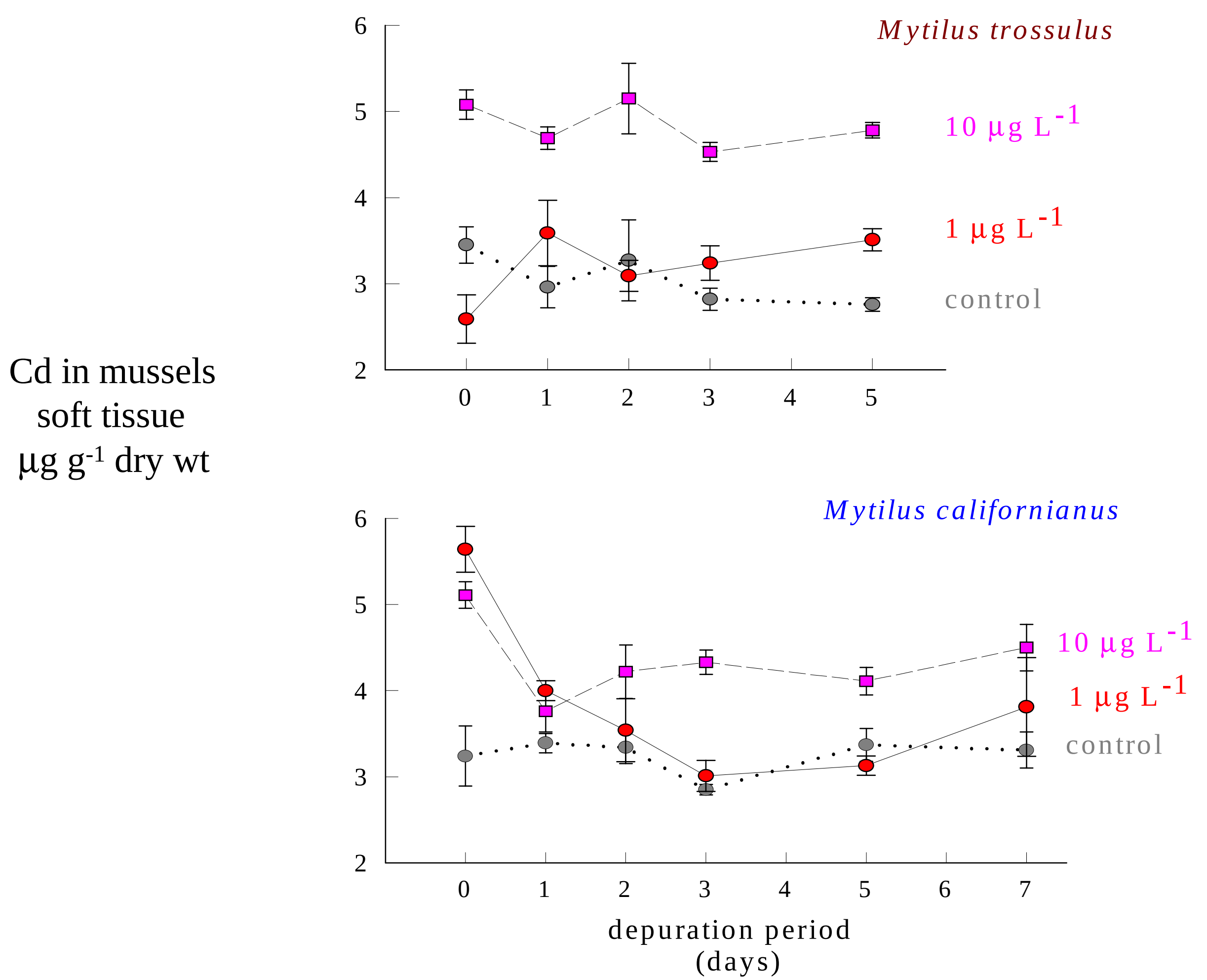
PCA for the study on the short-term variability of Cd in Amphitrite Point mussels

Factor Loadings for Principal components
(Varimax raw rotated)

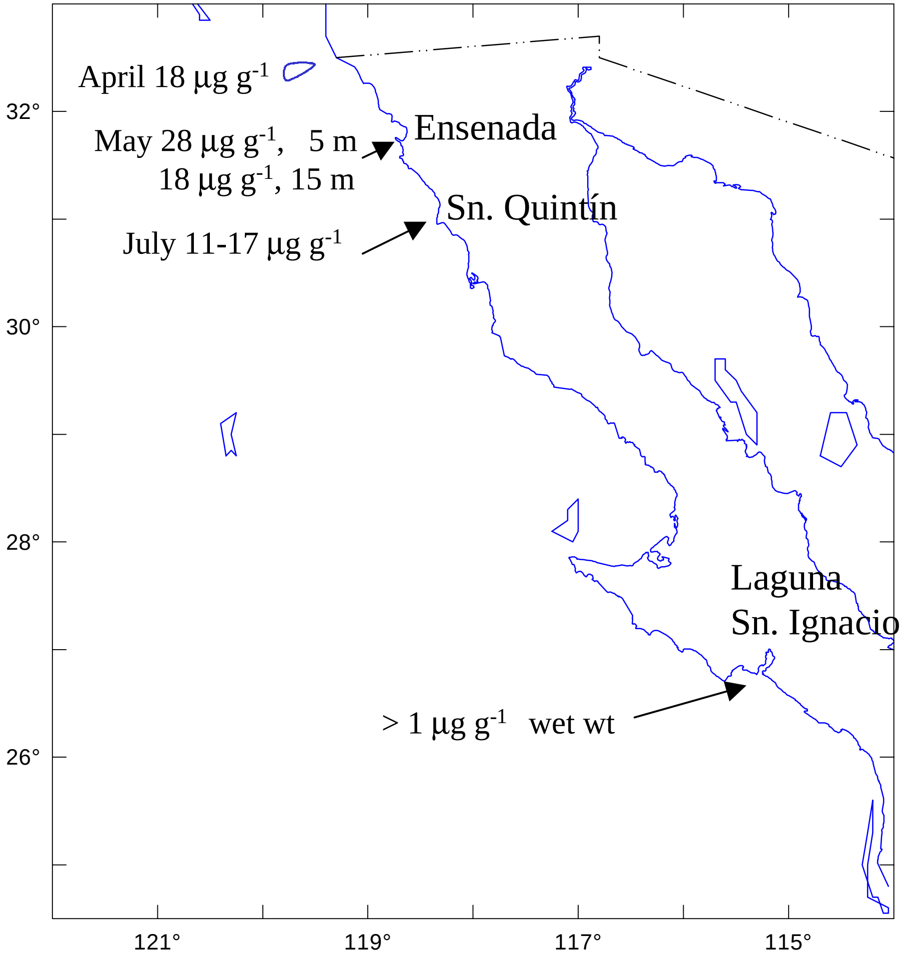
(* marked loadings are > .700)

	Factor 1	Factor 2	Factor 3
Sw Cd	0.757*	0.417	-0.020
PO_4	0.778*	-0.162	0.037
T	-0.341	-0.896*	0.006
S	-0.133	0.949*	0.153
M Cd	0.563	0.174	0.777*
Cond. Index	0.048	-0.032	-0.955*
Cd/shell wt	0.806*	0.084	0.294
% Expl. Var.	33	28	23

Differences in Cd elimination from *M. californianus* and *M. trossulus* soft tissue



Cd levels related to upwelling



Cadmium and oysters

Leah Bendell-Young
SFU

Lab and field based studies to determine:

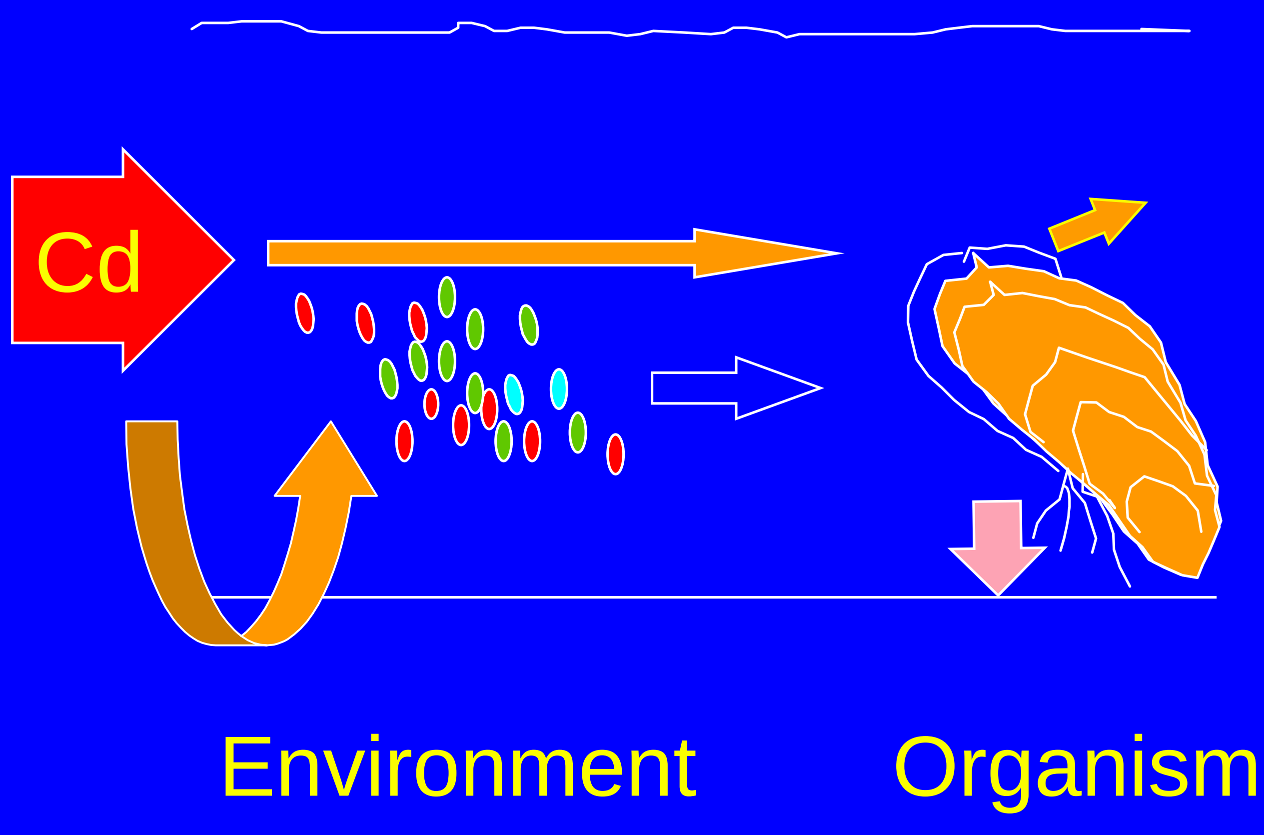
1)how bivalve feeding behaviour and

2) geochemistry

influence cadmium uptake in bivalves

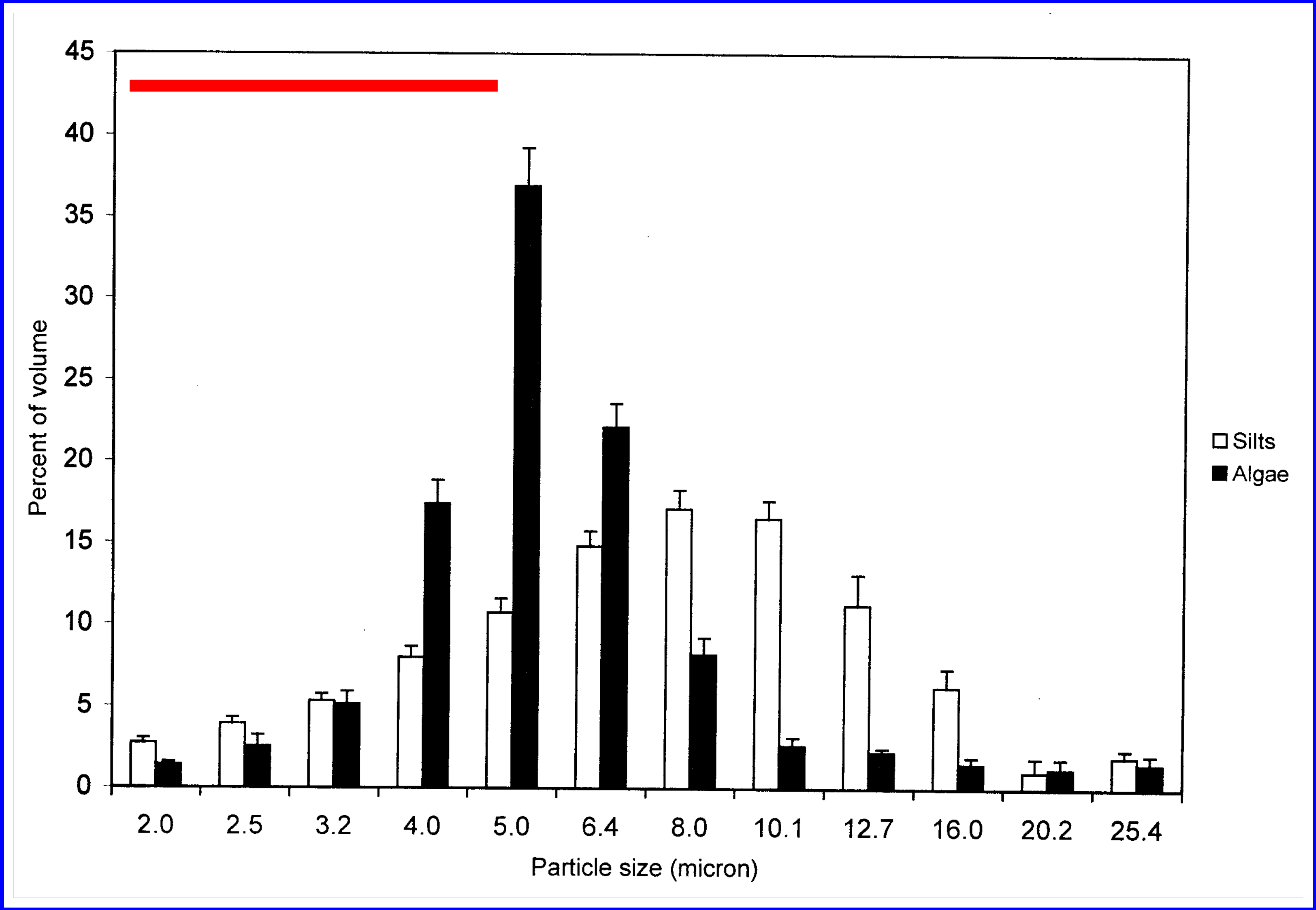
How does feeding behaviour influence cadmium exposure in bivalves?

Trace metal accumulation



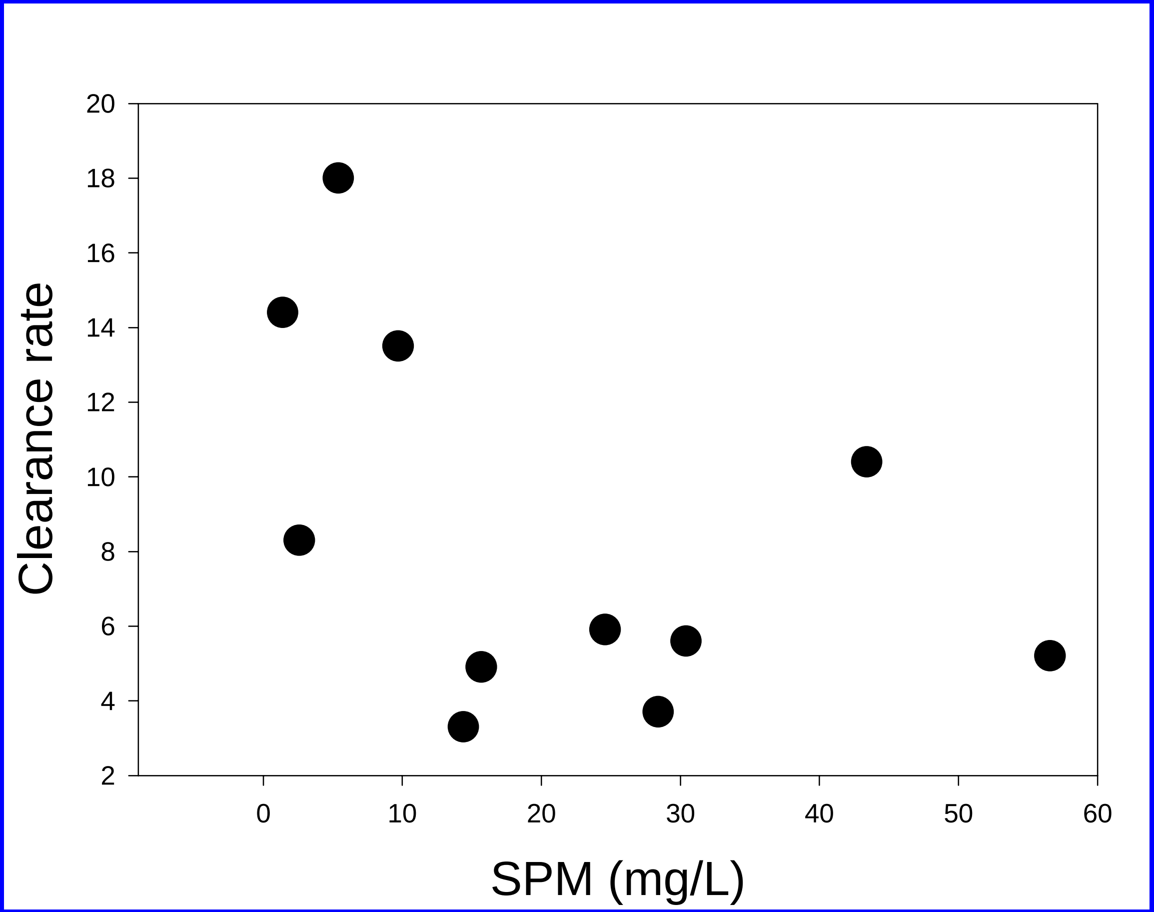
Bivalves will selectively feed based on:

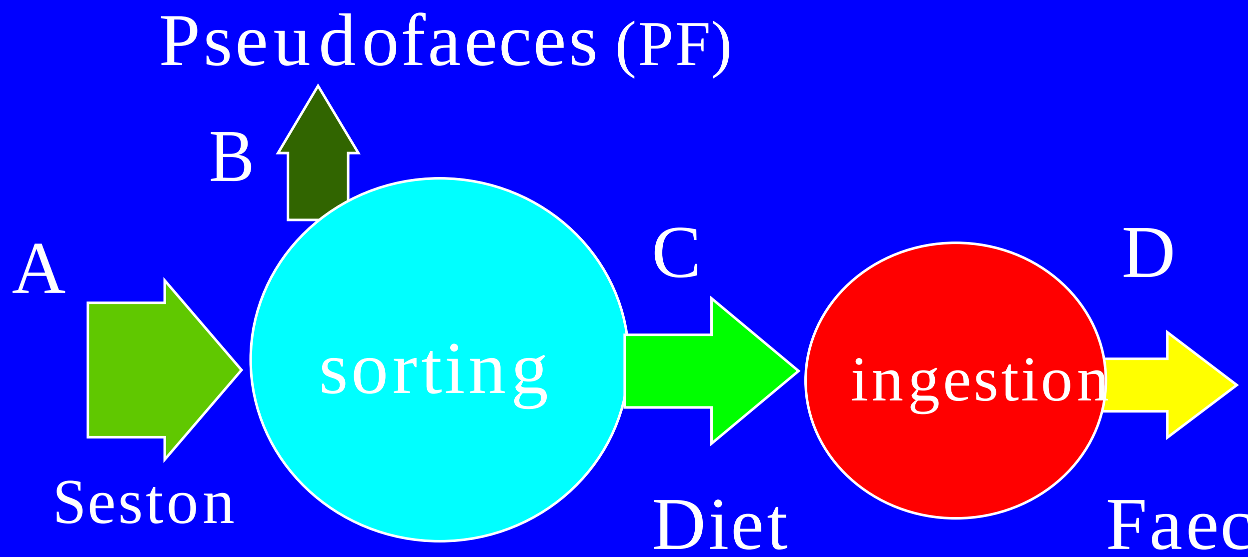
- Particle size (1.5-5 um)
- Quantity of food (mg/L)
- Quality of food (% organic matter



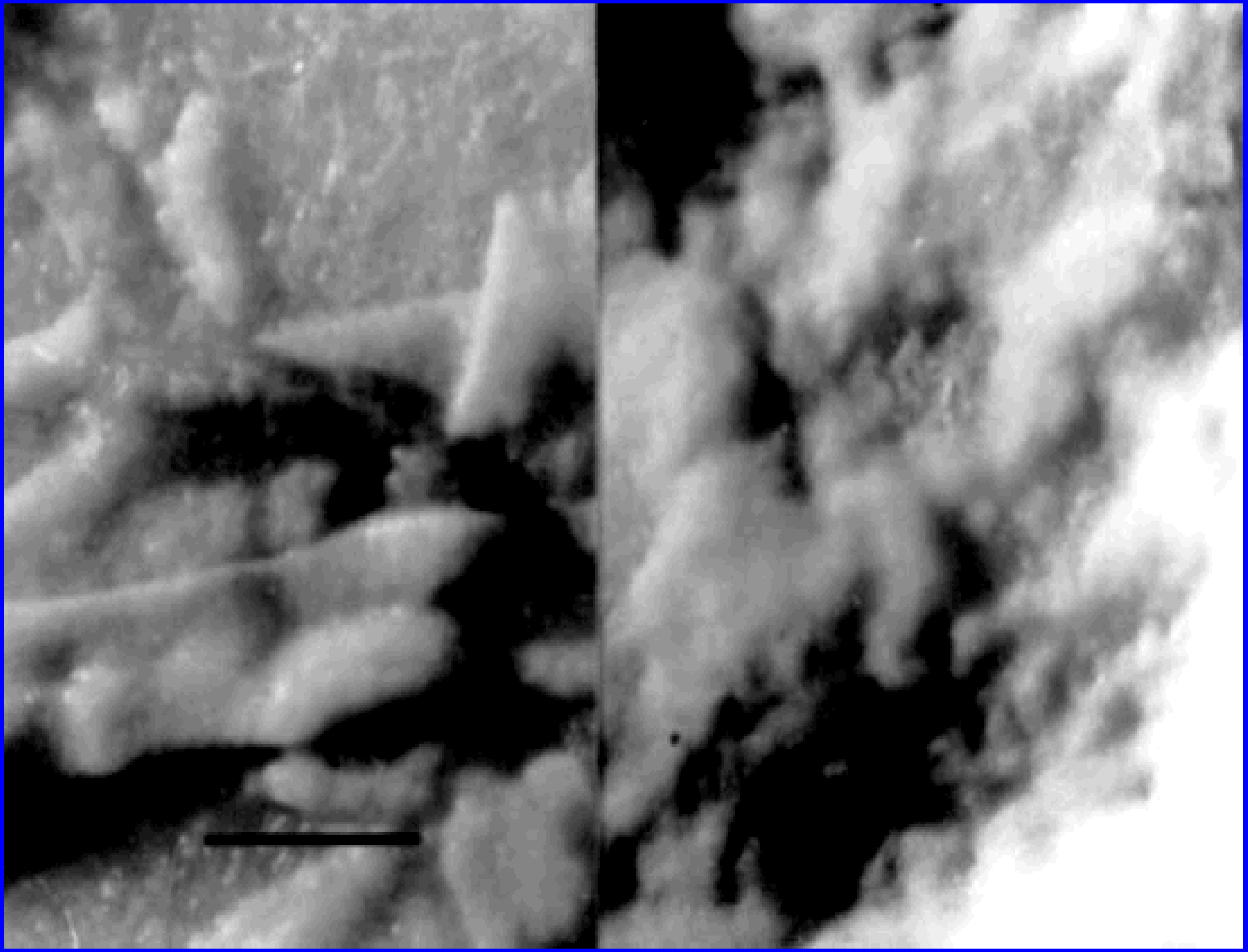
Particle size

Generally, clearance rate decreases with increase SPM concentration

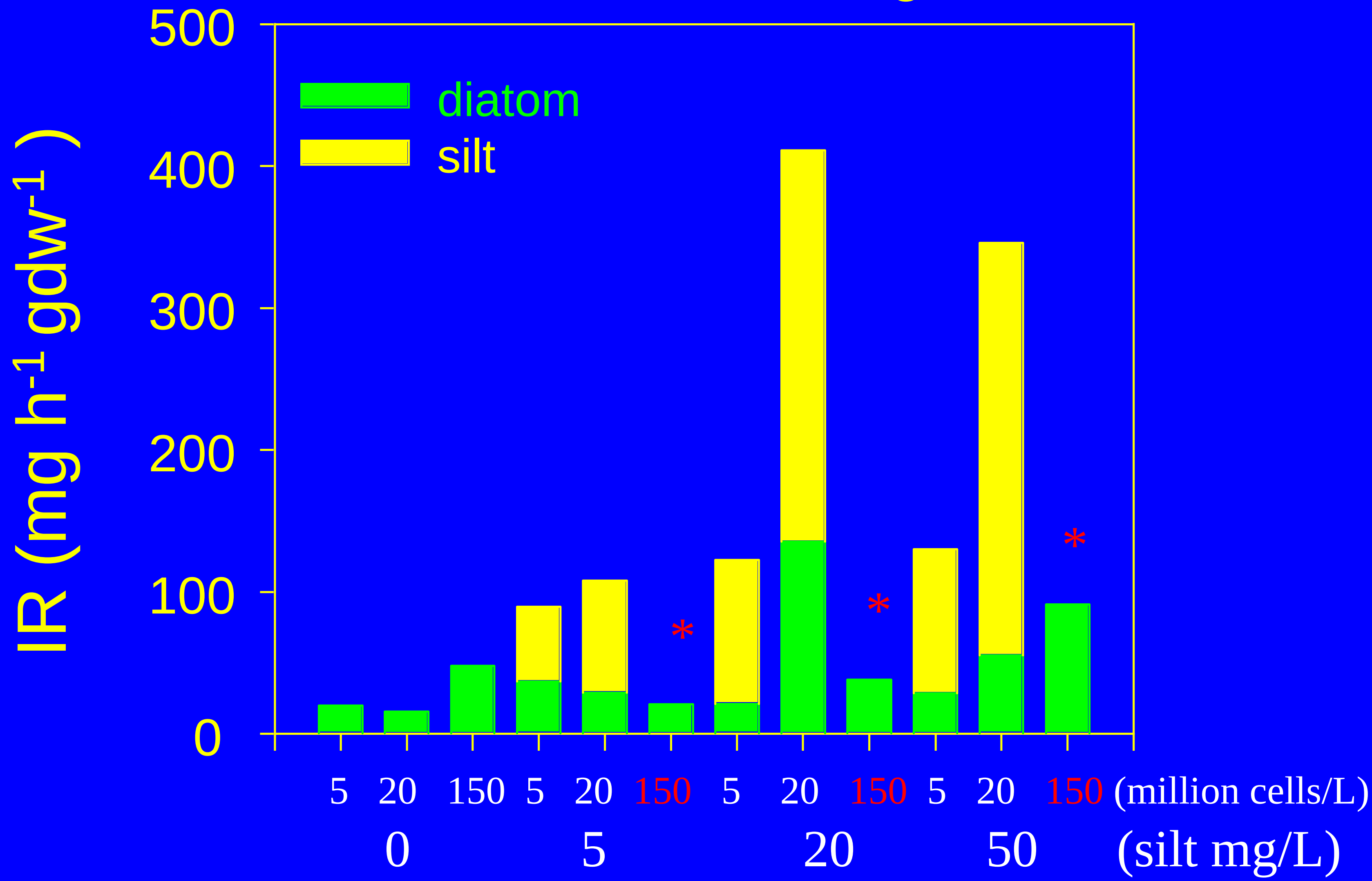




Based on quality of food bivalves can effectively sort to maximize carbon ingestion faeces pseudofaeces

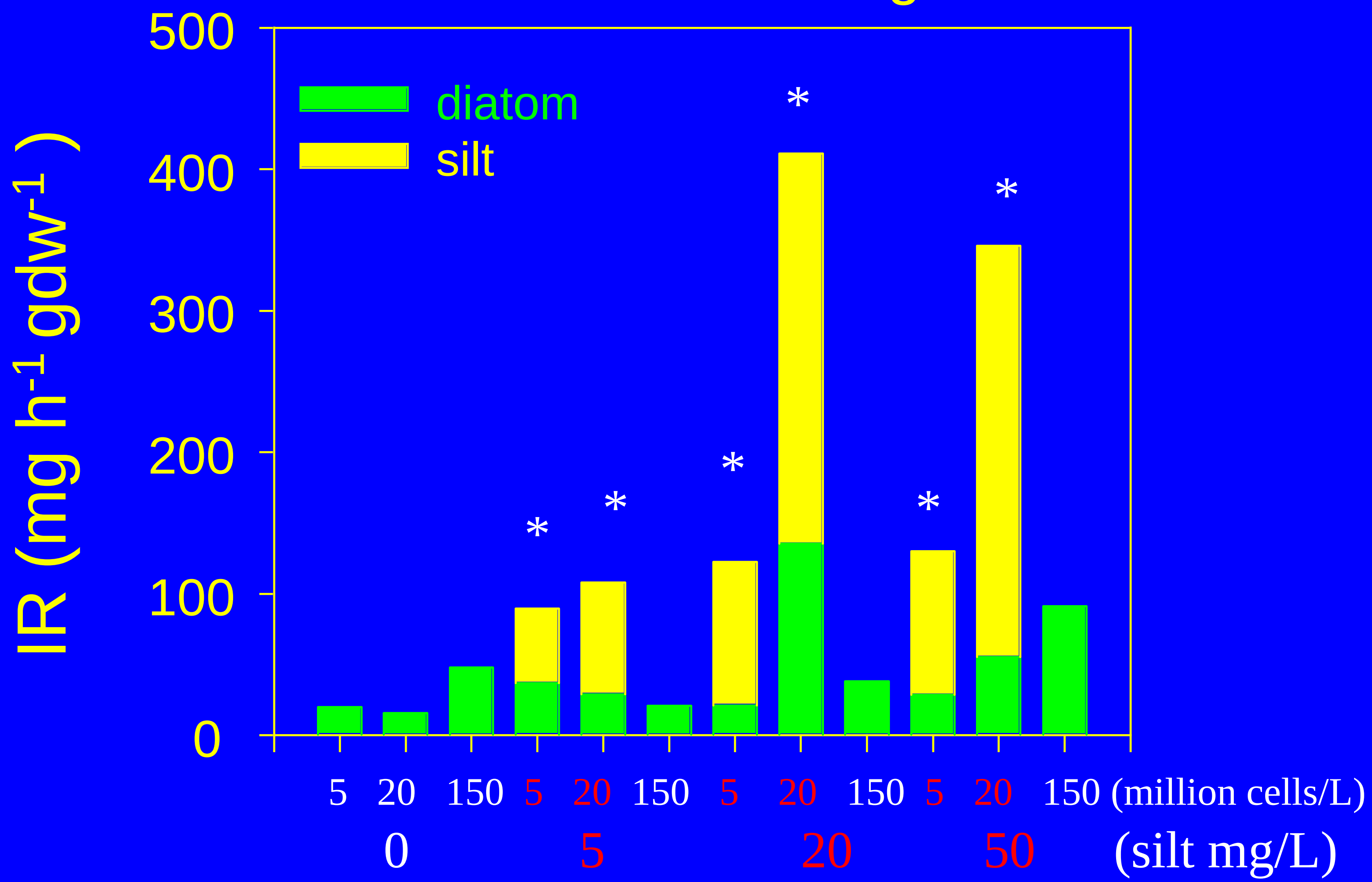


Seston matrices vs. Ingestion rate



* Effectively selecting only OM/rejecting all IM

Seston matrices vs. Ingestion rate



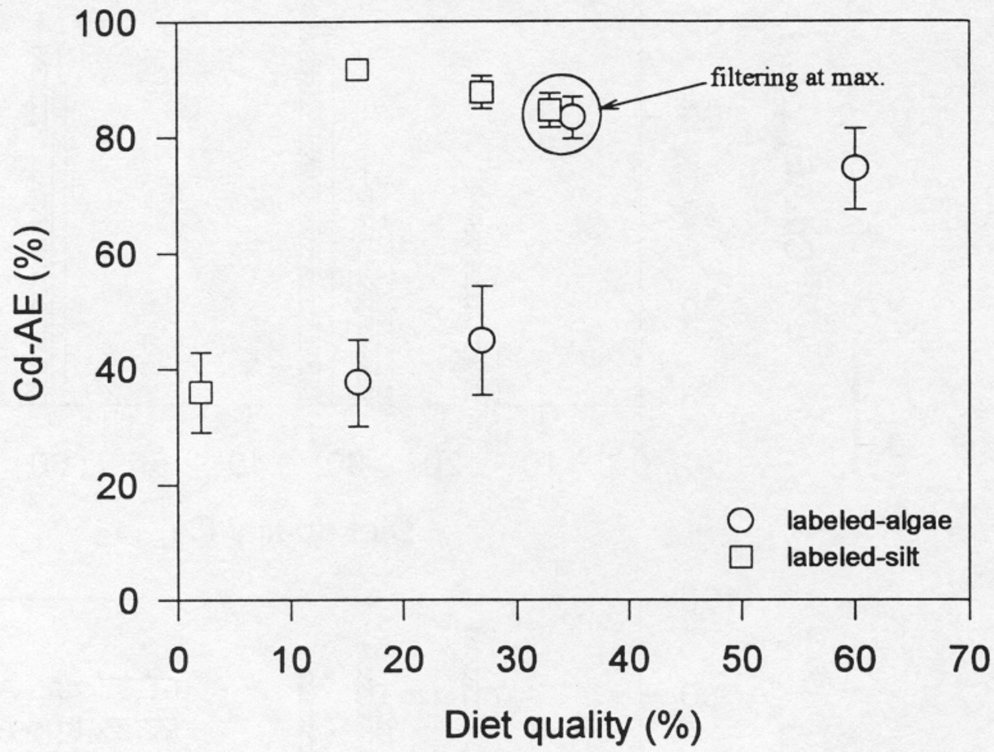
But when low in quantity select both OM and IM

What amount of Cd is actually assimilated* from food by the bivalve?

Where assimilation or assimilation efficiency (AE) is a first-order physiological parameter than can be used to systematically compare the bioavailability of cadmium from different foods (Wang and Fisher 1999)

In lab based studies comparing
the assimilation of Cd(109)
by the blue mussel, the mussel is assimilating
Cd(109)

from algae (OM) (actively)
and
from silt (IM) (passively)


100
80
60
40
20
0
Cd-AE (%)
filtering at max.
labeled-algae
labeled-silt
0
10
20
30
40
50
60
70
Diet quality (%)

Comparison of AE

Bivalve	Food	AE	Reference
Oyster	Algae	69%	Reinfelder et al.
Clam	Algae	88%	Decho and Luoma
Mussel	Algae	40%	Reinfelder et al.
Mussel	Sediment	15%	Gagnon and Fisher
Mussel	Silt/Algae	88%	Arifin and B-Y
Mussel	Algae	74%	Arifin and B-Y
Mussel	Silt	40%	Arifin and B-Y

Conclude that:

active assimilation from organic matter (%OM/ Algae) (active digestive processes breaking down OM Cd)

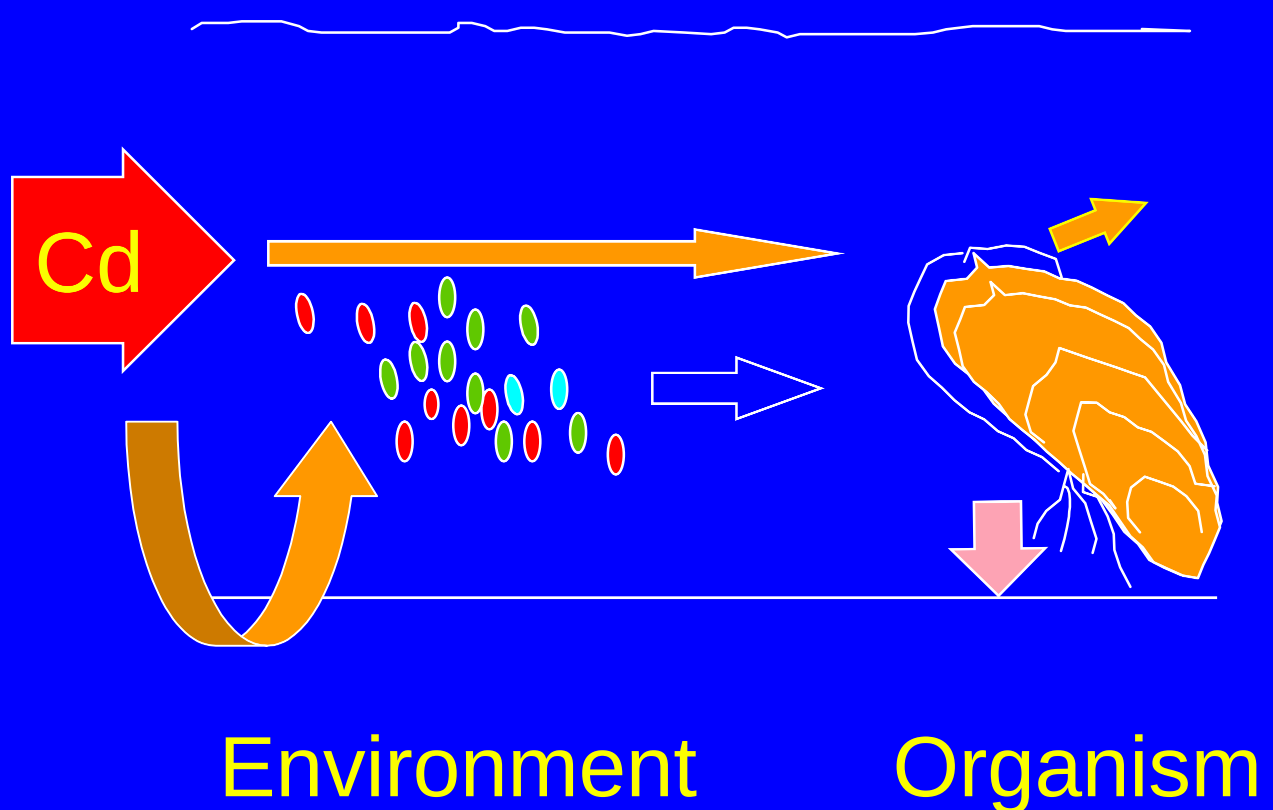
and

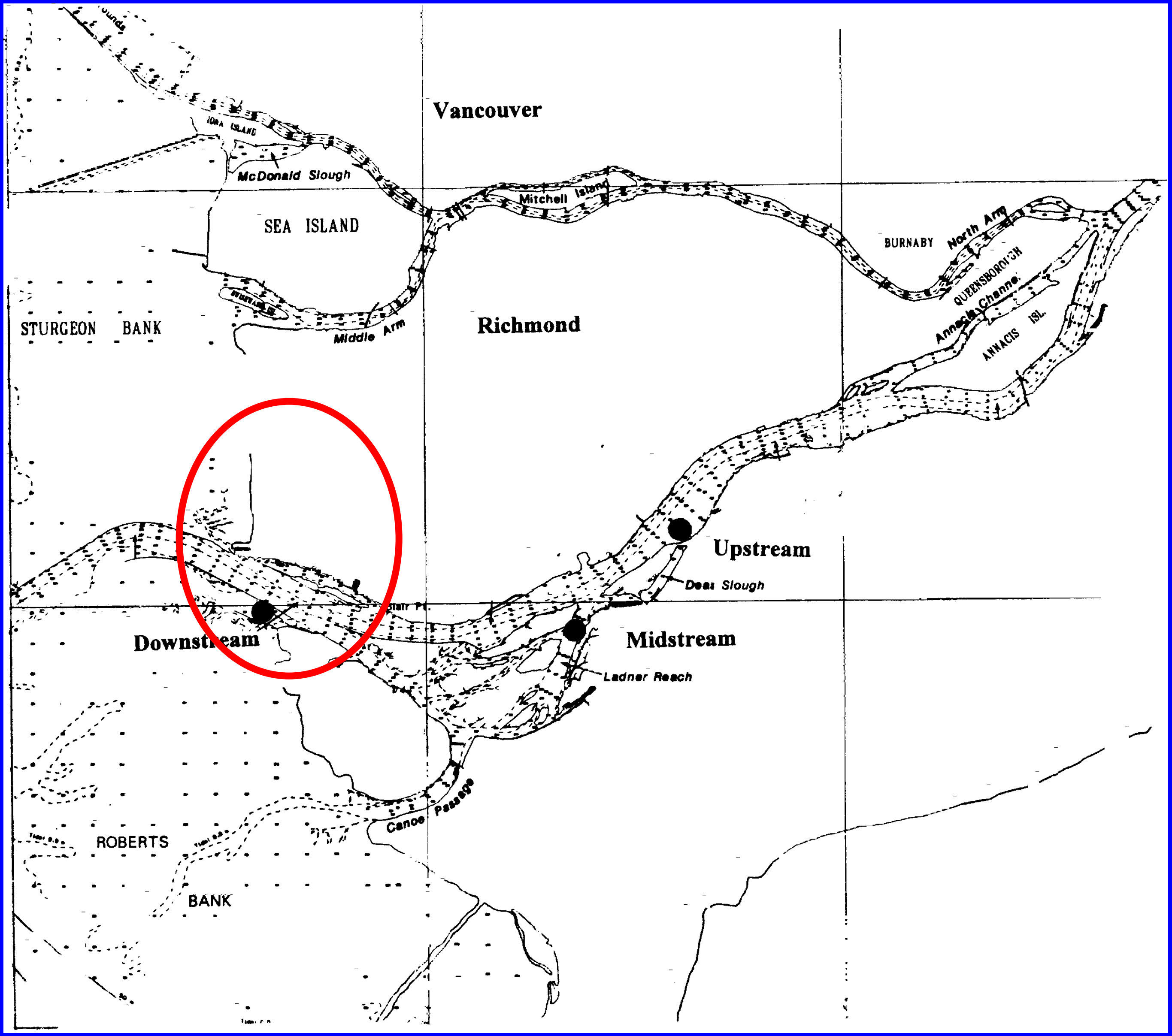
passive assimilation from inorganic matter (passive desorption from inorganic (IM) particulates)

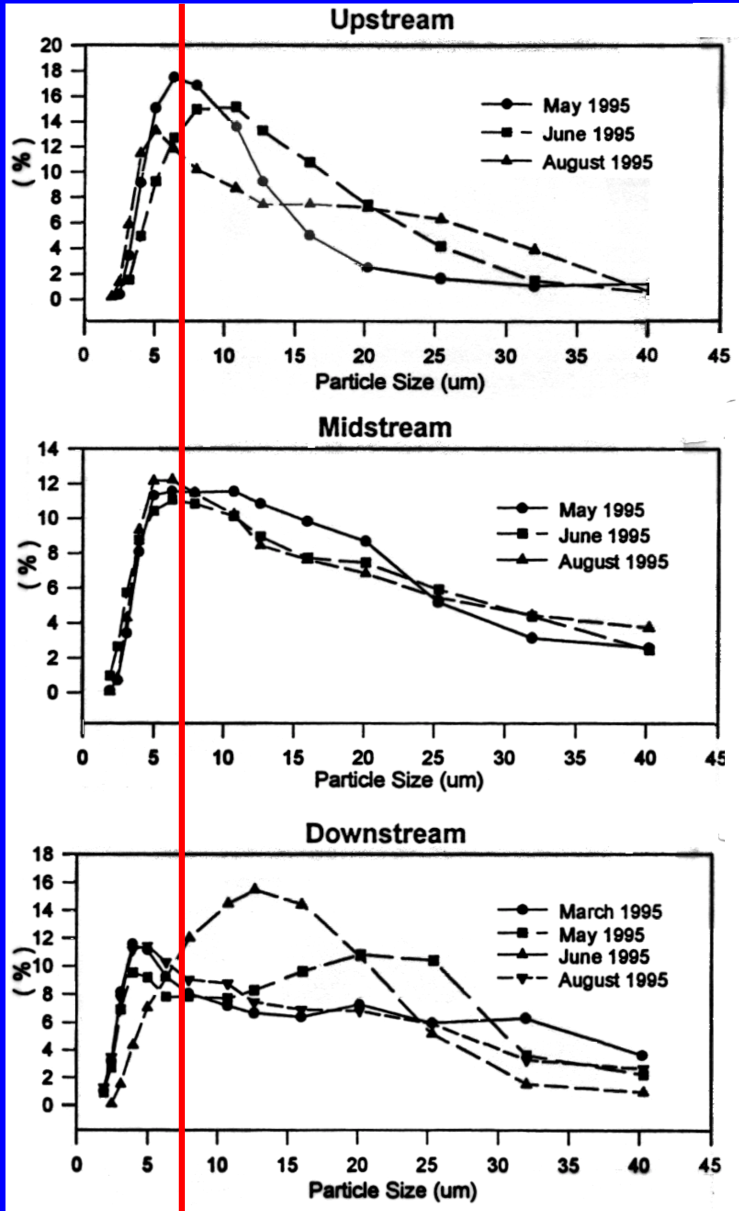
Both contribute to the pool of Cd ultimately incorporated into bivalve tissue.

How does geochemistry influence cadmium uptake in bivalves?

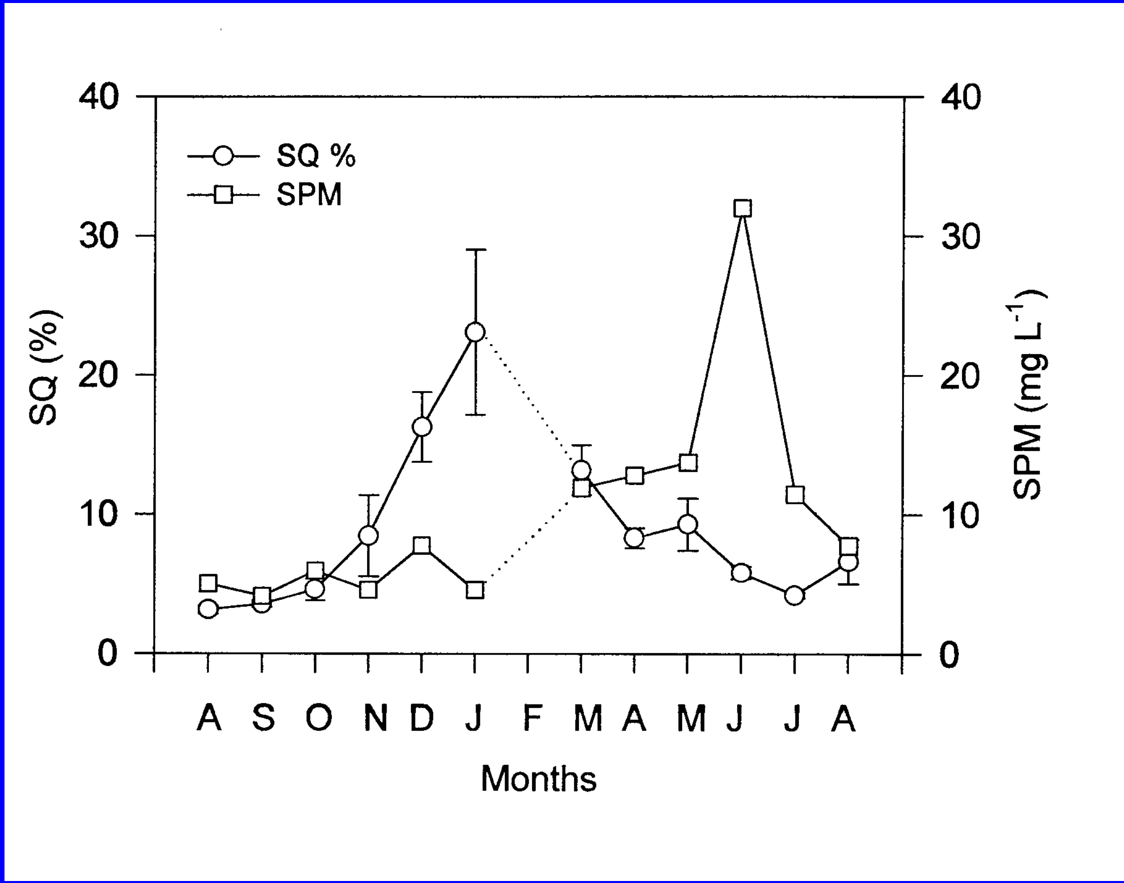
Trace metal accumulation

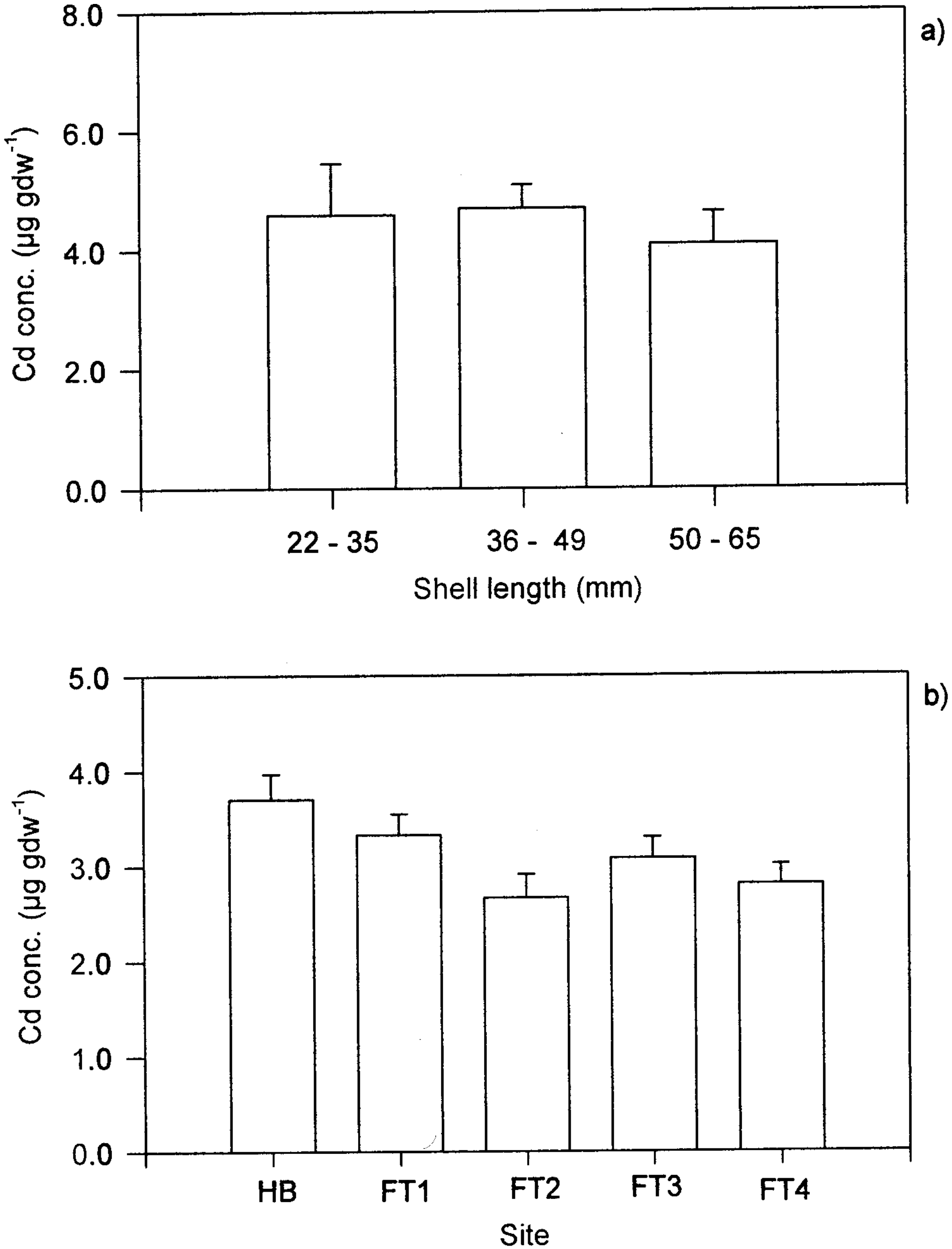



Vancouver
McDonald Slough
SEA ISLAND
Mitchell Island
BURNABY
North Arm
QUEENSBOROUGH
Annacis Channel
ANNACIS ISL.
STURGEON BANK
Middle Arm
Richmond
Upstream
Deas Slough
Downstream
Midstream
Ladner Reach
Canoe Passage
ROBERTS
BANK


Upstream
(%)
Particle Size (um)
May 1995
June 1995
August 1995
Midstream
(%)
Particle Size (um)
May 1995
June 1995
August 1995
Downstream
(%)
Particle Size (um)
March 1995
May 1995
June 1995
August 1995

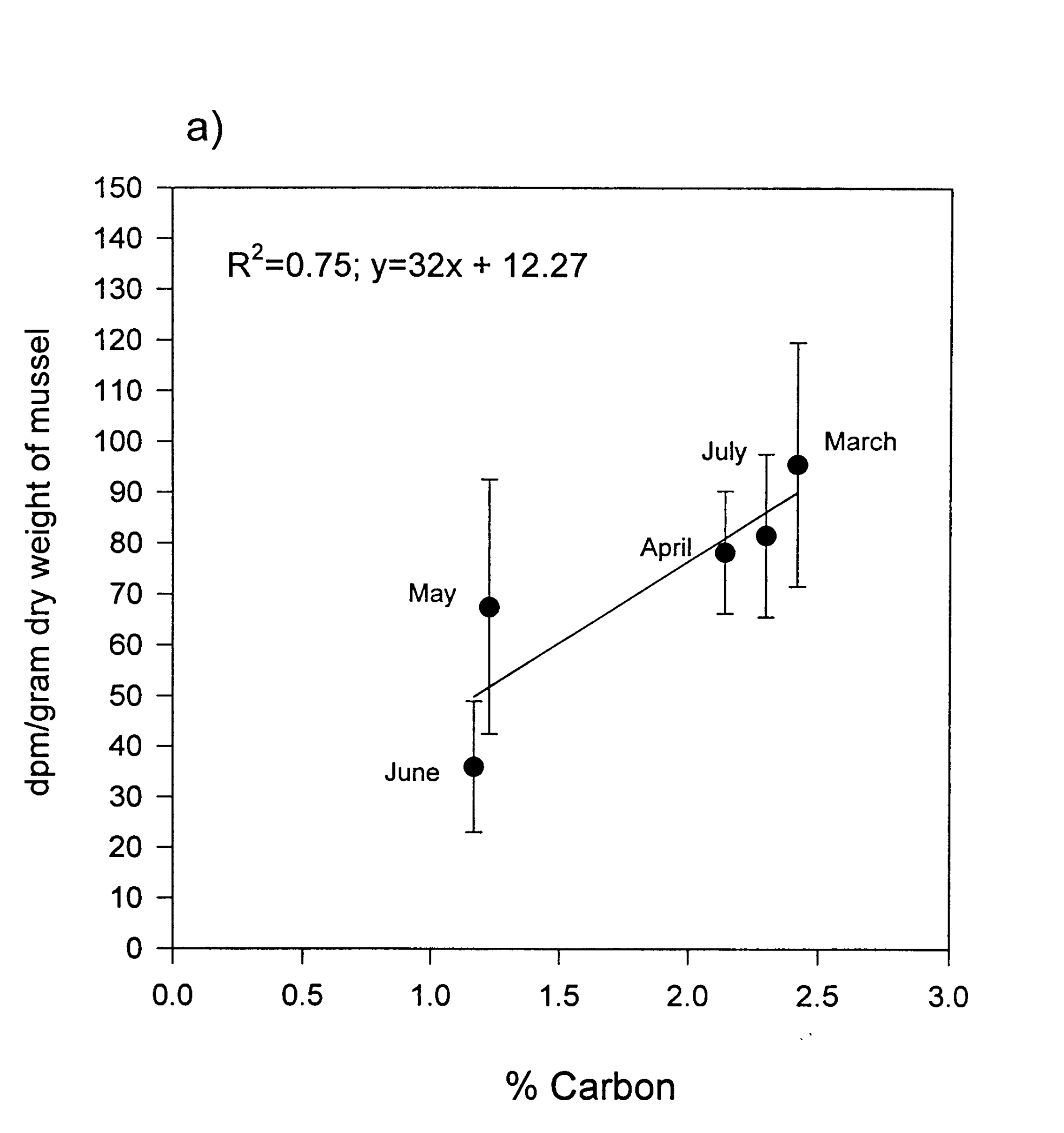
From feeding experiments know that mussels will be feeding on both IM and OM except possibly June

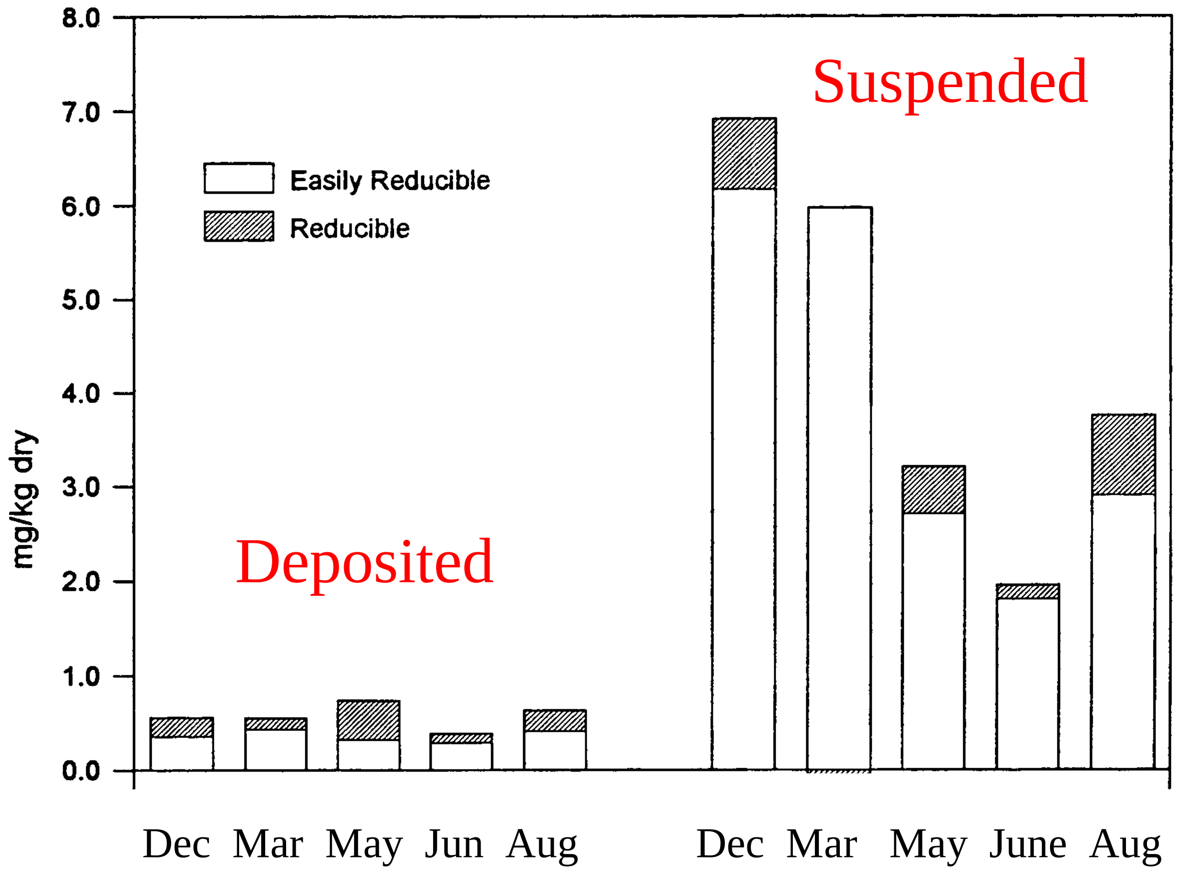




a)
Cd conc. (µg gdw-1)
8.0
6.0
4.0
2.0
0.0
22 - 35
36 - 49
50 - 65
Shell length (mm)
b)
Cd conc. (µg gdw-1)
5.0
4.0
3.0
2.0
1.0
0.0
HB
FT1
FT2
FT3
FT4
Site

Like lab based studies uptake of Cd(109) is dependent on %OM





8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
mg/kg dry
Easily Reducible
Reducible
Suspended
Deposited
Dec
Mar
May
Jun
Aug
Dec
Mar
May
June
Aug

Laboratory based studies suggest that both OM and IM important pools of bioavailable Cd.

Generally Cd assimilated actively from OM; passively from IM

Field studies show that Cd accumulating in mussels (oysters)

Studies on the geochemistry of Cd in SPM in immediate environment show that Cd is associated with IM, not OM

Conclude:

Passive uptake of Cd from the IM of suspended sediment while actively breaking down OM for nutrient gain.

Important EXPOSURE information would be

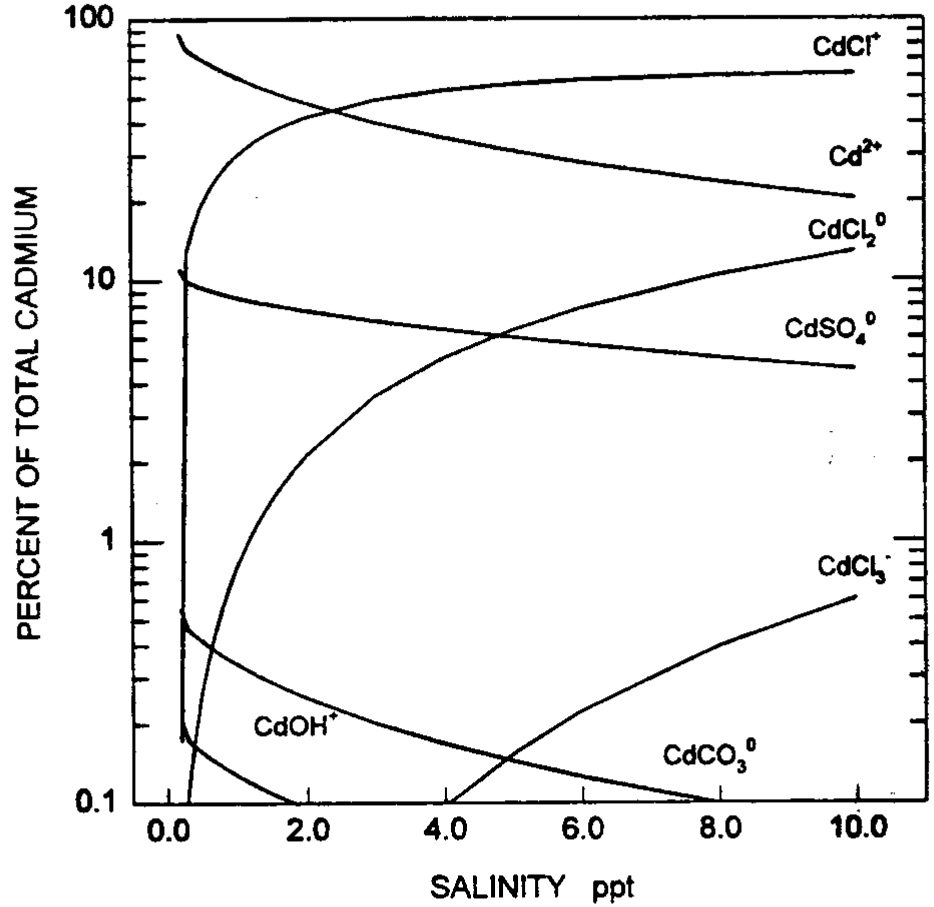
[Cd] in IM of SPM

Are factors such as

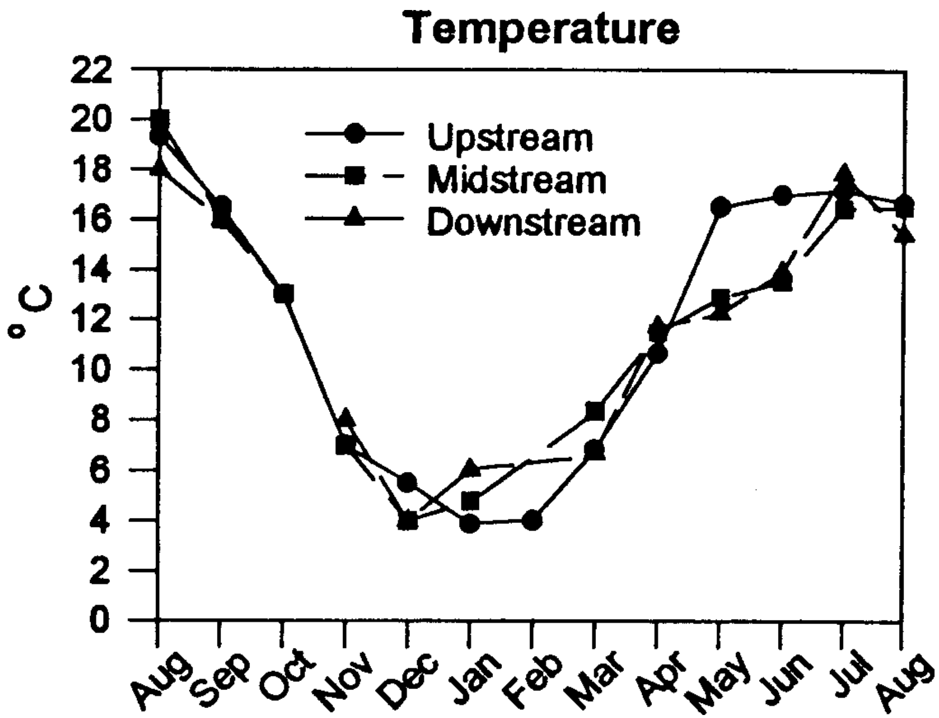
Salinity

Temperature (season)

important to consider?



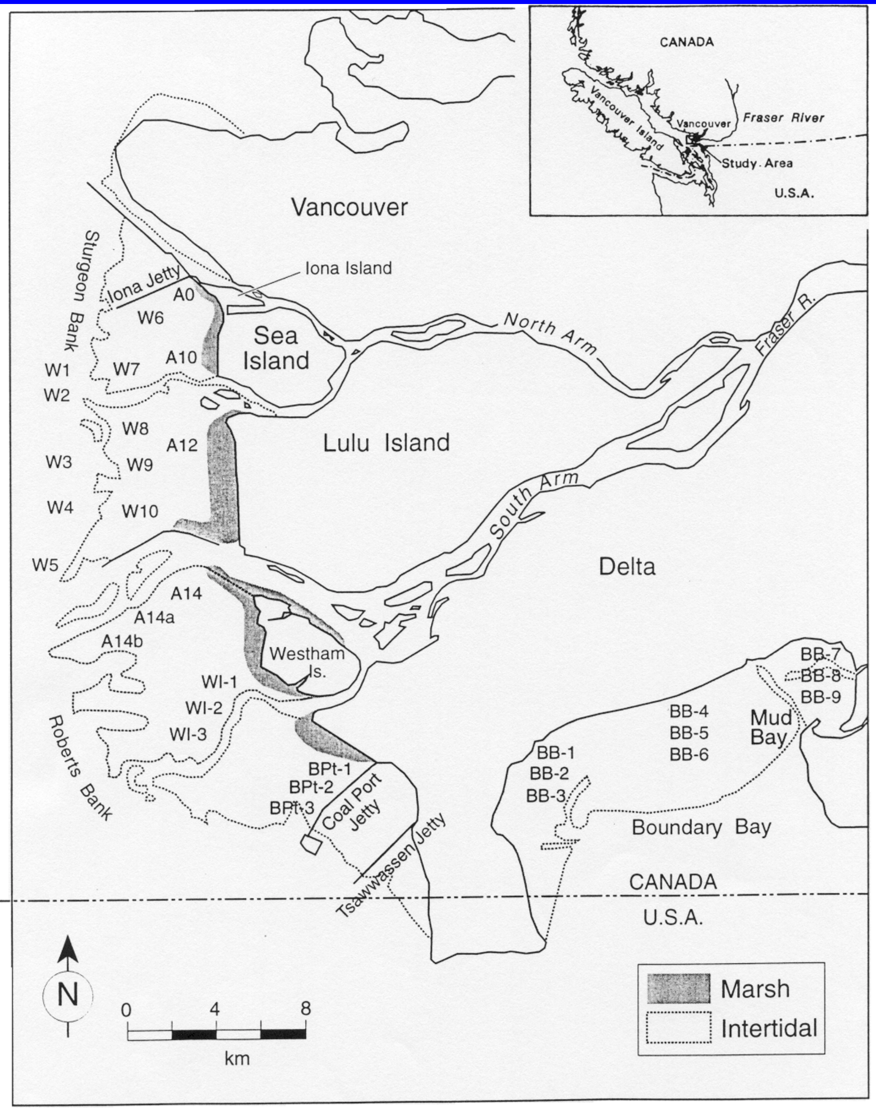
PERCENT OF TOTAL CADMIUM
100
10
1
0.1
0.0
2.0
4.0
6.0
8.0
10.0
SALINITY ppt
$CdCl^{+}$
Cd^{2+}
$CdCl_2^0$
$CdSO_4^0$
$CdCl_3^-$
$CdOH^{+}$
$CdCO_3^0$

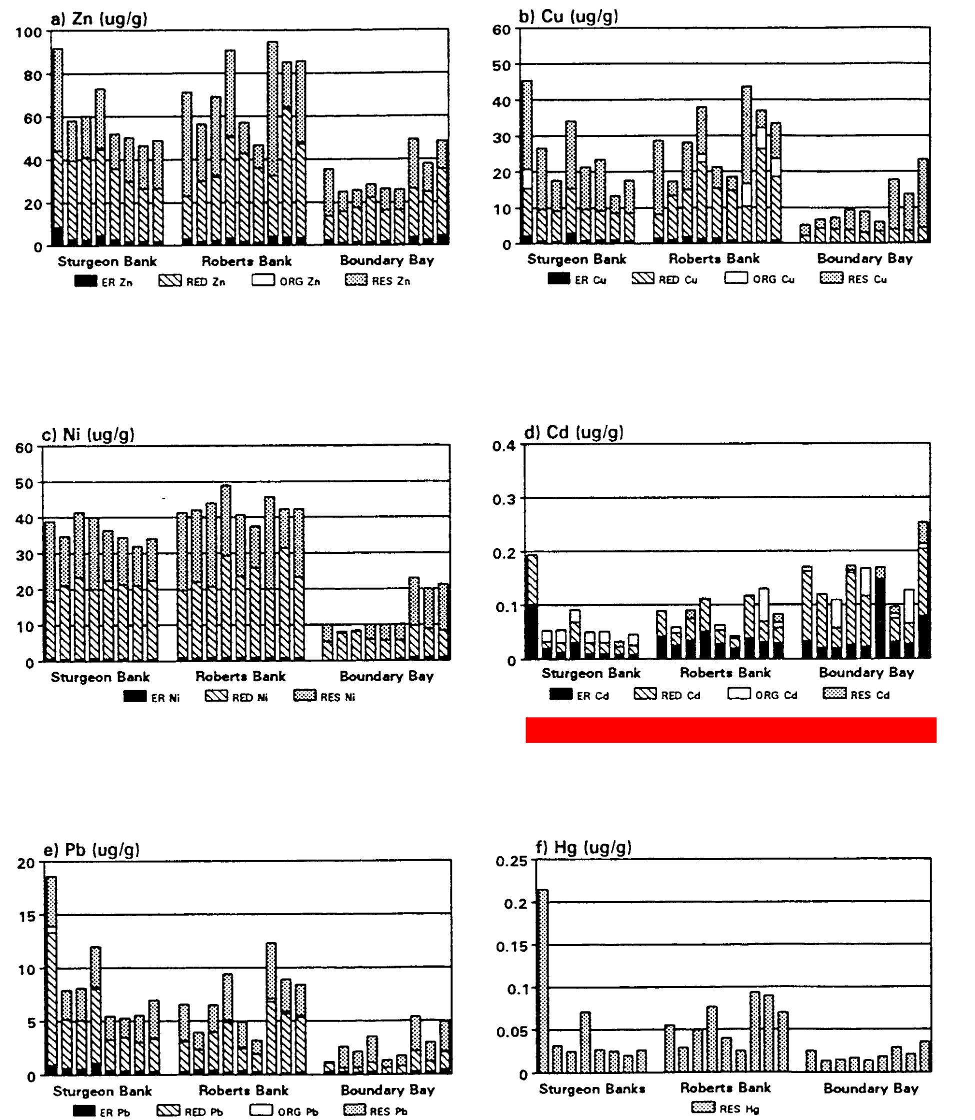


Might expect a T dependence

Potential sources of cadmium:

Use of fertilizers: (?)


CANADA
Vancouver
Fraser River
Vancouver Island
Study Area
U.S.A.
Vancouver
Sturgeon Bank
Iona Jetty
Iona Island
A0
W6
Sea Island
North Arm
Fraser R.
W1
W2
W7
A10
W8
A12
Lulu Island
W3
W9
W4
W10
South Arm
W5
Delta
A14
A14a
A14b
Westham Is.
WI-1
WI-2
WI-3
Roberts Bank
BB-7
BB-8
BB-9
BB-4
BB-5
BB-6
Mud Bay
BB-1
BB-2
BB-3
BPt-1
BPt-2
BPt-3
Coal Port Jetty
Tsawwassen Jetty
Boundary Bay
CANADA
U.S.A.
N
0
4
8
km
Marsh
Intertidal


a) Zn (ug/g)
0
20
40
60
80
100
Sturgeon Bank
Roberts Bank
Boundary Bay
ER Zn
RED Zn
ORG Zn
RES Zn
b) Cu (ug/g)
0
10
20
30
40
50
60
Sturgeon Bank
Roberts Bank
Boundary Bay
ER Cu
RED Cu
ORG Cu
RES Cu
c) Ni (ug/g)
0
10
20
30
40
50
60
Sturgeon Bank
Roberts Bank
Boundary Bay
ER Ni
RED Ni
RES Ni
d) Cd (ug/g)
0
0.1
0.2
0.3
0.4
Sturgeon Bank
Roberts Bank
Boundary Bay
ER Cd
RED Cd
ORG Cd
RES Cd
e) Pb (ug/g)
0
5
10
15
20
Sturgeon Bank
Roberts Bank
Boundary Bay
ER Pb
RED Pb
ORG Pb
RES Pb
f) Hg (ug/g)
0
0.05
0.1
0.15
0.2
0.25
Sturgeon Banks
Roberts Bank
Boundary Bay
RES Hg

Need:

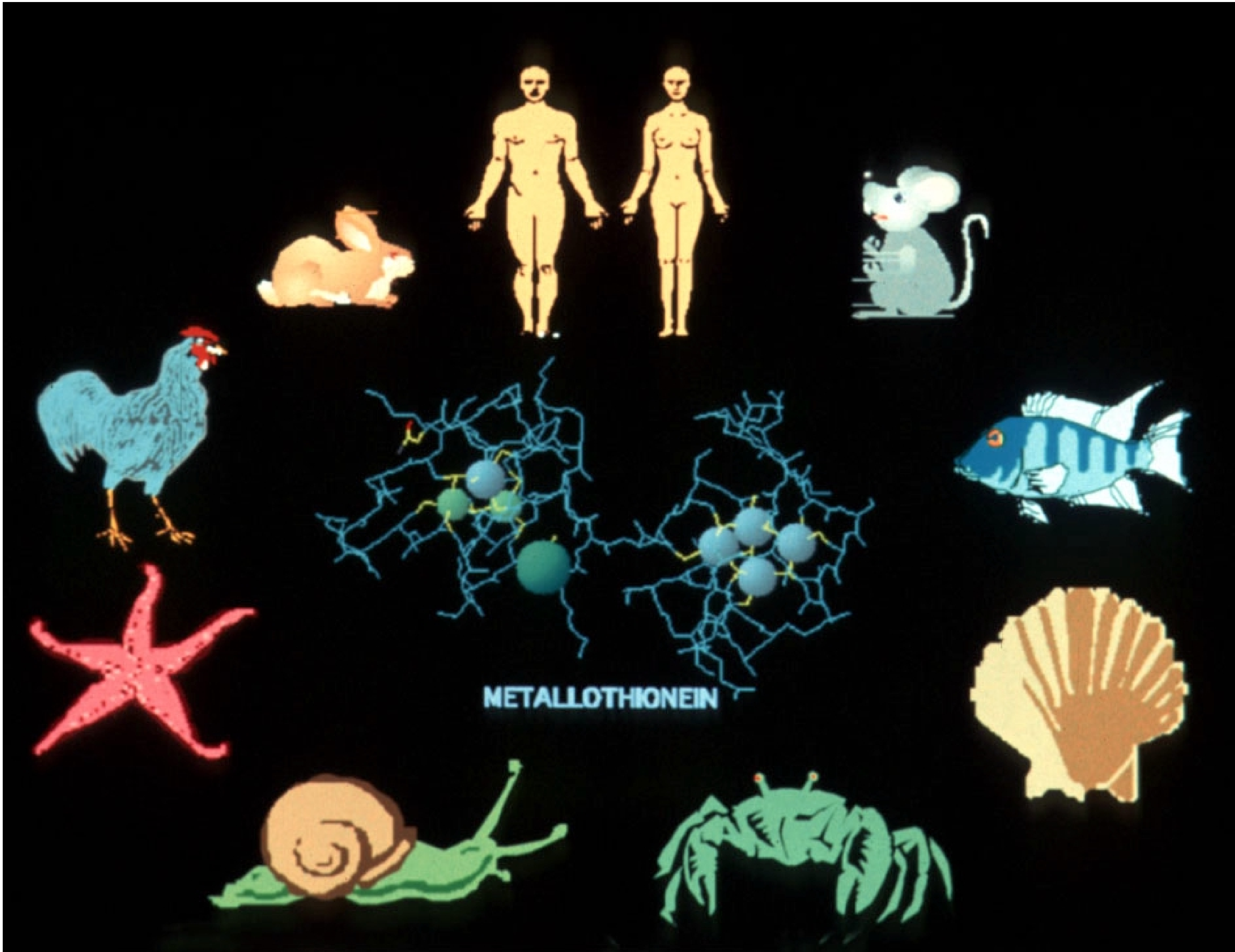
1) Realistic field measurements of exposure:

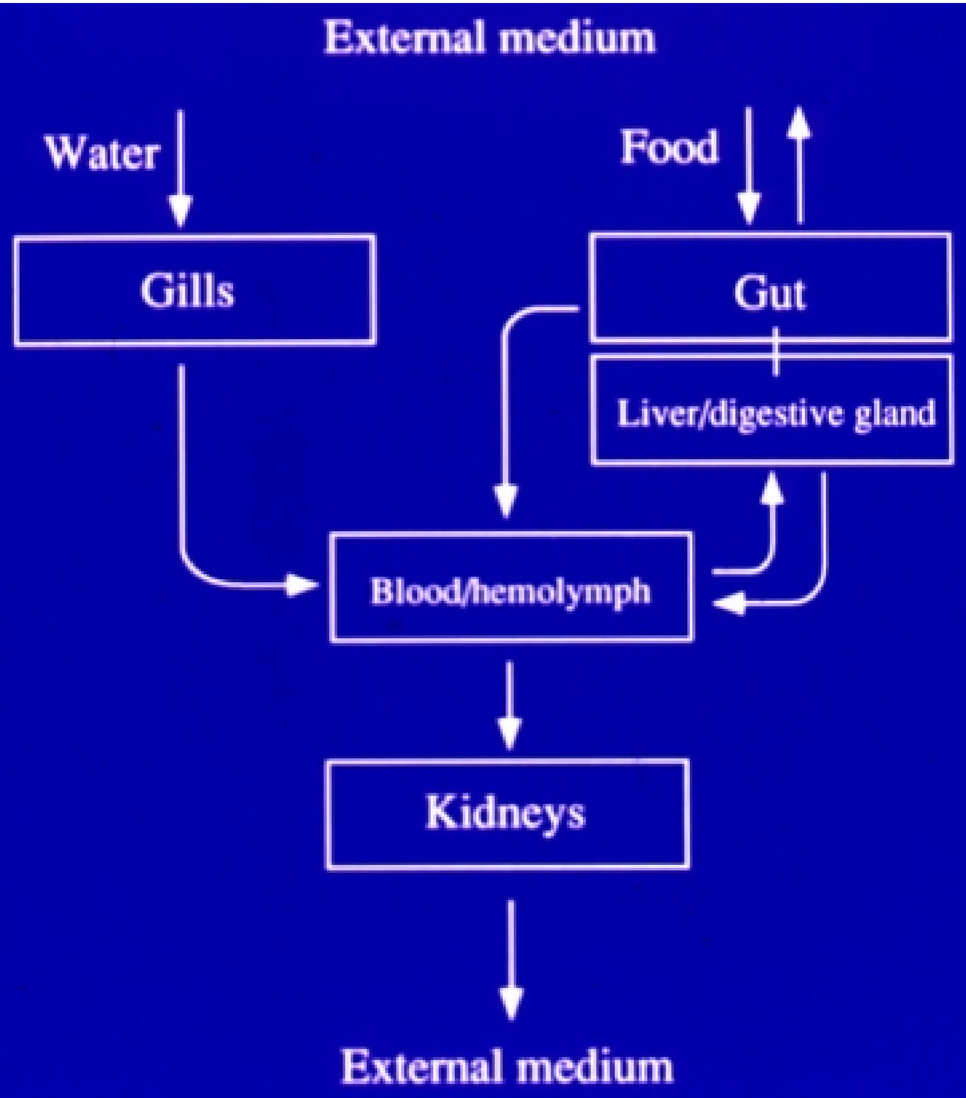
(suspended sediments that are geochemically characterized with respect to Cd speciation)

2) Realistic field derived Cd assimilation efficiencies: (AE) (%)

3) Realistic field derived Cd elimination rates:

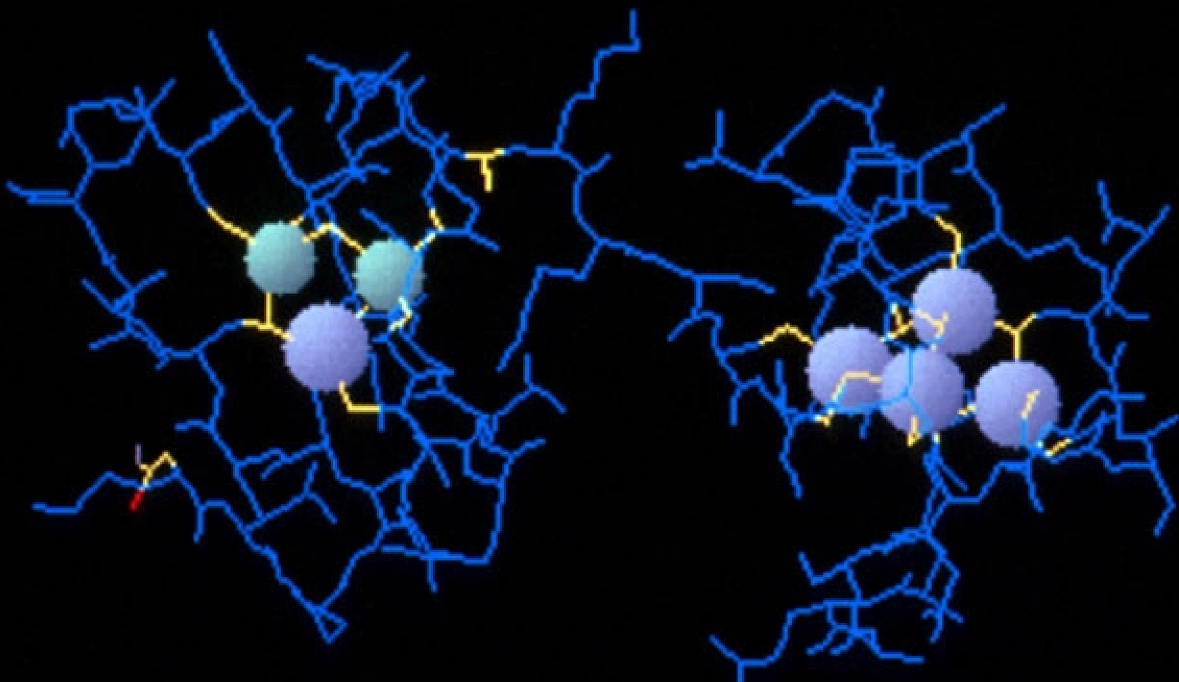
(k) (d^{-1})


METALLOTHIONEIN

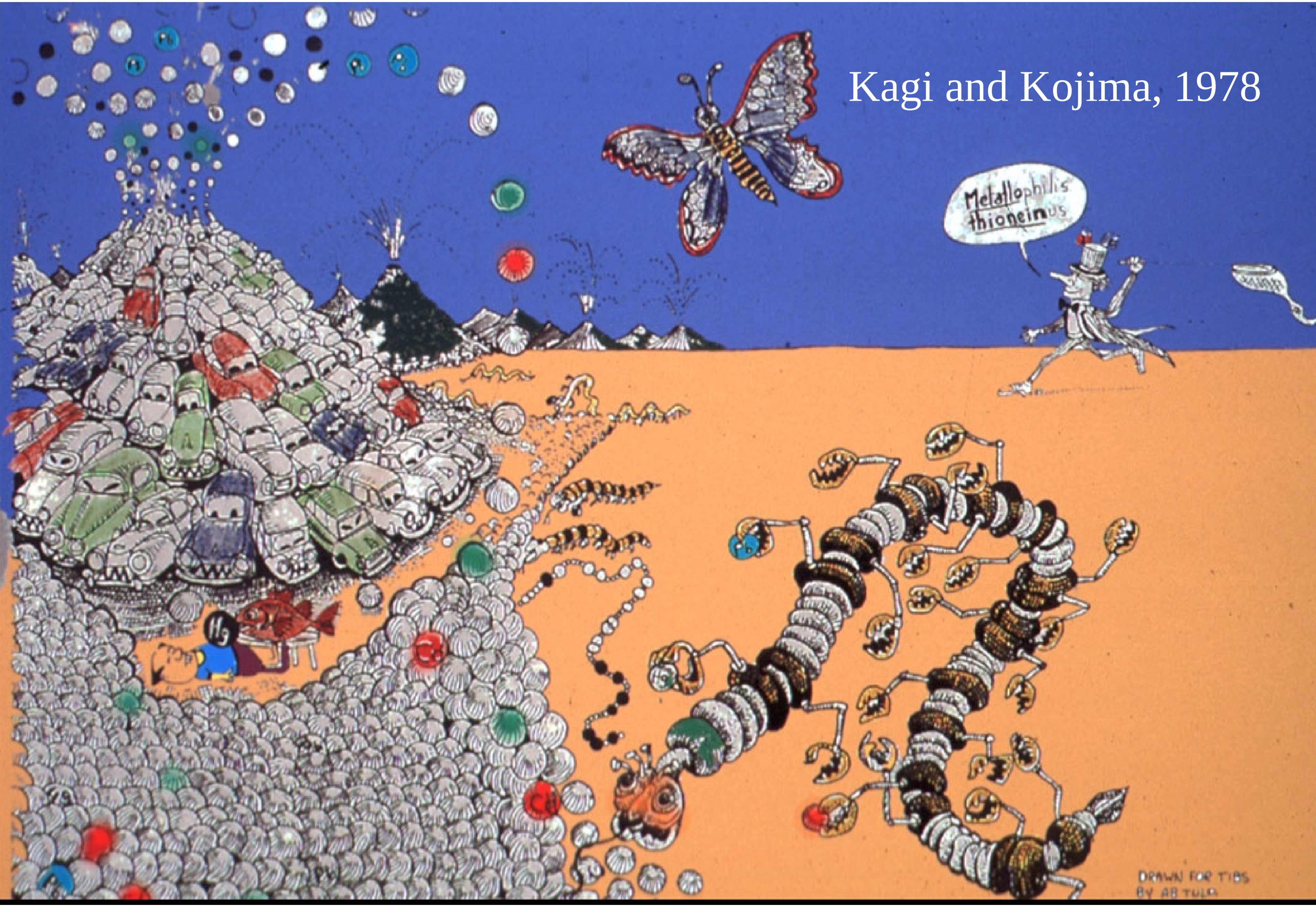


Routes of substance uptake and
Distribution in aquatic animals

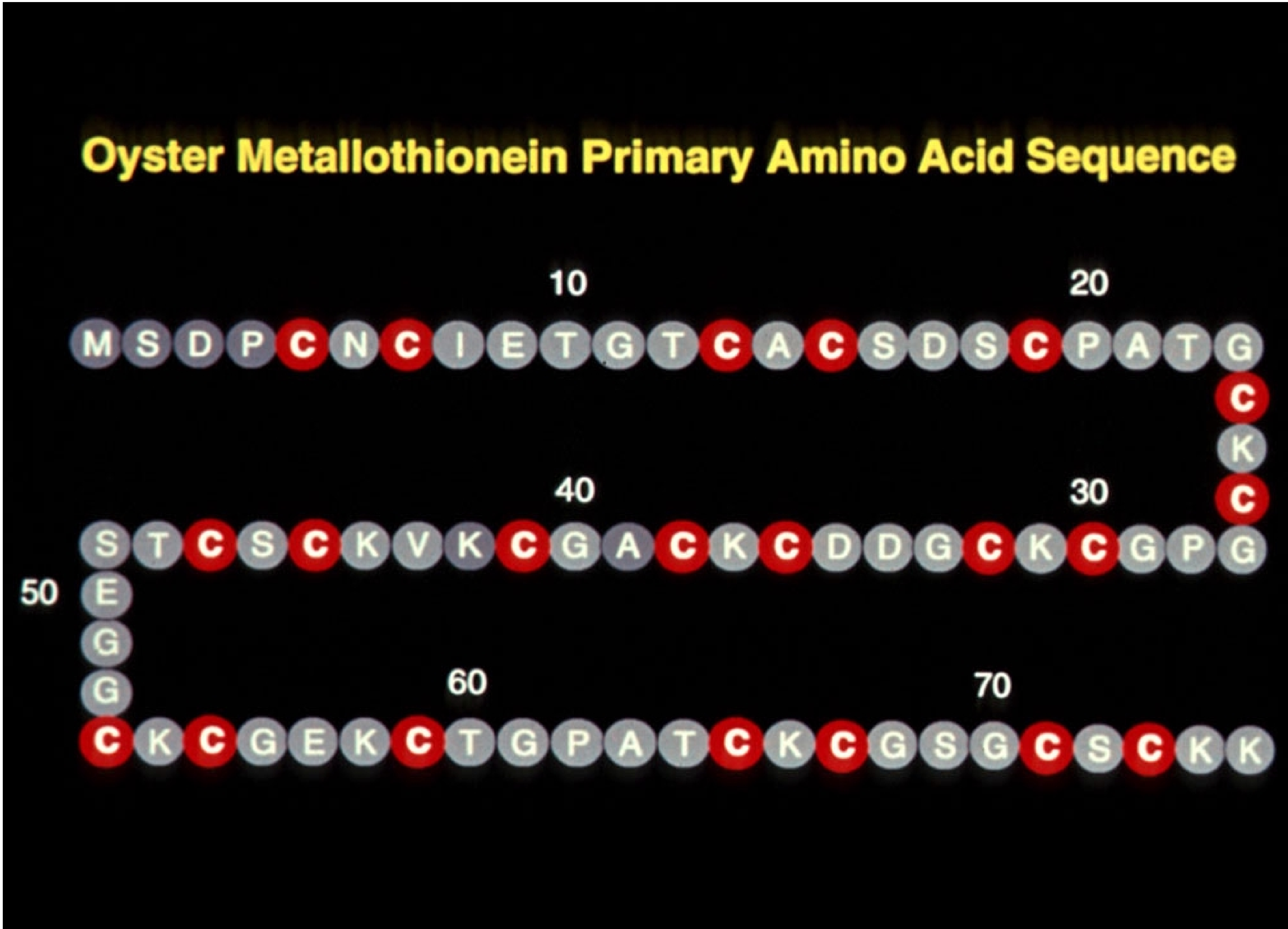
MOLECULAR ECOTOXICOLOGY OF CADMIUM



3-D structure of rabbit metallothionein

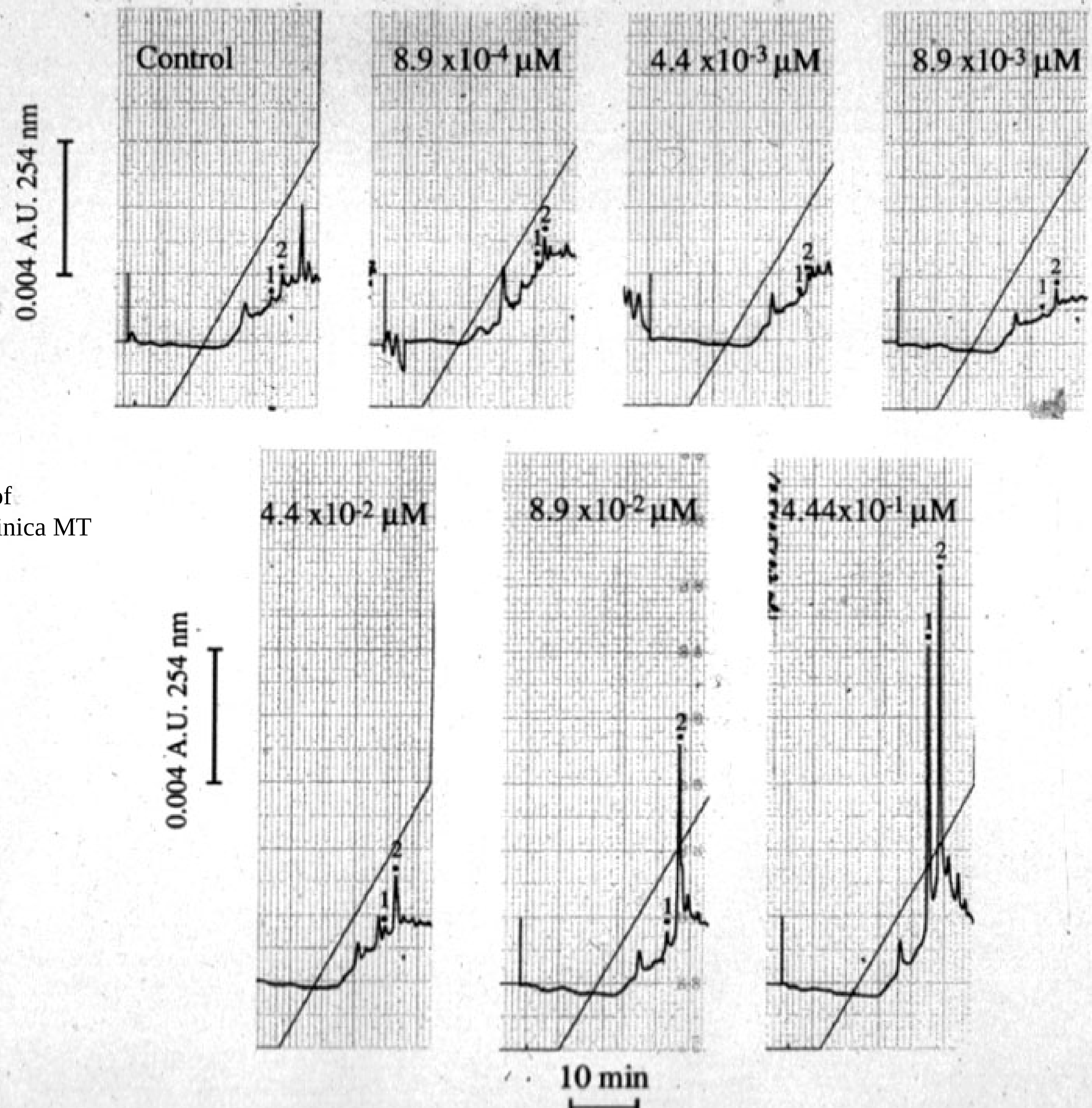

Kagi and Kojima, 1978
Metallophilis thioneinus
DRAWN FOR TIBS


Crassostrea virginica



Oyster Metallothionein Primary Amino Acid Sequence
10
20
M S D P C N C I E T G T C A C S D S C P A T G
C
K
C
40
30
S T C S C K V K C G A C K C D D G C K C G P G
50
E
G
G
60
70
C K C G E K C T G P A T C K C G S G C S C K K

HPLC of
C. Virginica MT



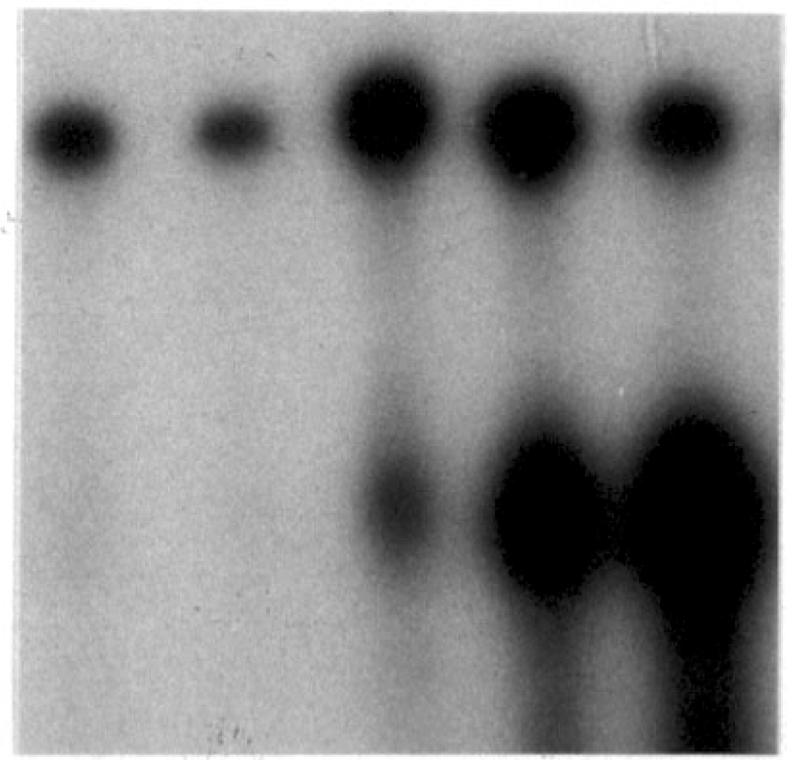
Ribonuclease protection assays with coding-region probe and sense-strand external standard

Cd exposure (μM)

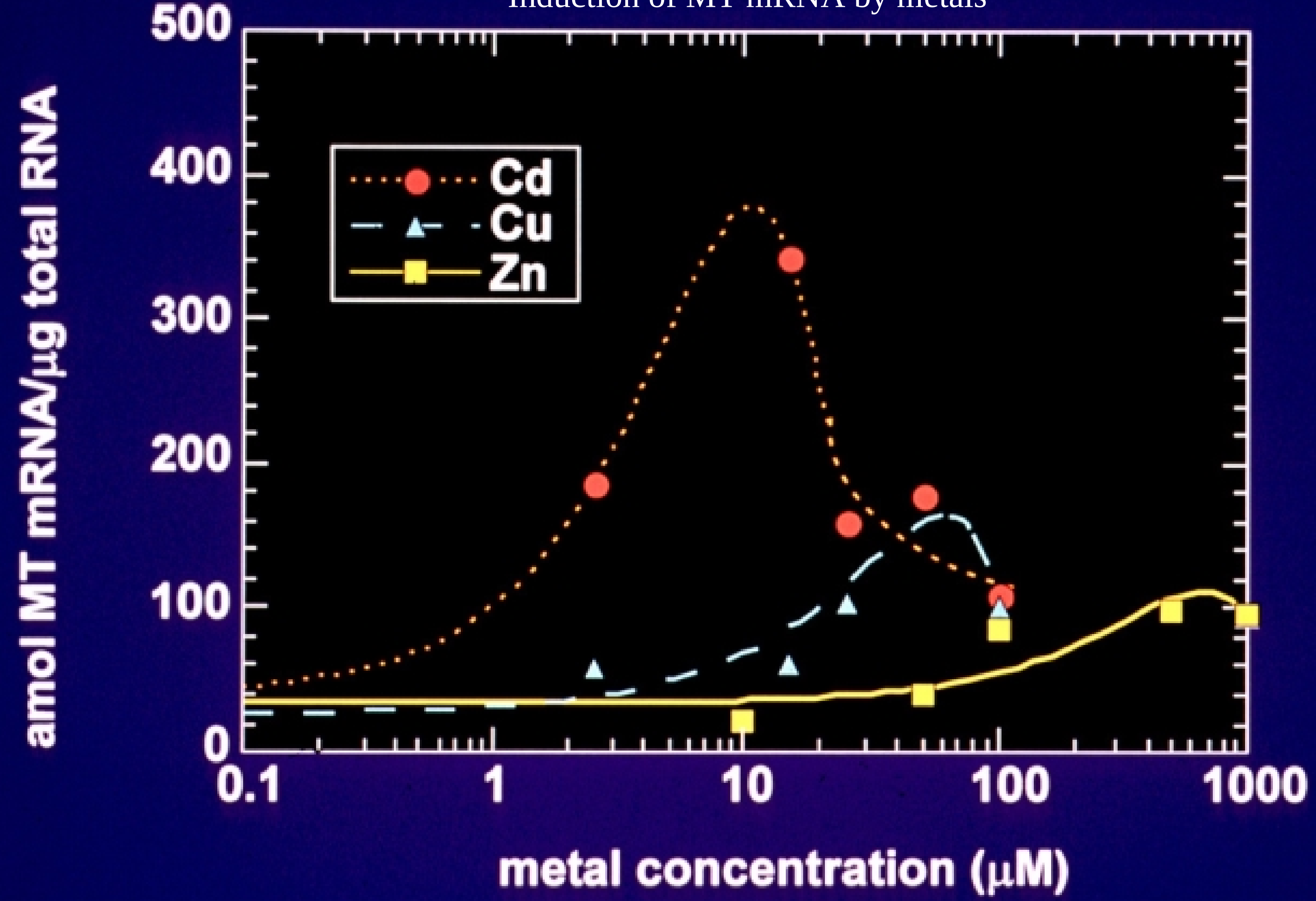
Protected Band Con 0.0005 0.01 0.04 0.2

Ext Std 258 bases

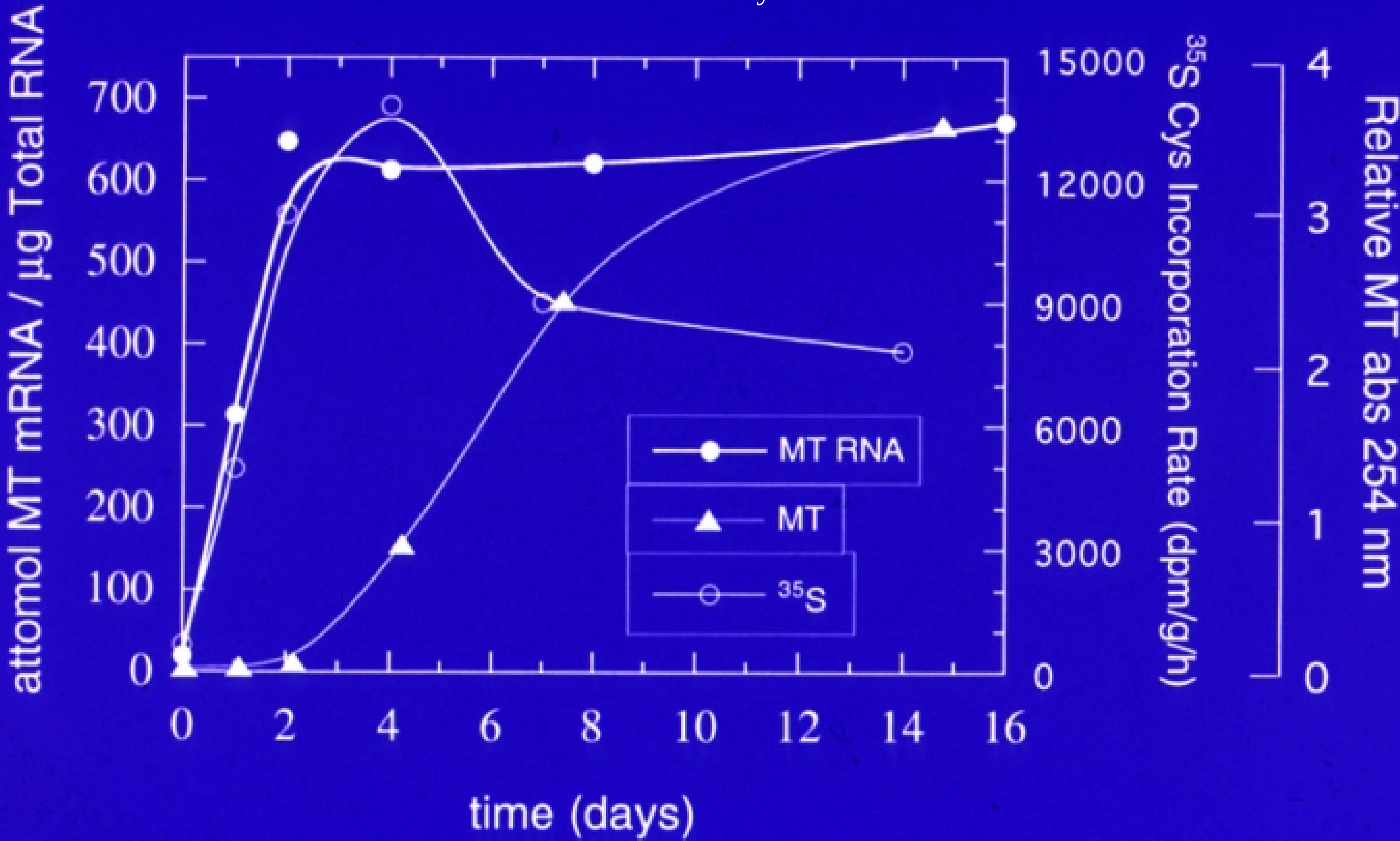
MT mRNA 200 bases



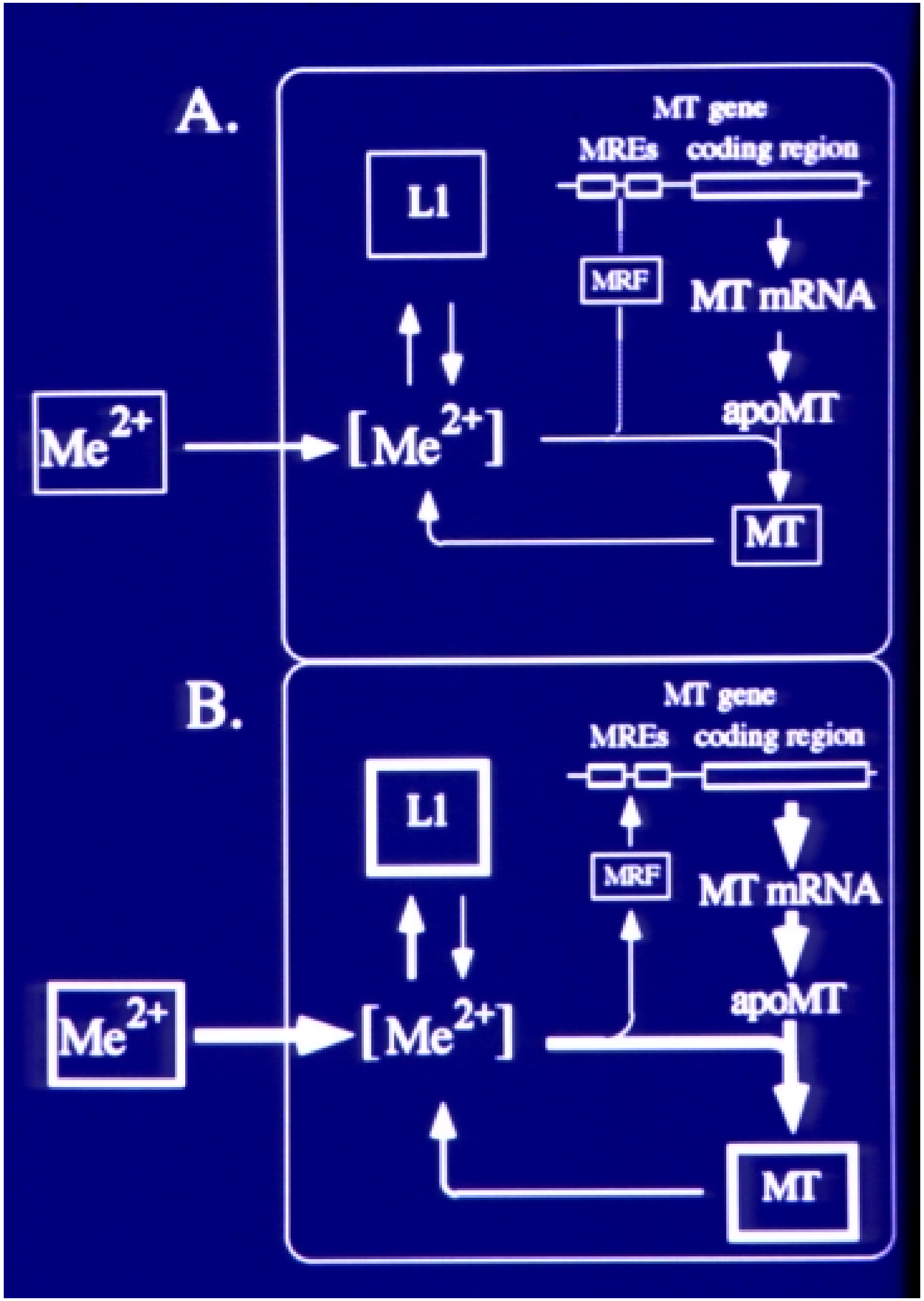
Induction of MT mRNA by metals

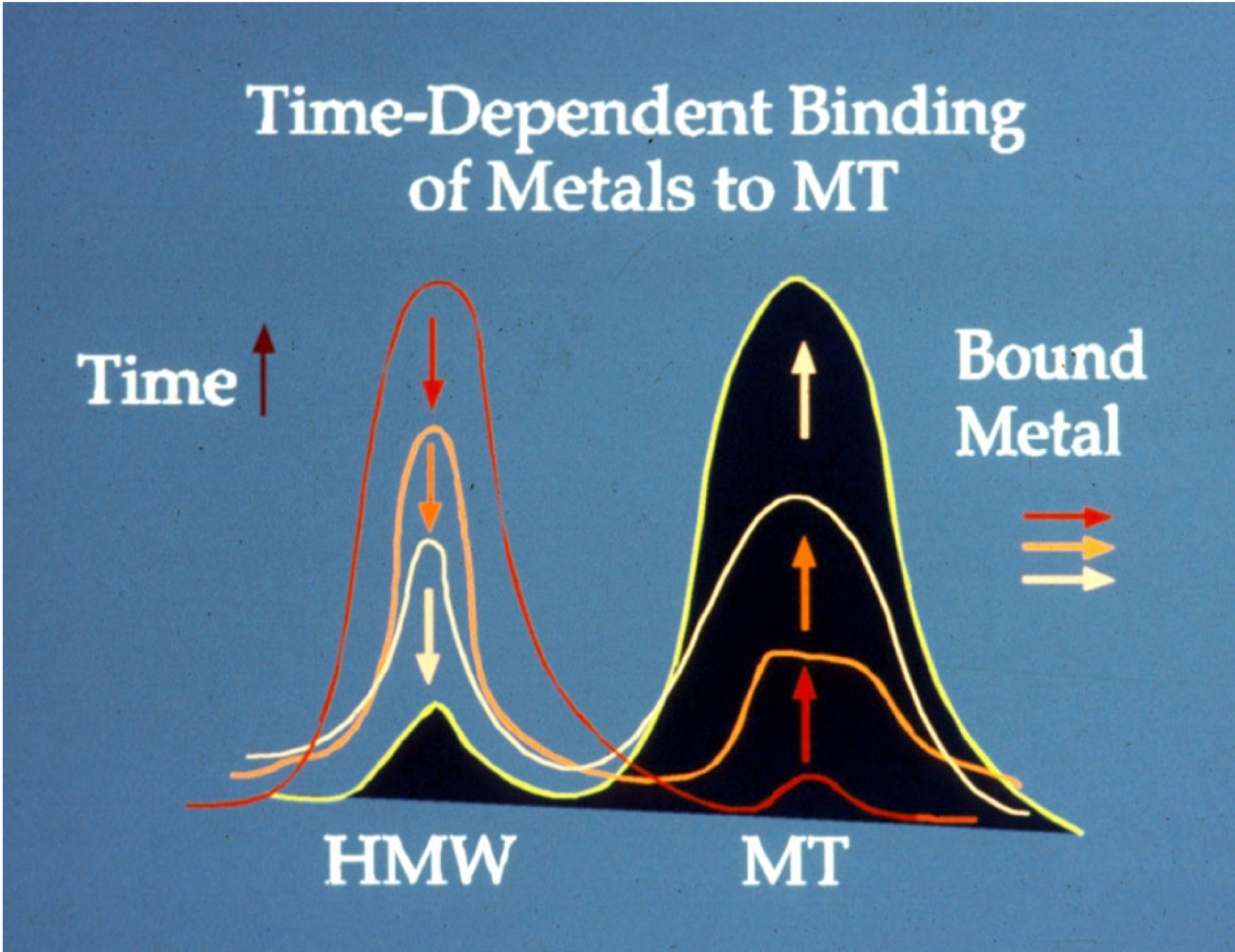


MT induction by cadmium

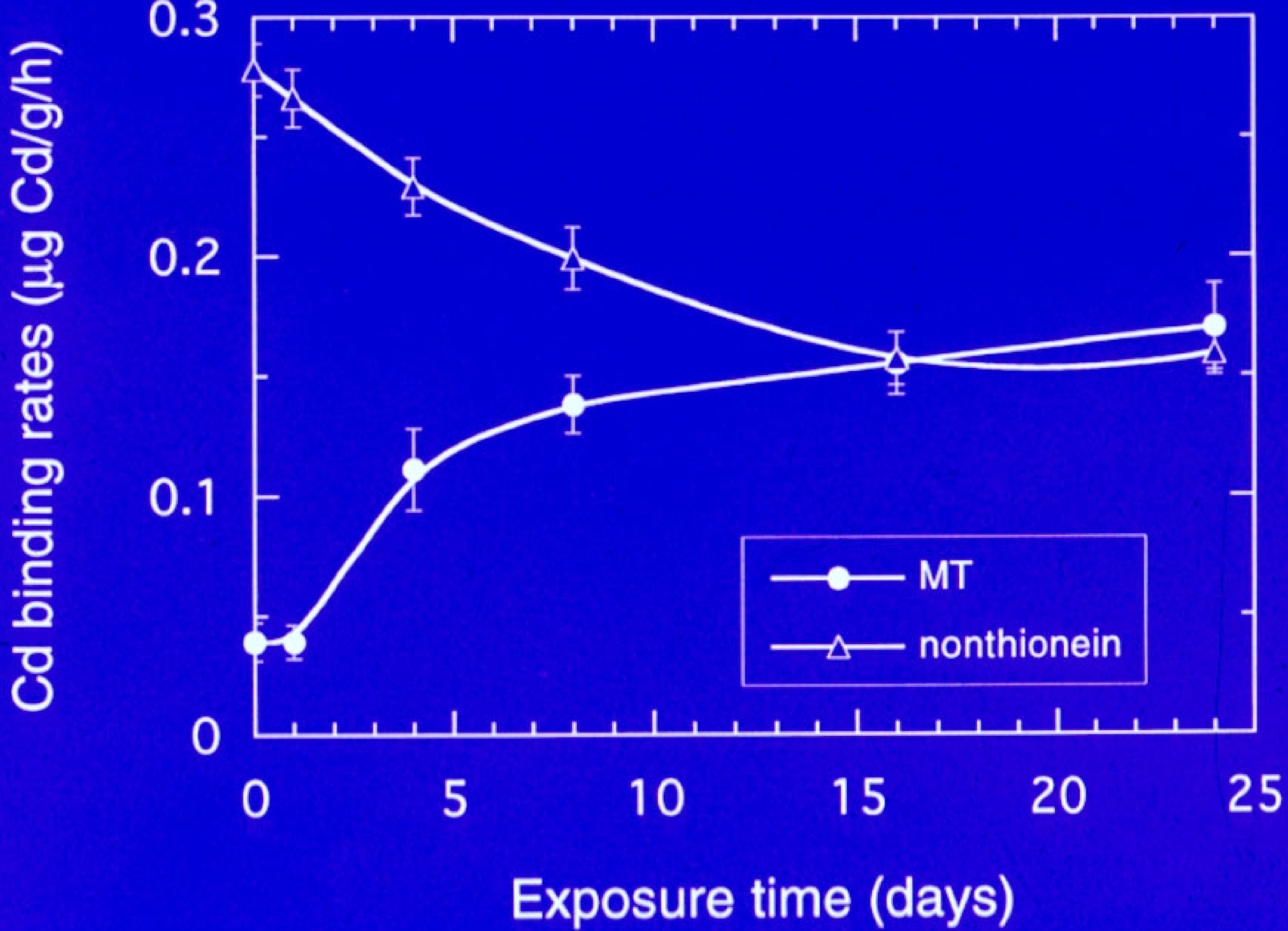


MT expression in metal regulation

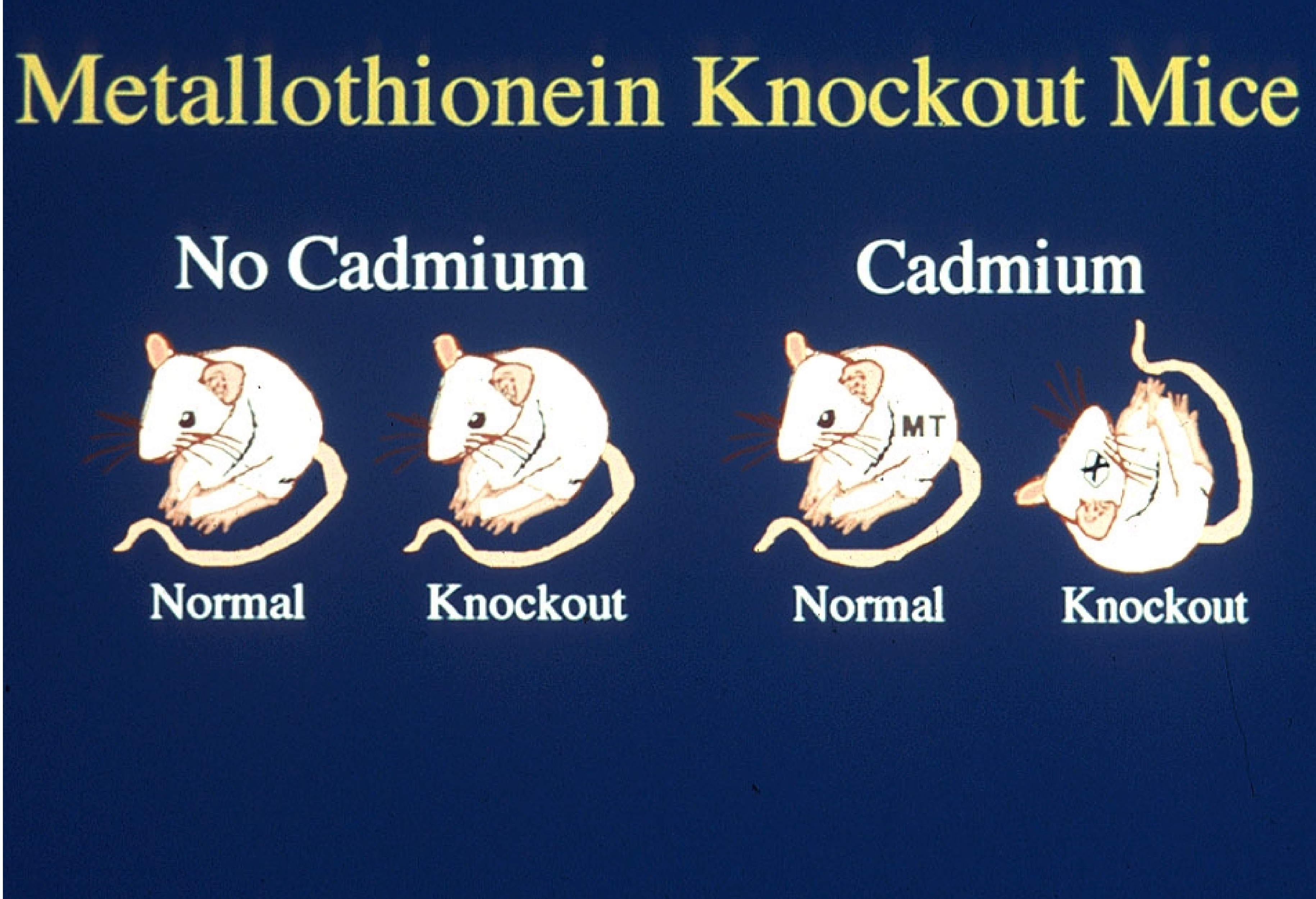



Time-Dependent Binding
of Metals to MT
Time
Bound
Metal
HMW
MT

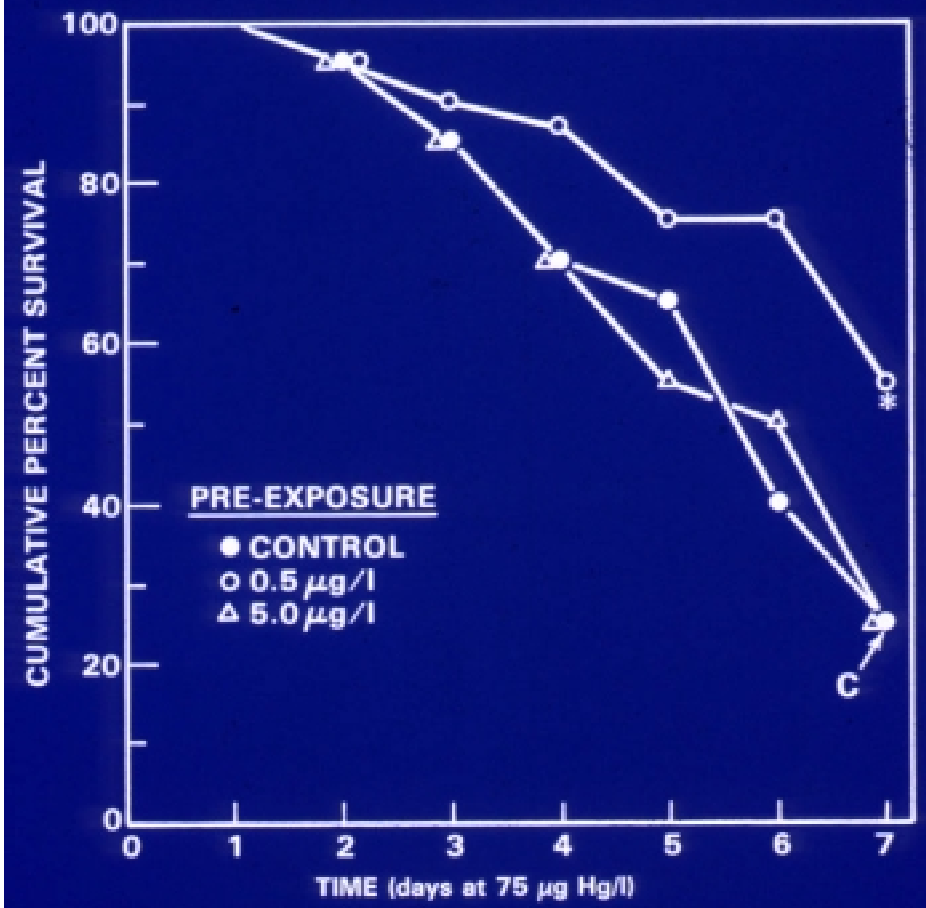
Cadmium binding to MT and nonMT fractions

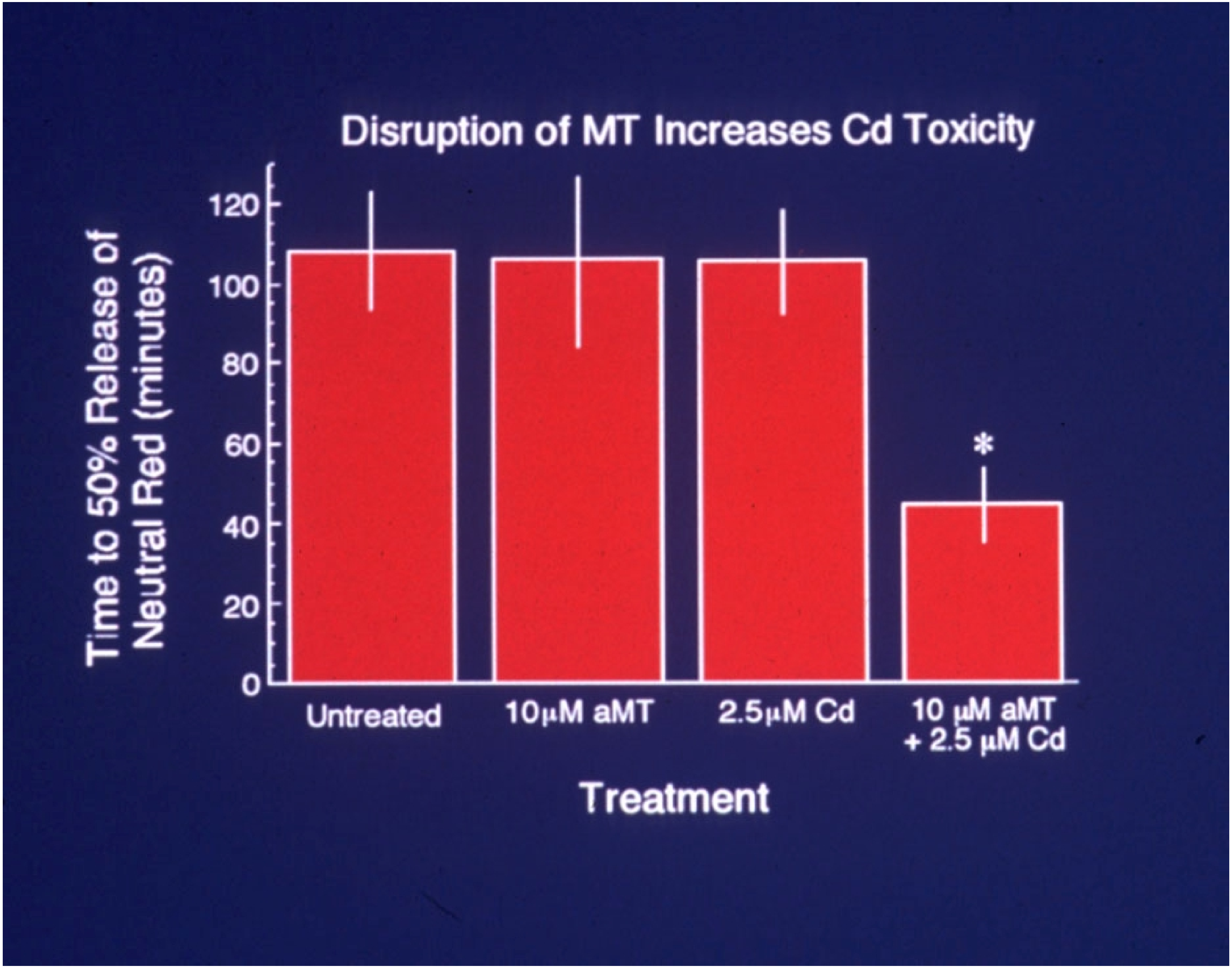


MT knockout mice lose resistance to cadmium toxicity

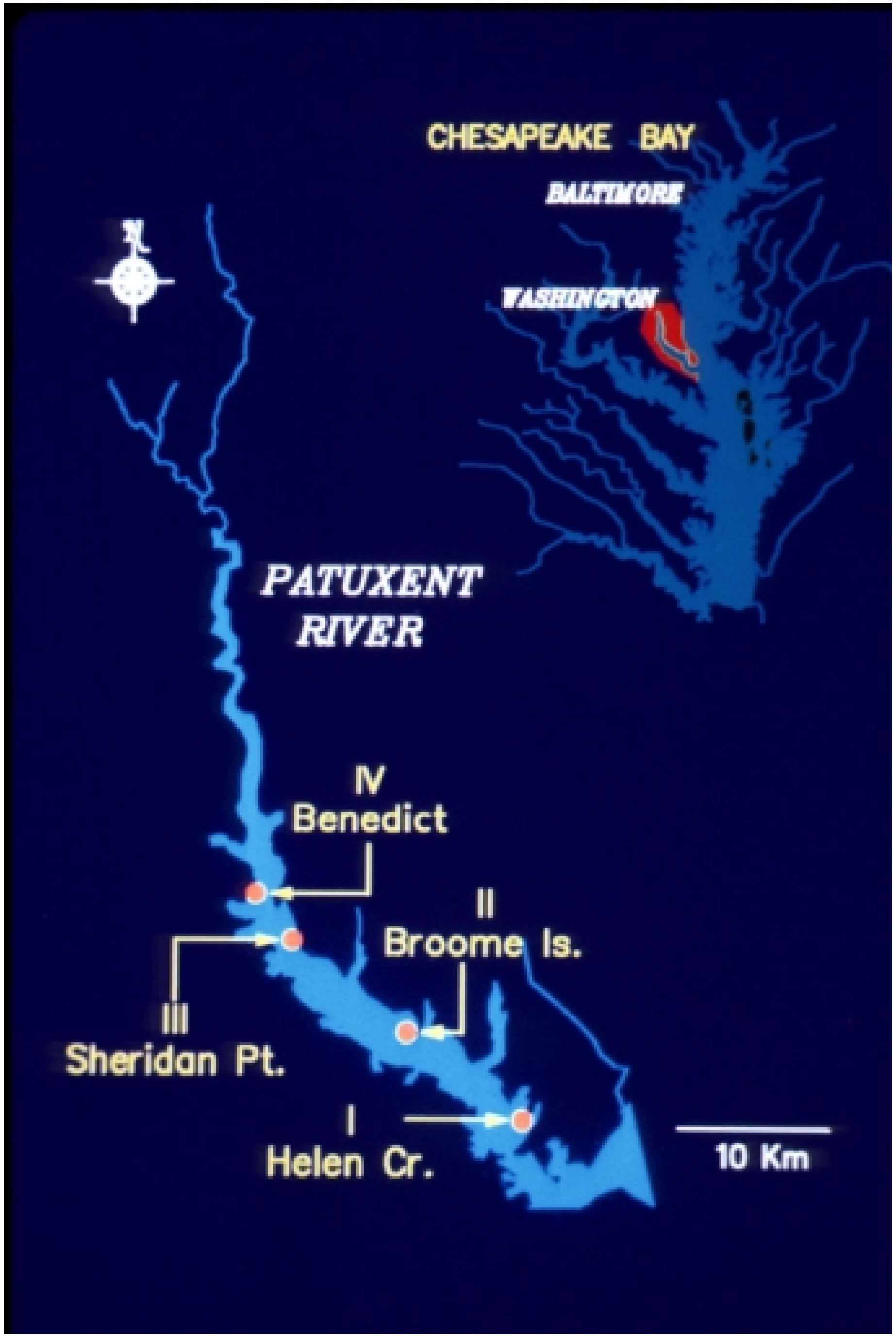


Pre-exposure to low levels o f mercury confers
Resistance to toxic levels in mussels



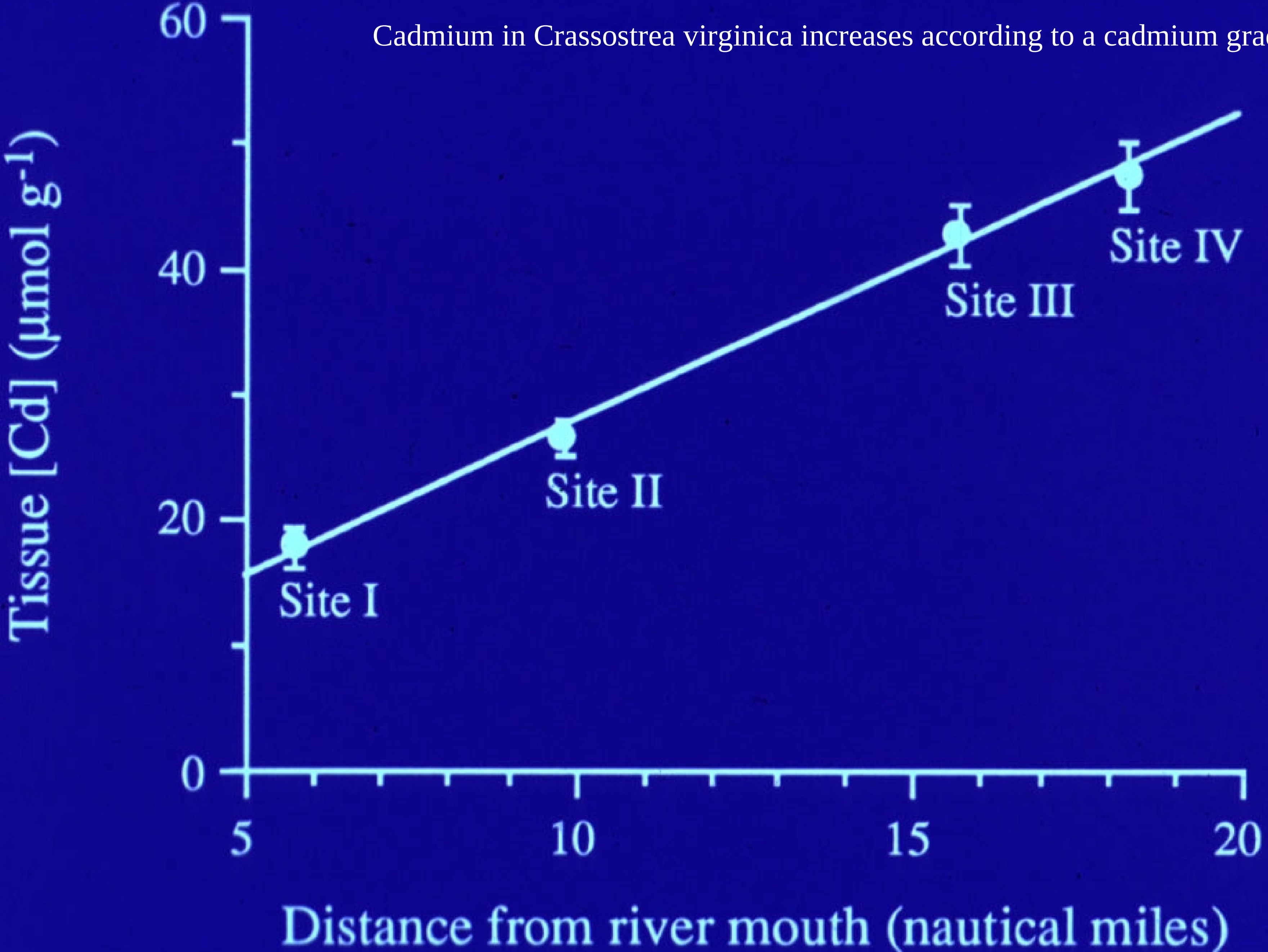


Disruption of MT Increases Cd Toxicity
Time to 50% Release of Neutral Red (minutes)
120
100
80
60
40
20
0
*
Untreated
10μM aMT
2.5μM Cd
10 μM aMT + 2.5 μM Cd
Treatment

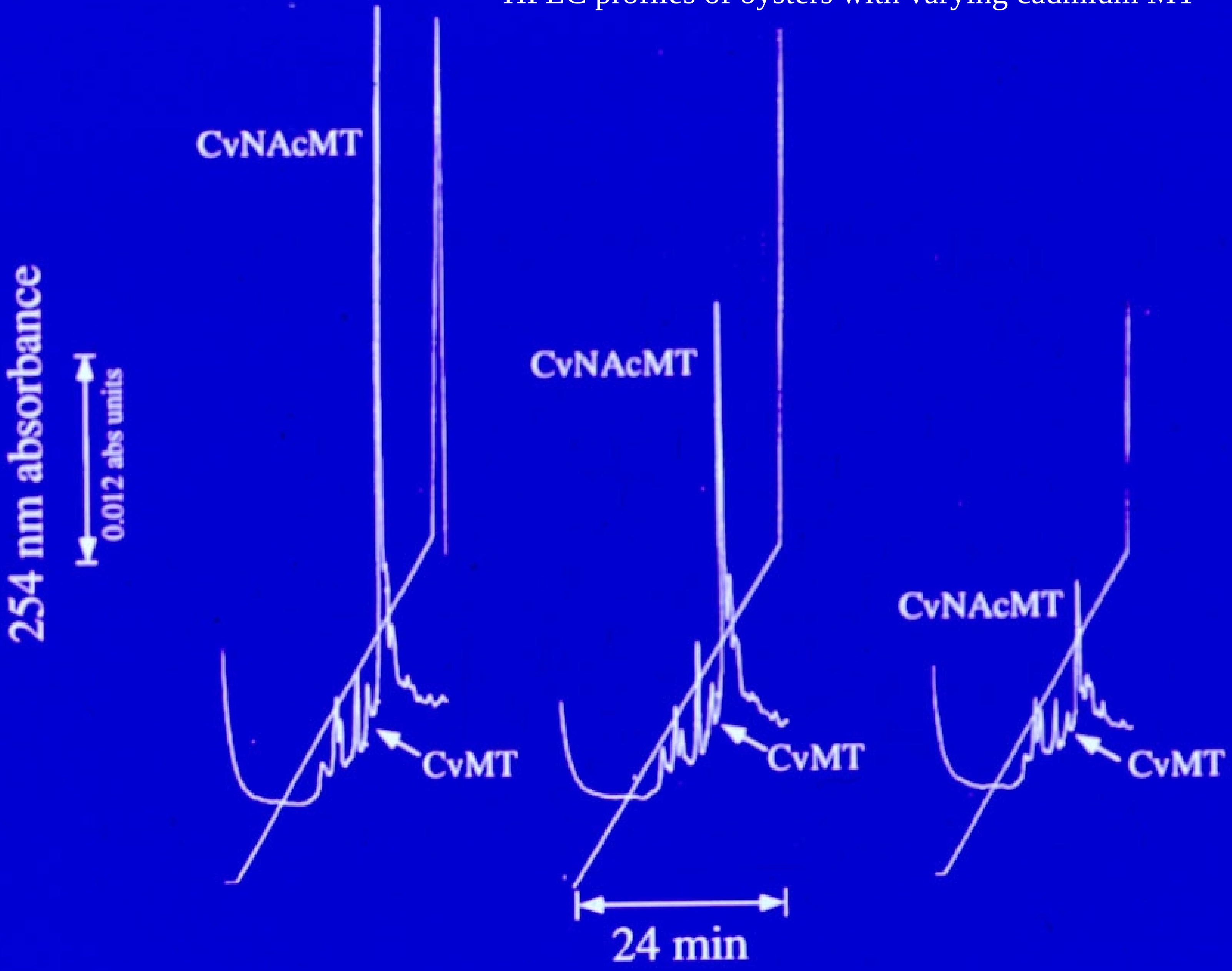


CHESAPEAKE BAY
BALTIMORE
WASHINGTON
N
PATUXENT
RIVER
IV
Benedict
II
Broome Is.
III
Sheridan Pt.
I
Helen Cr.
10 Km

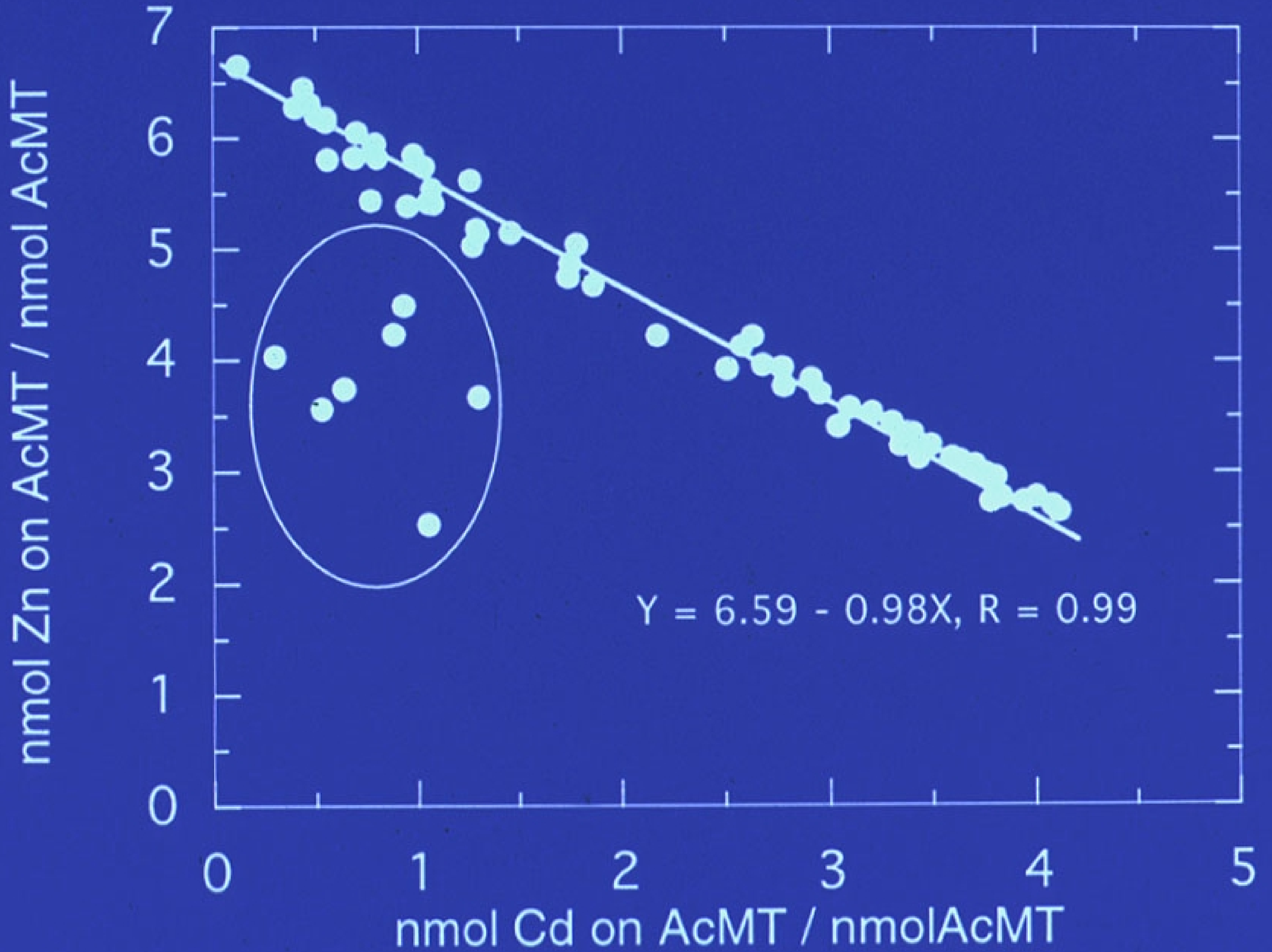
Cadmium in Crassostrea virginica increases according to a cadmium gradient



HPLC profiles of oysters with varying cadmium MT



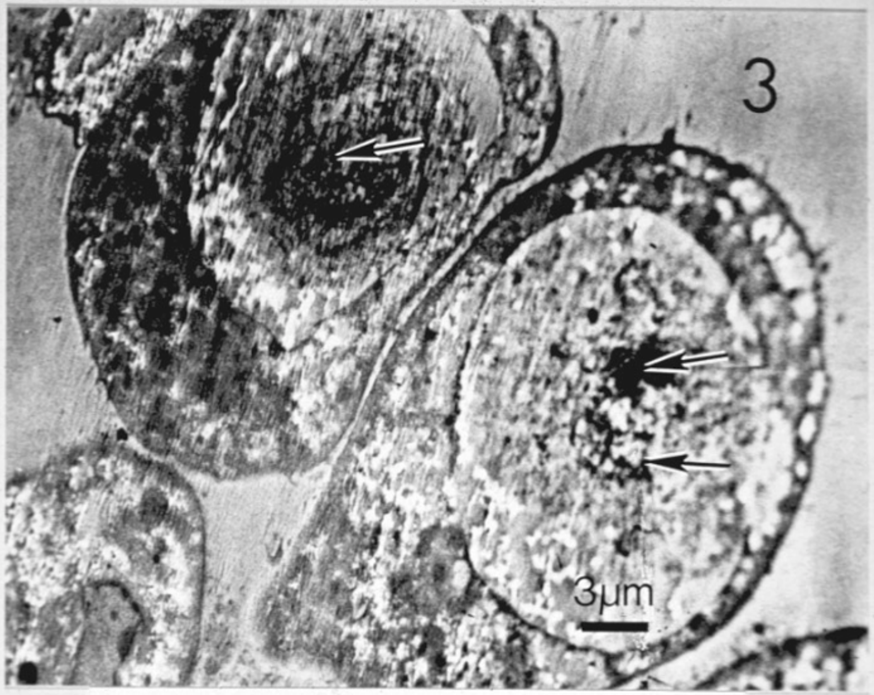
Cadmium substitutes for zinc on oyster MT

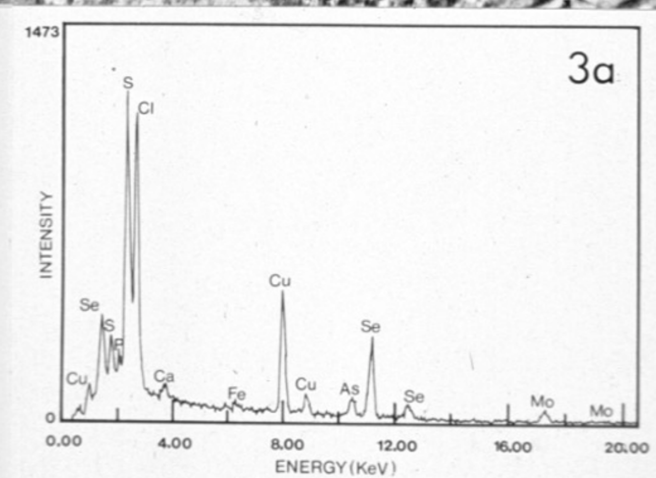


Metal composition of MT in oysters from the Patuxent River

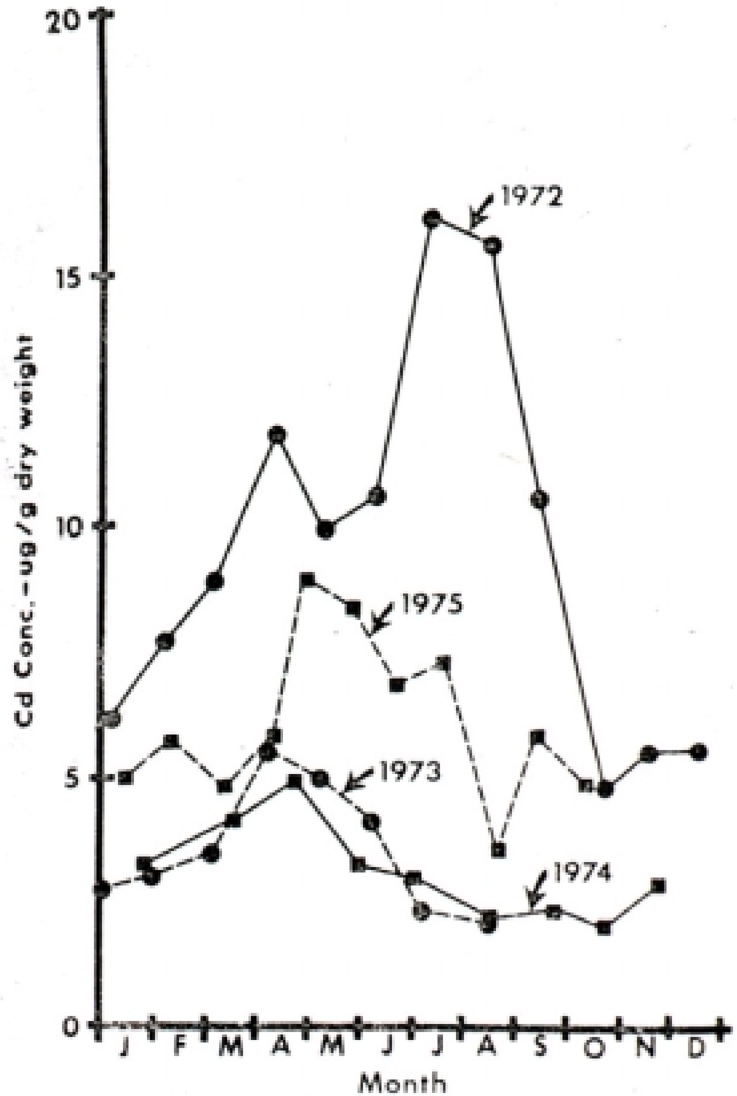
Percent of tissue cadmium, zinc, and copper bound to metallothioneins (mean + SD)

Metal	Percent Bound to MTs
Cadmium	21.6 ± 9.6
Zinc	0.29 ± 0.13
Copper	0.90 ± 0.53





Granules in kidneys from a hydrothermal vent clam



Frazier, 1979

Apparent Zinc and Cadmium Stability Constants for Different Zinc Finger Motifs and Metallothionein, pH7

Protein	Ligand	Zinc	Cadmium
CP-1	CCHH	$1.8x10^{11}$	$5.8x10^{8}$
CP-1	CCHC	$3.2x10^{11}$	$1.6x10^{11}$
CP-1	CCCC	$9.1x10^{11}$	$2.5x10^{13}$
MT	S4	$2.0x10^{12}$	$2.0x10^{16}$

Figure 1

Cd content of various oyster species in NZ

Country and species	*Locality*	*ppm Cd wet weight*
New Zealand Tiostrea chilensis	Wellington	0.12
	Marlborough Sounds	1.3
	Golden Bay	1.42
	Foveaux Strait	5.75
Crassostrea glomerata	Bay of Islands	0.65
	Auckland	0.75
	Bay of Plenty	0.55
United Kingdom Ostrea edulis	England and Wales	1.2
United States Crassostrea virginica	East Coast	2.40
	Florida	0.2

Cadmium concentrations in NZ scallops, *Pecten Novazealandiae*

Location	*[Cd] ppm wet weight*
Collingwood	3.6
Titirangi Bay	4.0
Breaksea Sound	9.4
Milford Sound	12
Paterson Inlet	15
Chatham Islands	66

Figure 3 Map of Currents

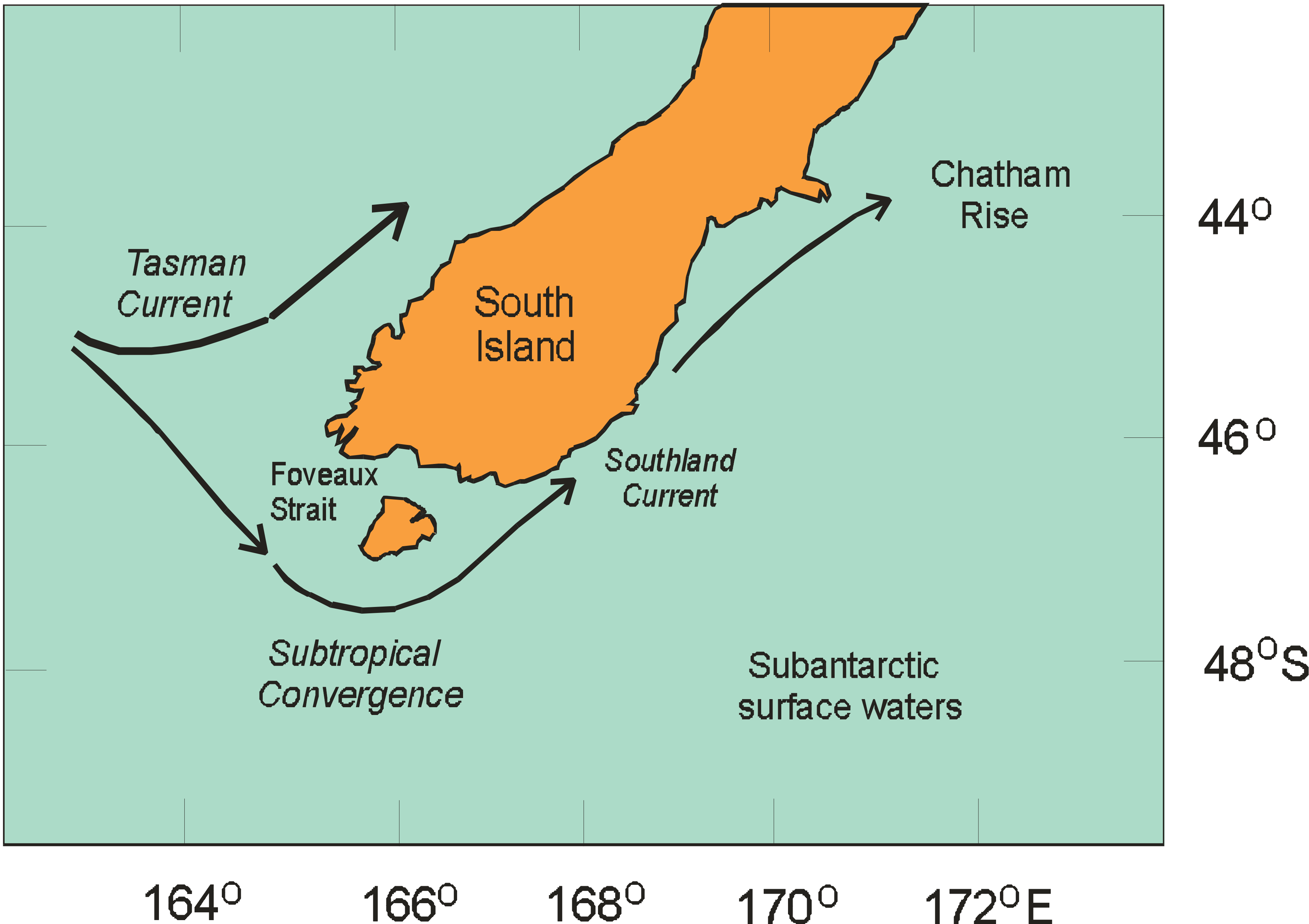
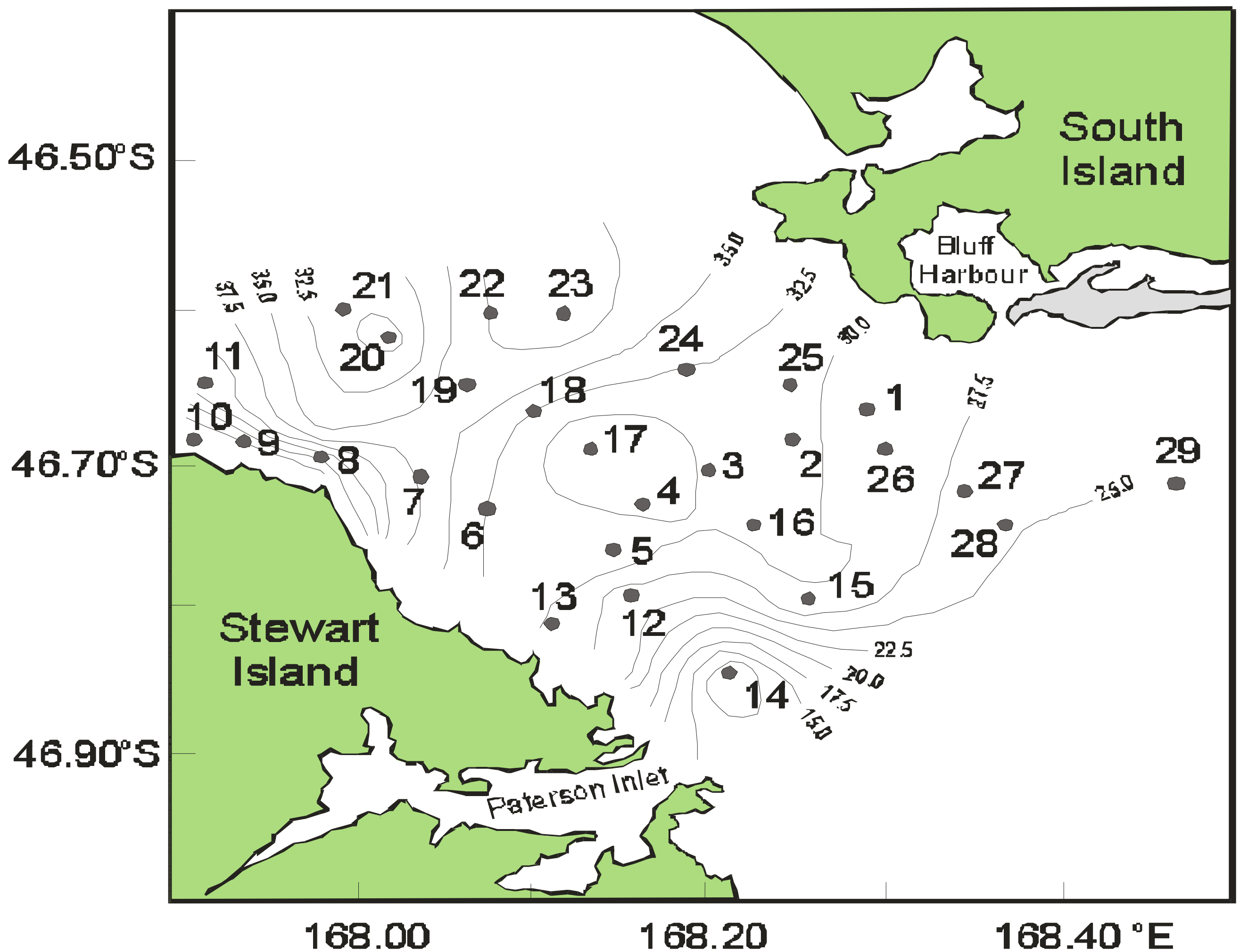


Figure 4. Map of oyster and sediment sampling stations in Foveaux Strait, Frew *et al.* (1997)



Bathymetry of study area (m)

Figure 5 Map of oyster and sediment sampling stations in Foveaux Strait, Frew *et al*. (1997), detail around Stewart Island

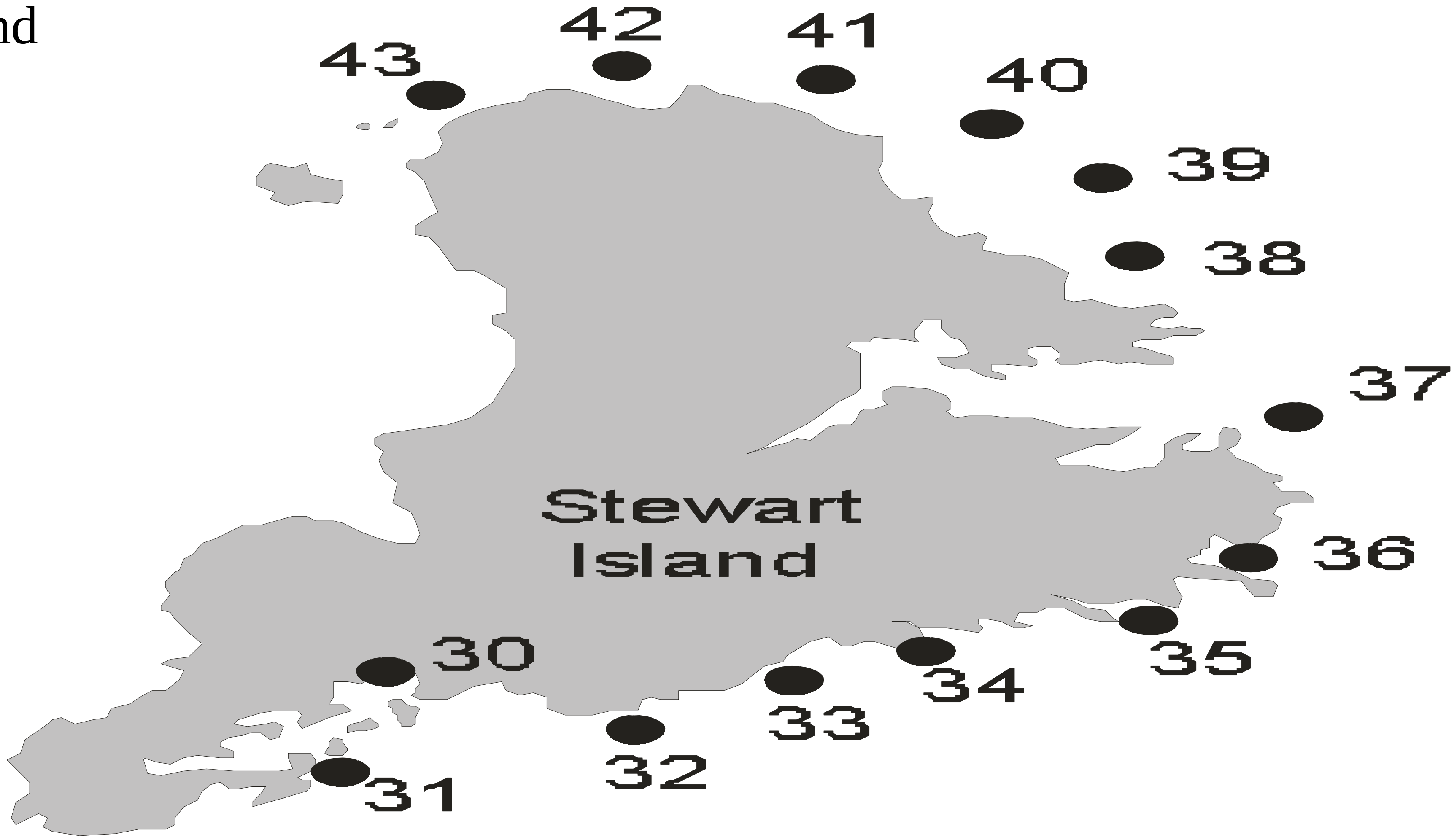


Figure 6 Histogram of Cd concentrations in oysters from Foveaux Strait, Frew *et al.* (1997)

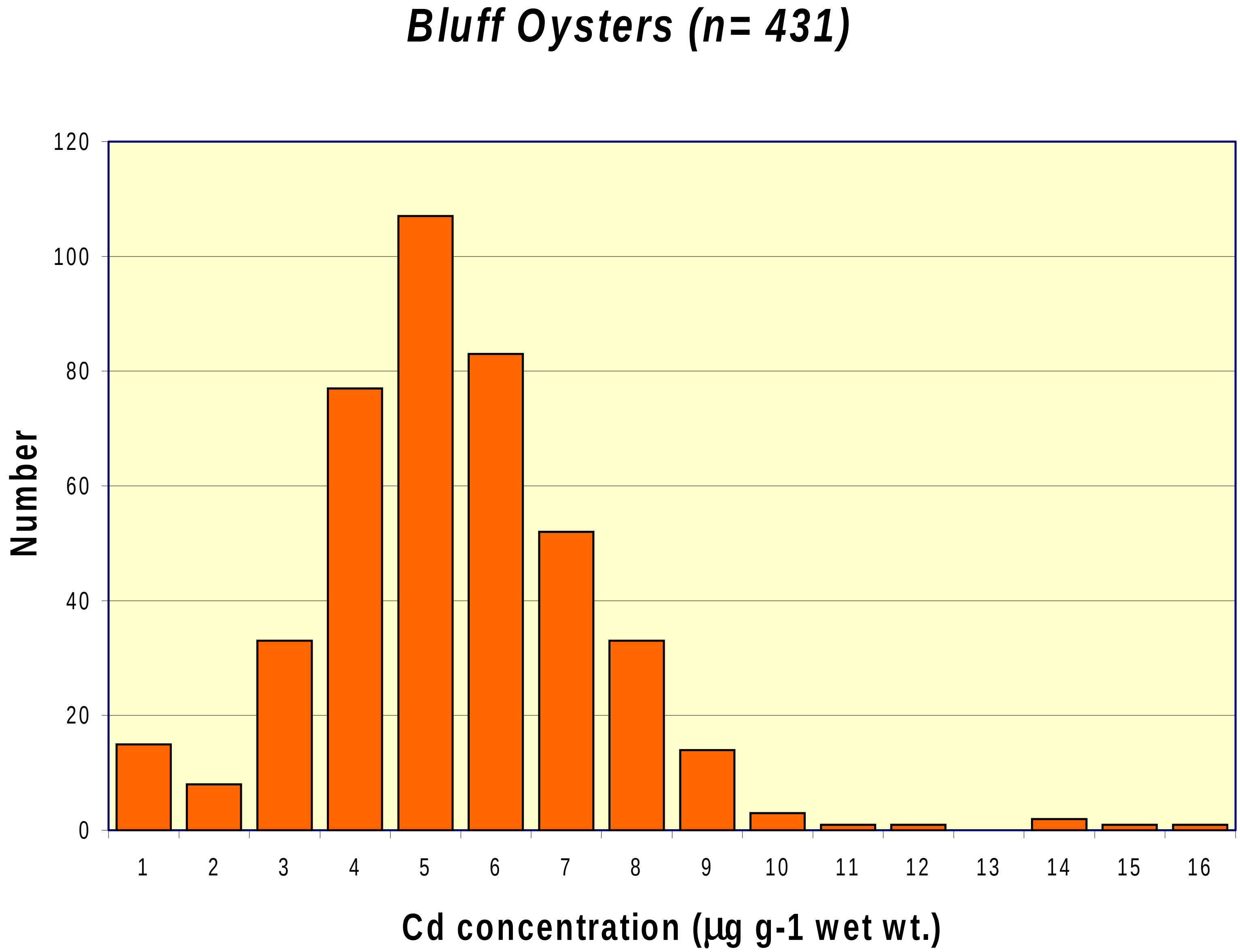


Figure 7 Distribution of Cd concentrations in tissues of oysters from Foveaux Strait, Frew *et al*. (1997)

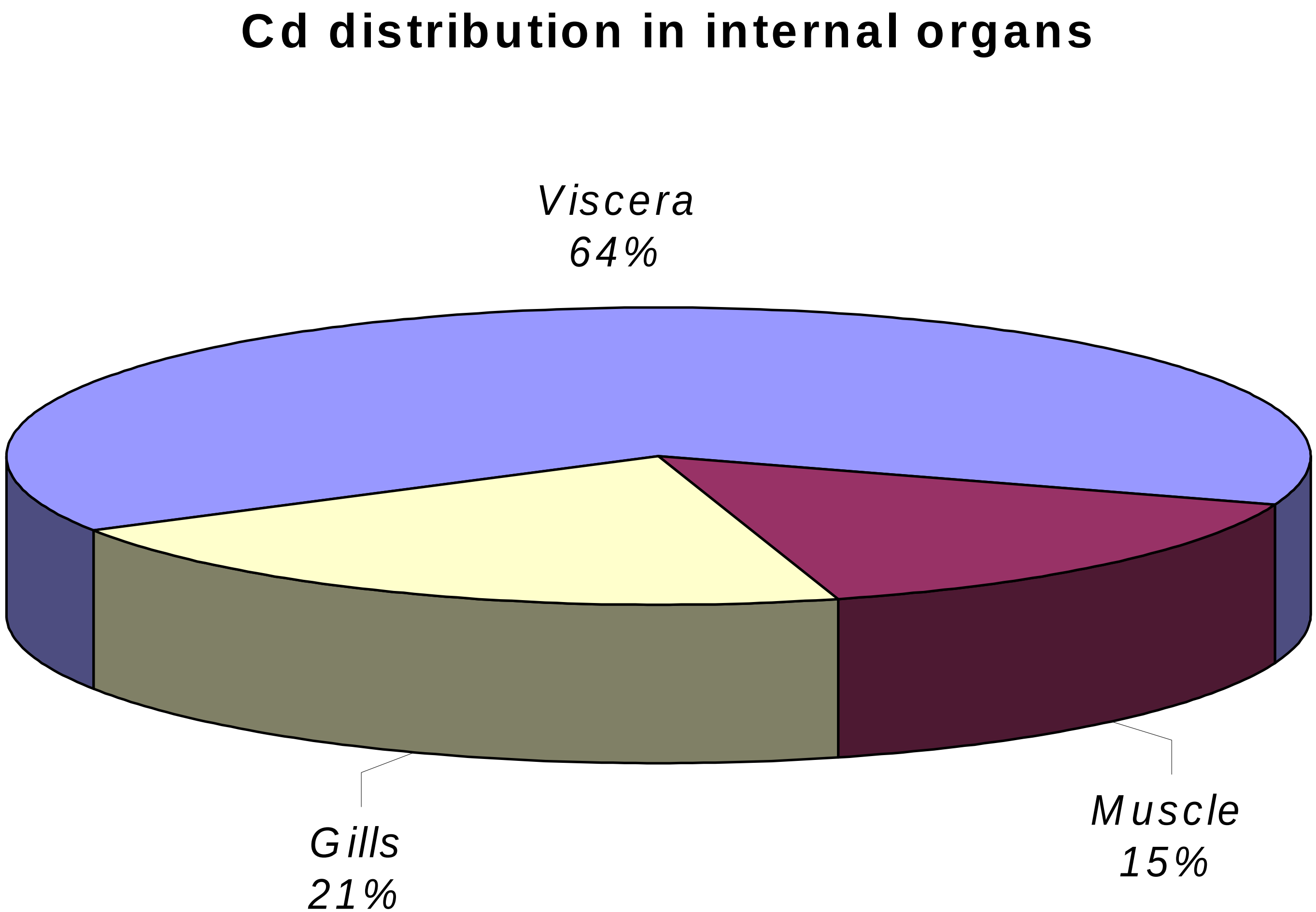


Figure 8 Geographic distribution of Cd concentrations in oysters from Foveaux Strait, Frew *et al.* (1997)

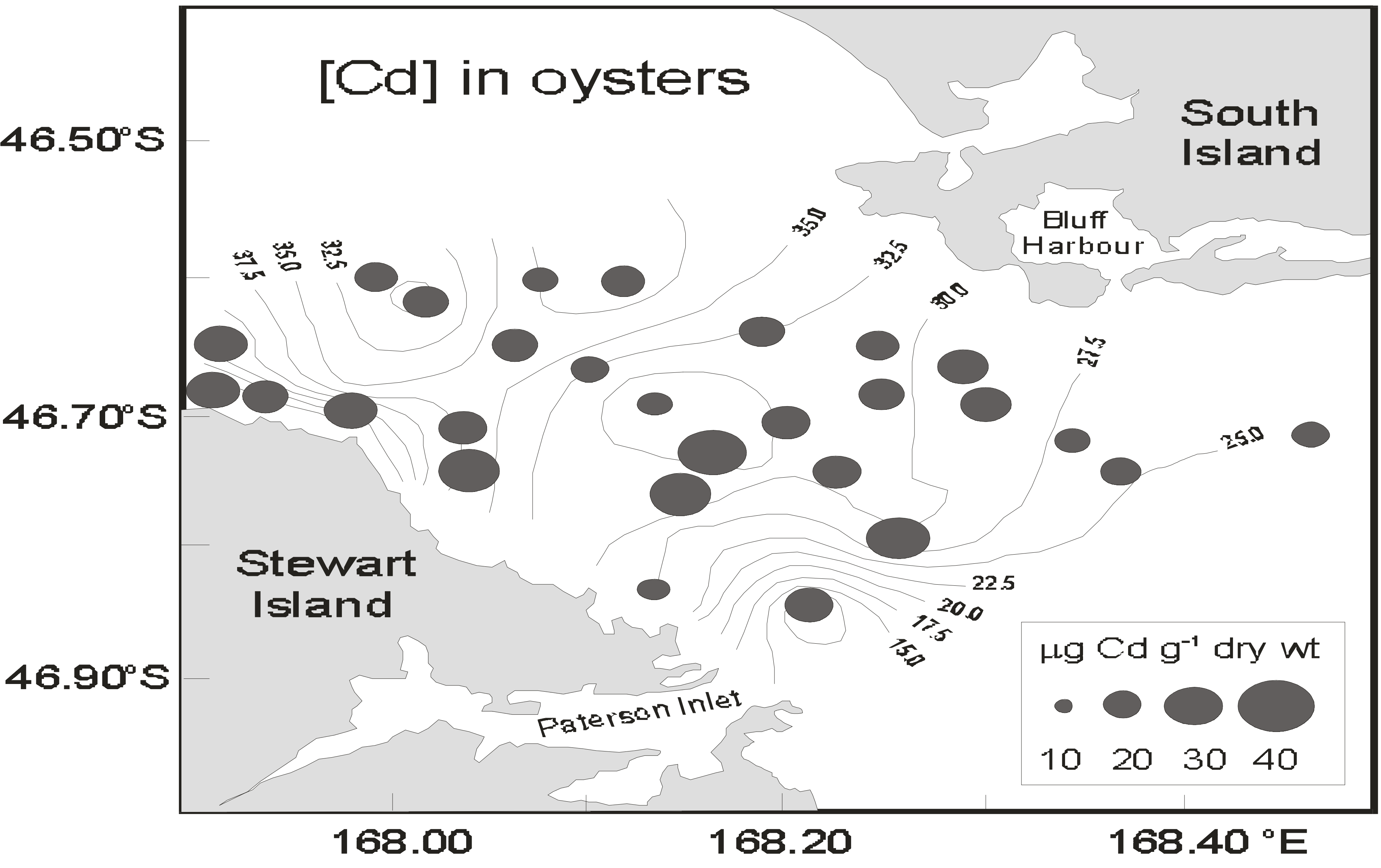


Figure 9 Geographic distribution of Cd uptake rate in oysters from Foveaux Strait, Frew *et al.* (1997)

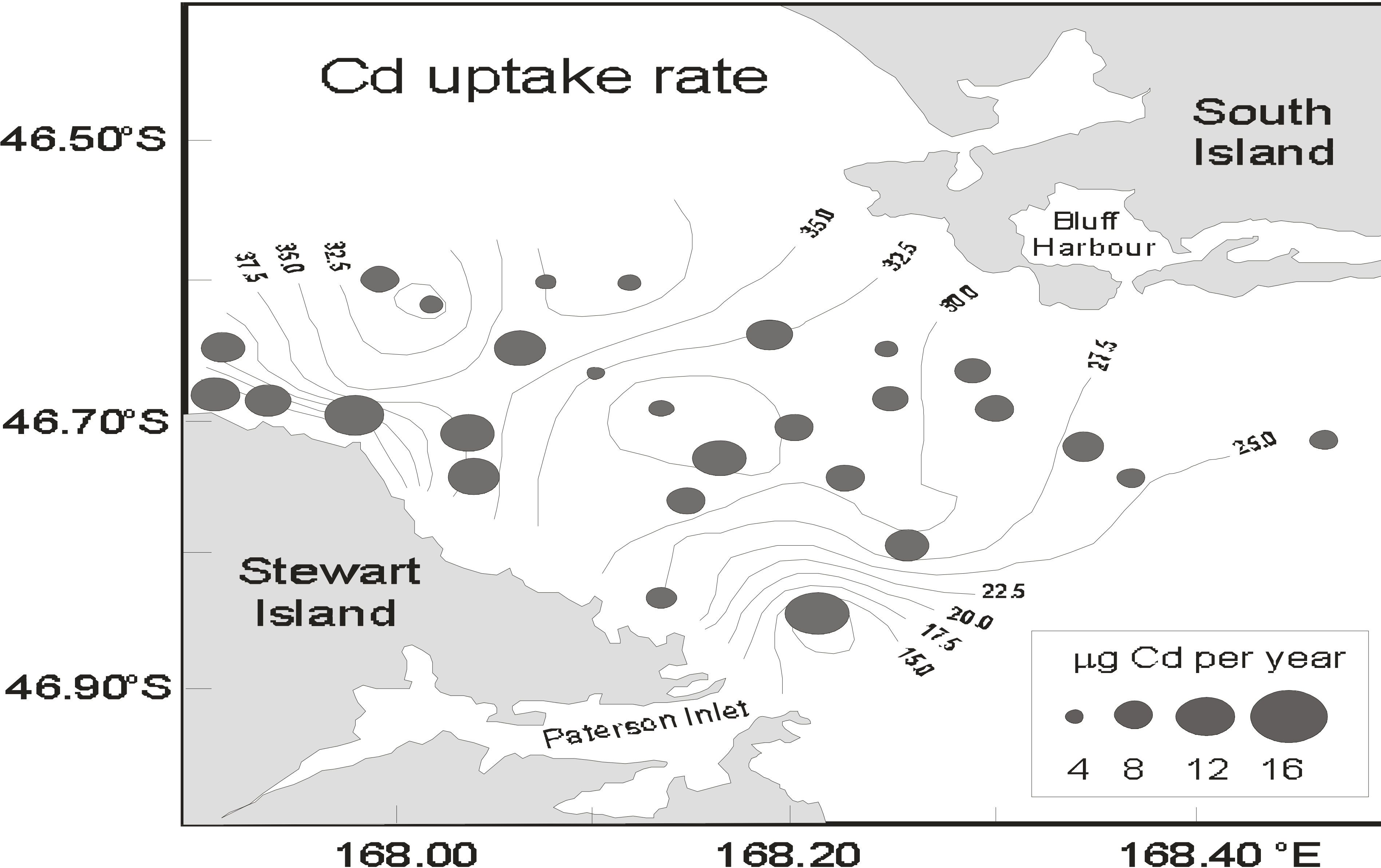
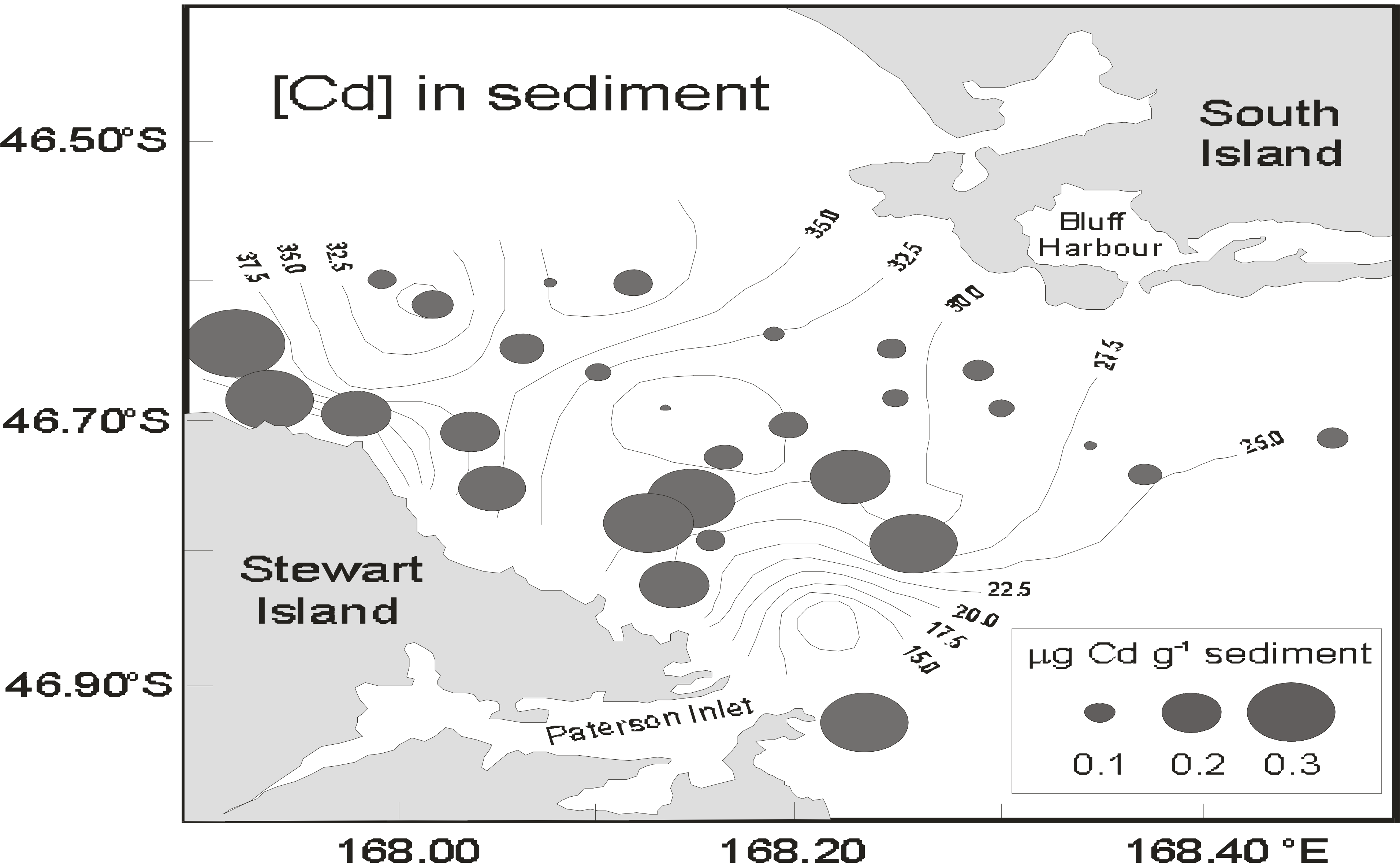
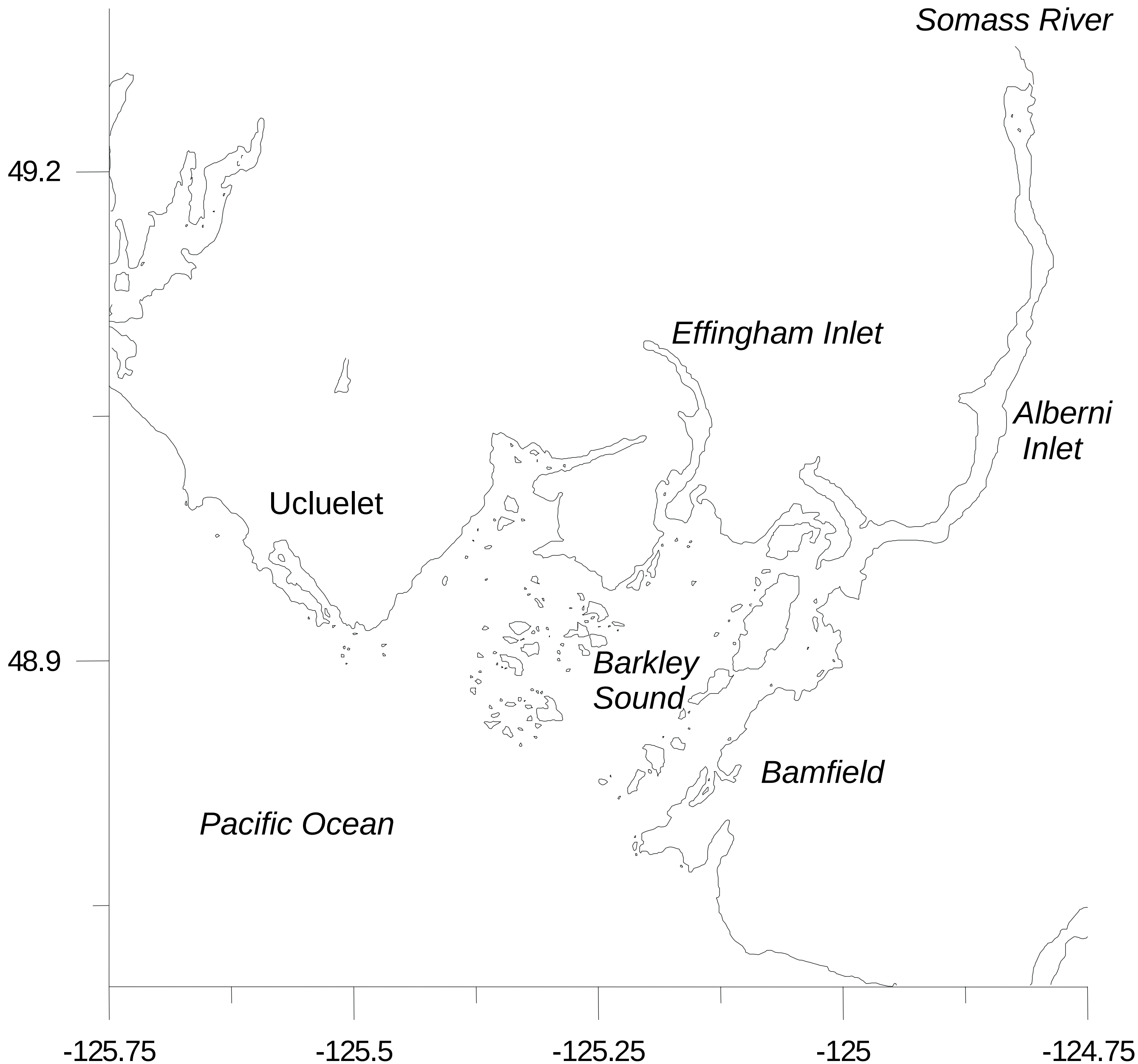


Figure 10 Geographic distribution of Cd concentrations in sediments from Foveaux Strait, Frew *et al.* (1997)

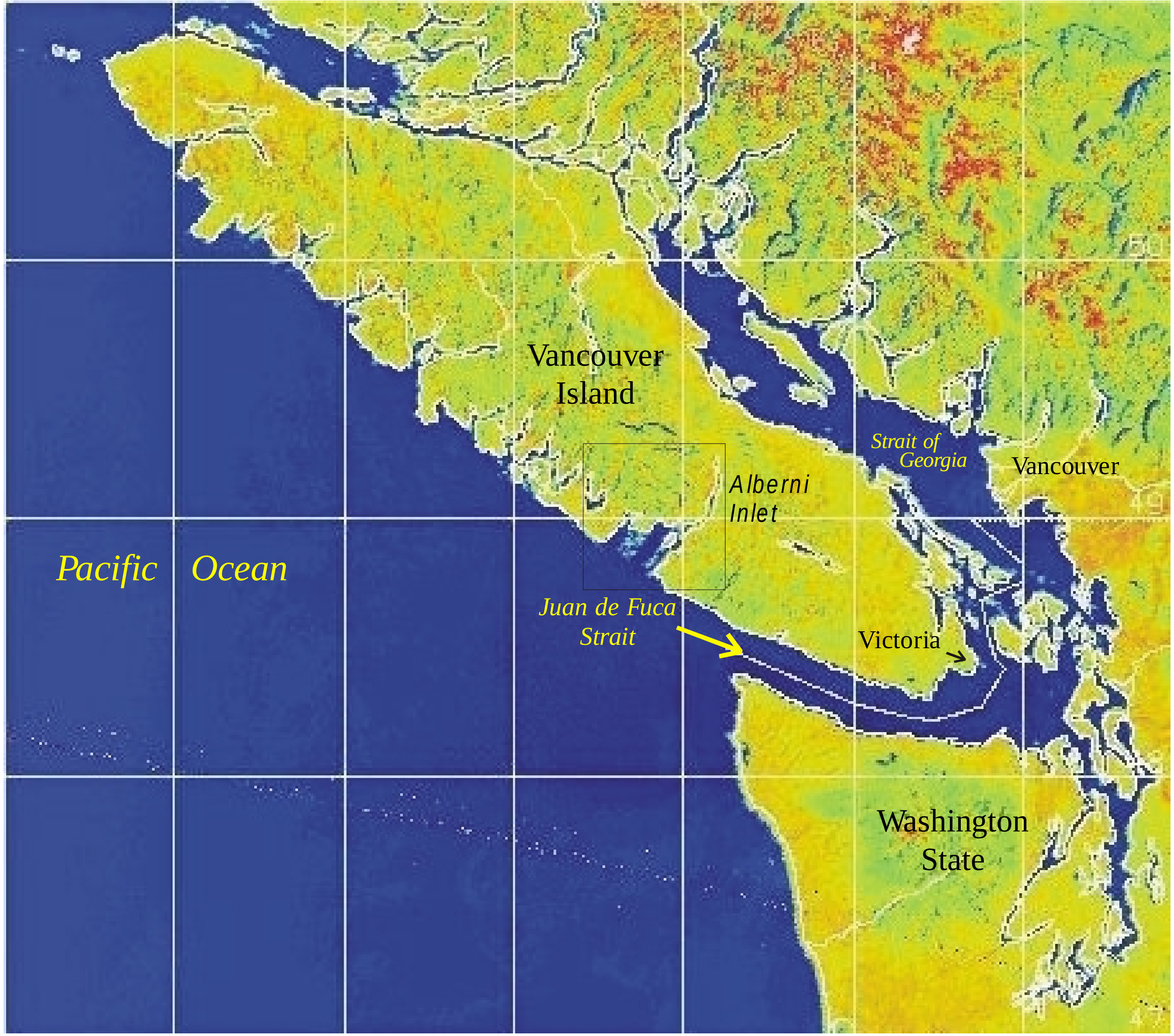


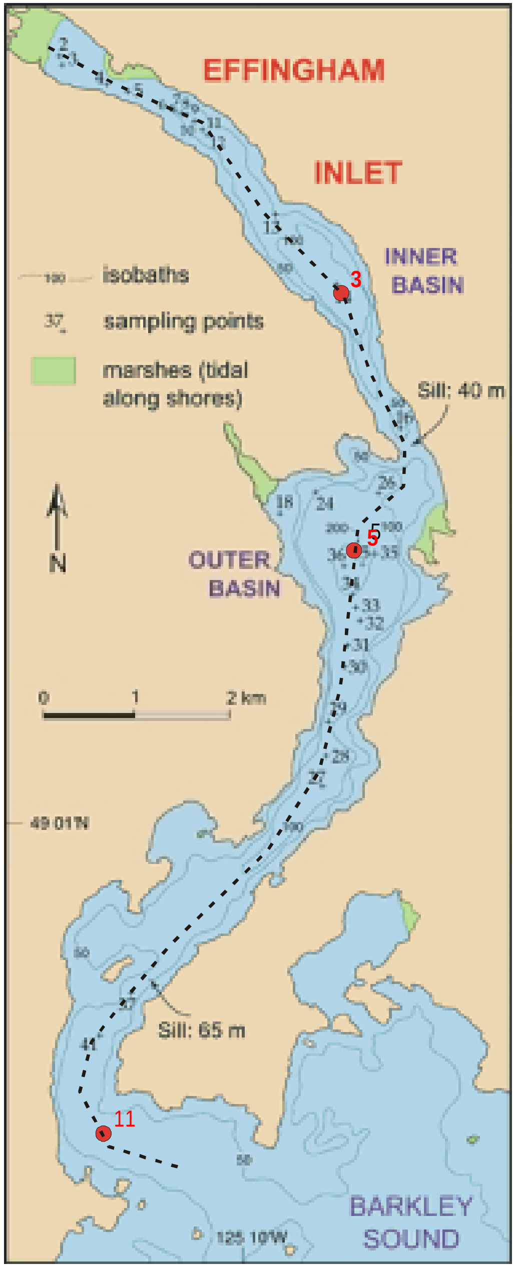
Effingham Inlet Study
R.E. Thomson *et al*

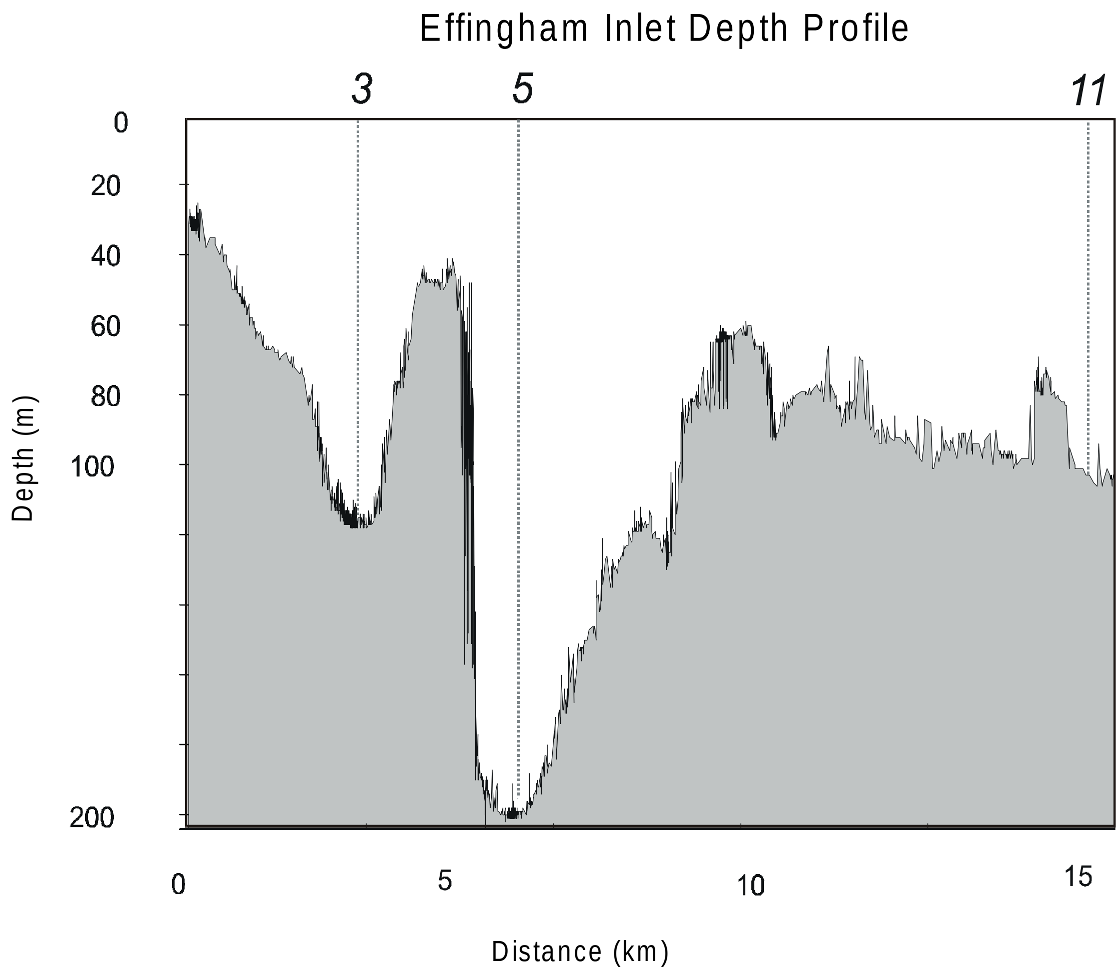
- A multi-disciplinary paleoceanographic study of long-term fish stock abundances and coastal upwelling intensity.
- Collaborative coring study with Scripps, U of W, UBC Centro de Investigacion Cientifica (Mexico) and Carleton University
- Study began in 1995
- No known publications or data prior to this study



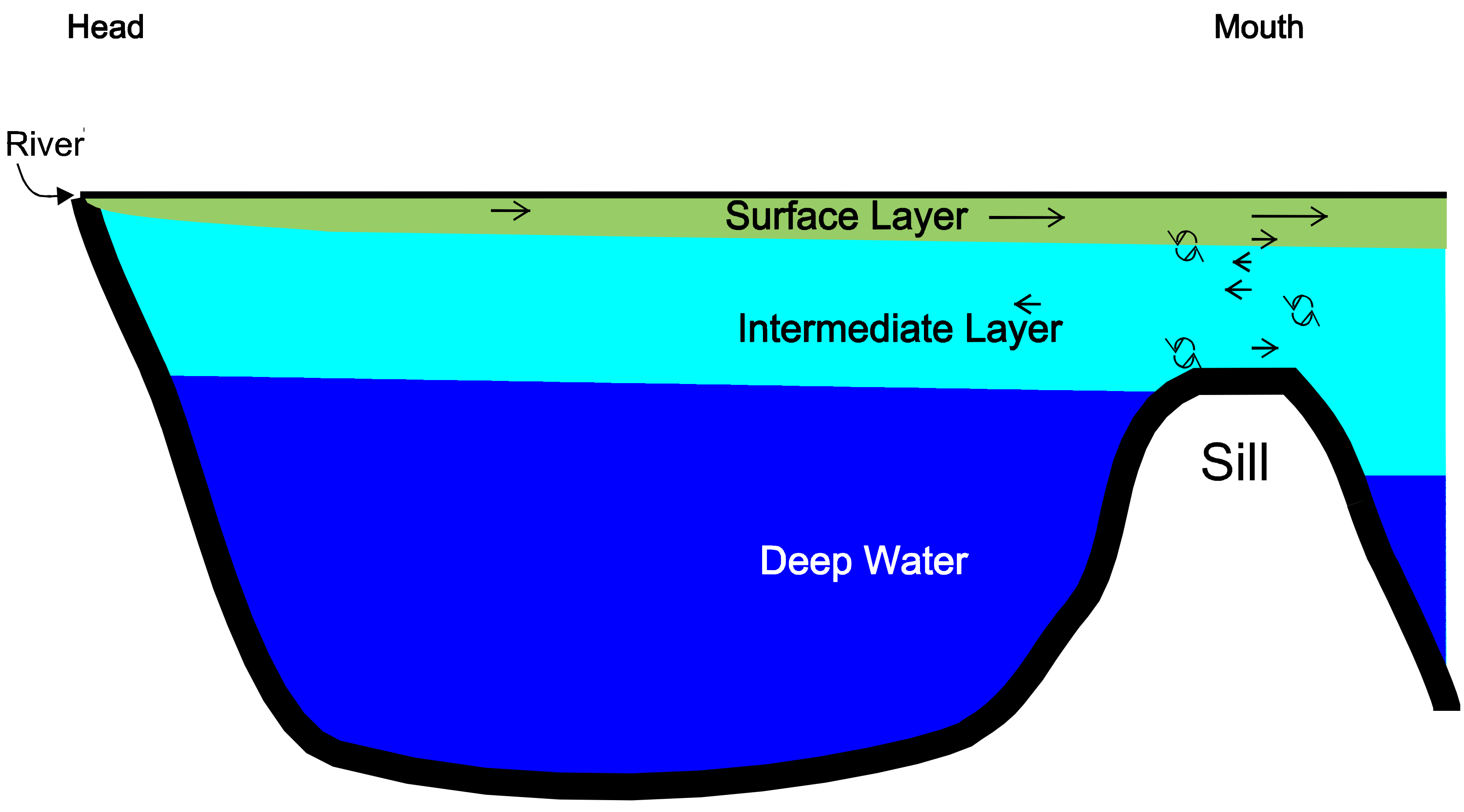
Somass River
49.2
Effingham Inlet
Alberni
Inlet
Ucluelet
48.9
Barkley
Sound
Bamfield
Pacific Ocean
-125.75
-125.5
-125.25
-125
-124.75

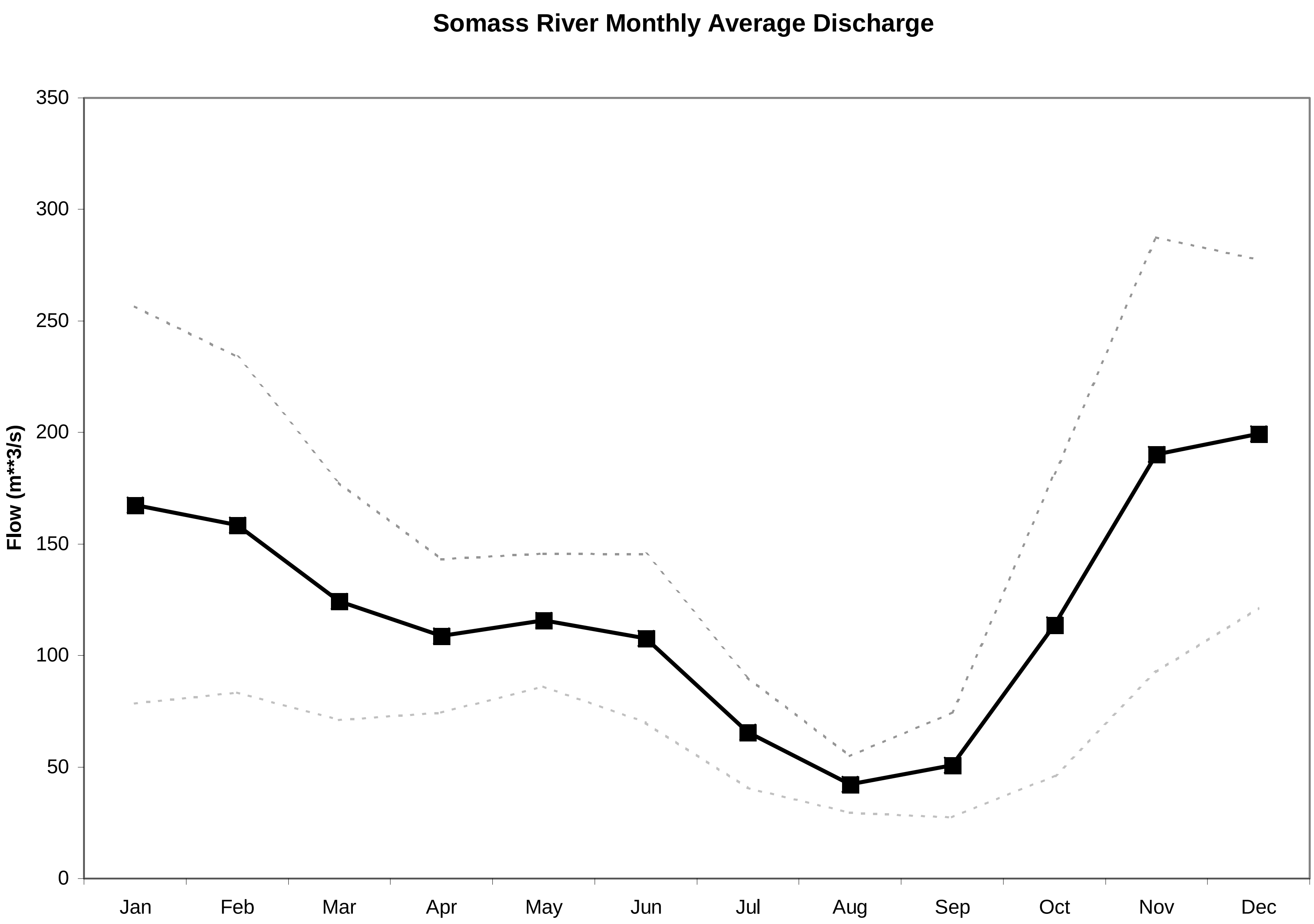

Vancouver Island
Alberni Inlet
Strait of Georgia
Vancouver
Pacific Ocean
Juan de Fuca Strait
Victoria
Washington State
Seattle


EFFINGHAM
INLET
INNER
BASIN
isobaths
sampling points
marshes (tidal
along shores)
Sill: 40 m
OUTER
BASIN
N
0
1
2 km
49 01'N
Sill: 65 m
BARKLEY
SOUND
125 10'W
3
5
11


Effingham Inlet Depth Profile
3
5
11
0
20
40
60
80
100
200
Depth (m)
0
5
10
15
Distance (km)

Schematic Diagram of Fjord

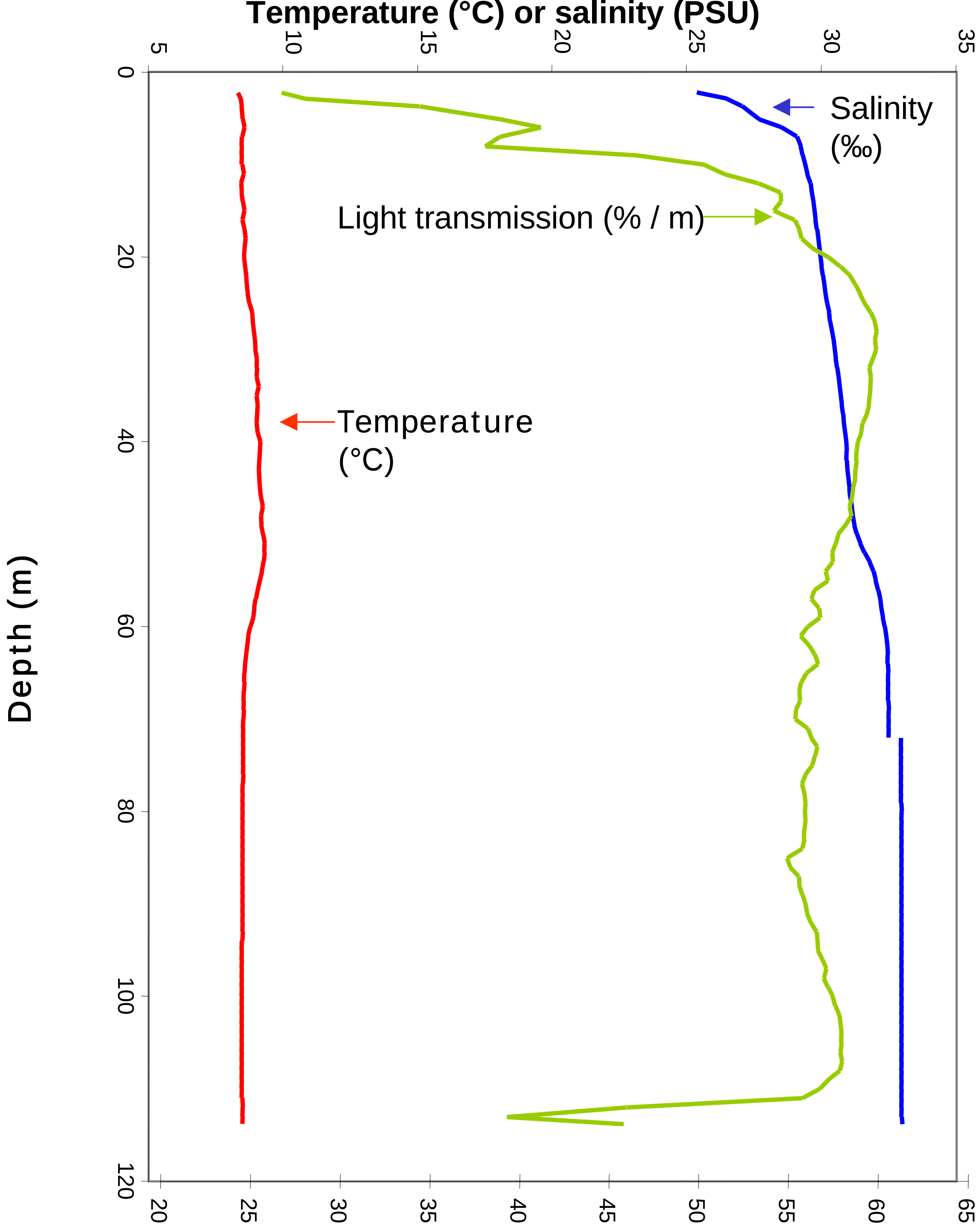


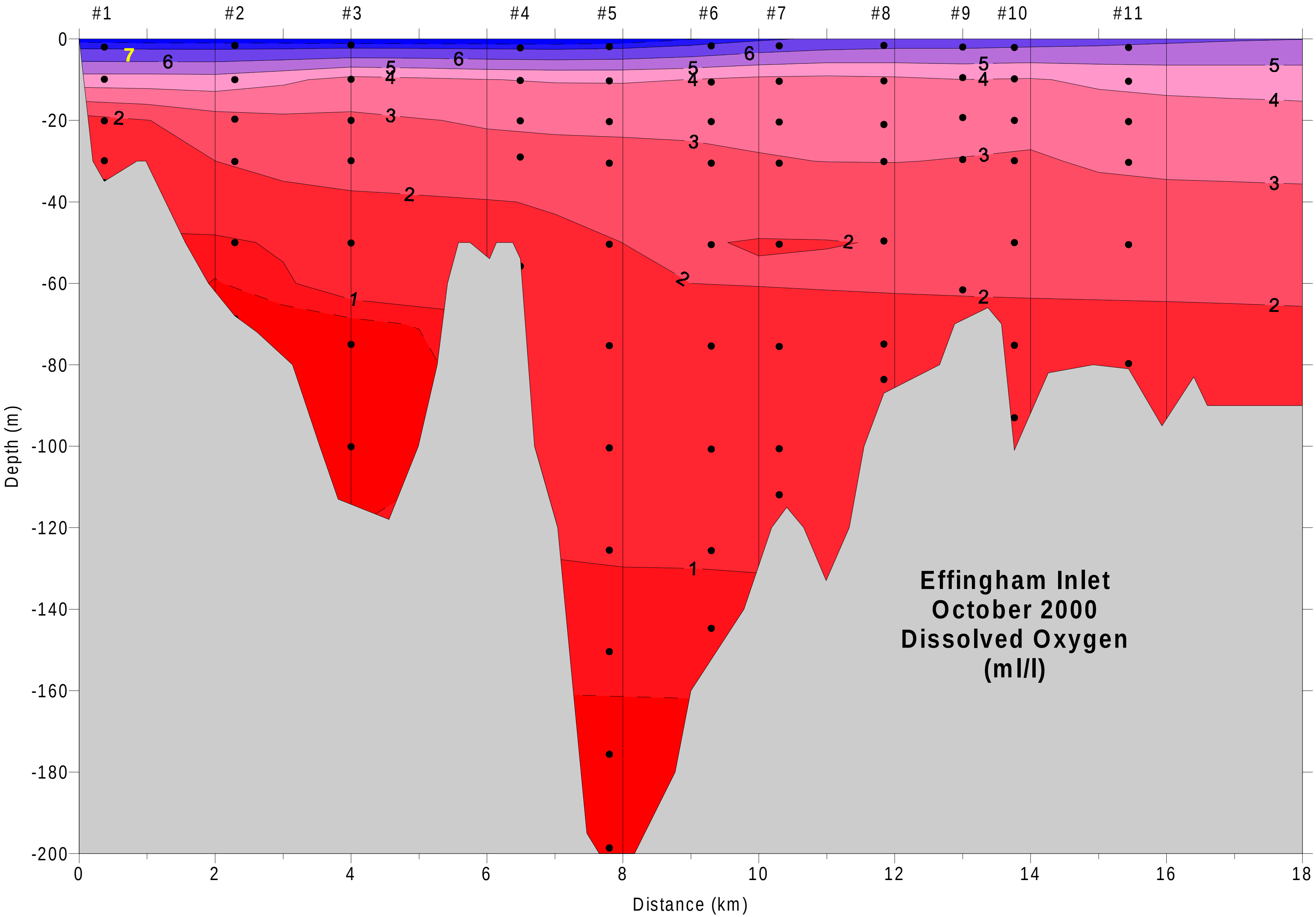

Somass River Monthly Average Discharge
Flow (m**3/s)
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

CTD/rosette for profiling
and water sampling

Effingham Inlet

Water Property Profiles





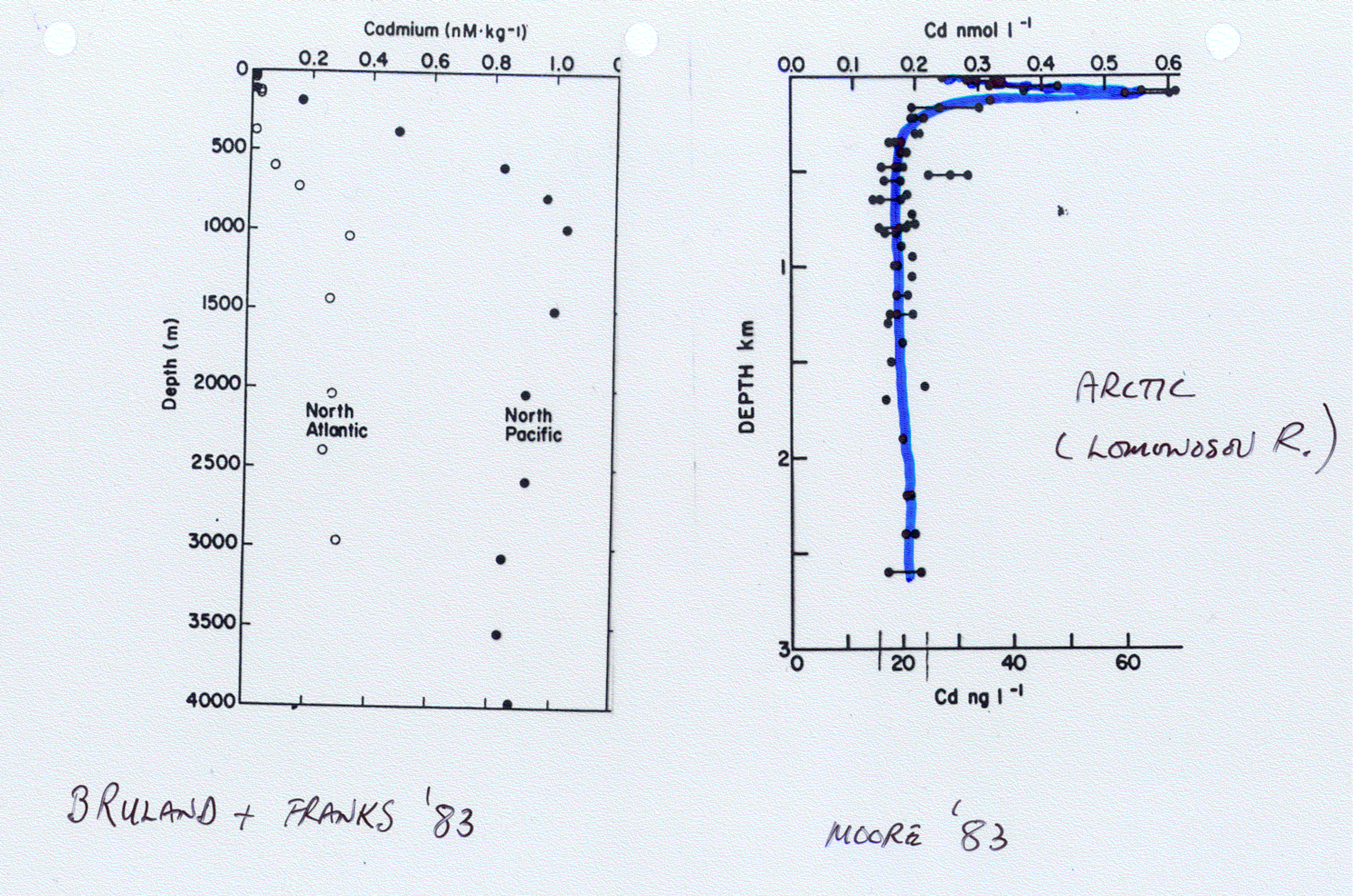
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)
0
2
4
6
8
10
12
14
16
18
Distance (km)
7
6
5
4
3
2
1
Effingham Inlet
October 2000
Dissolved Oxygen
(ml/l)


Effingham Inlet - logging


Pulp Mill


Fish Farm

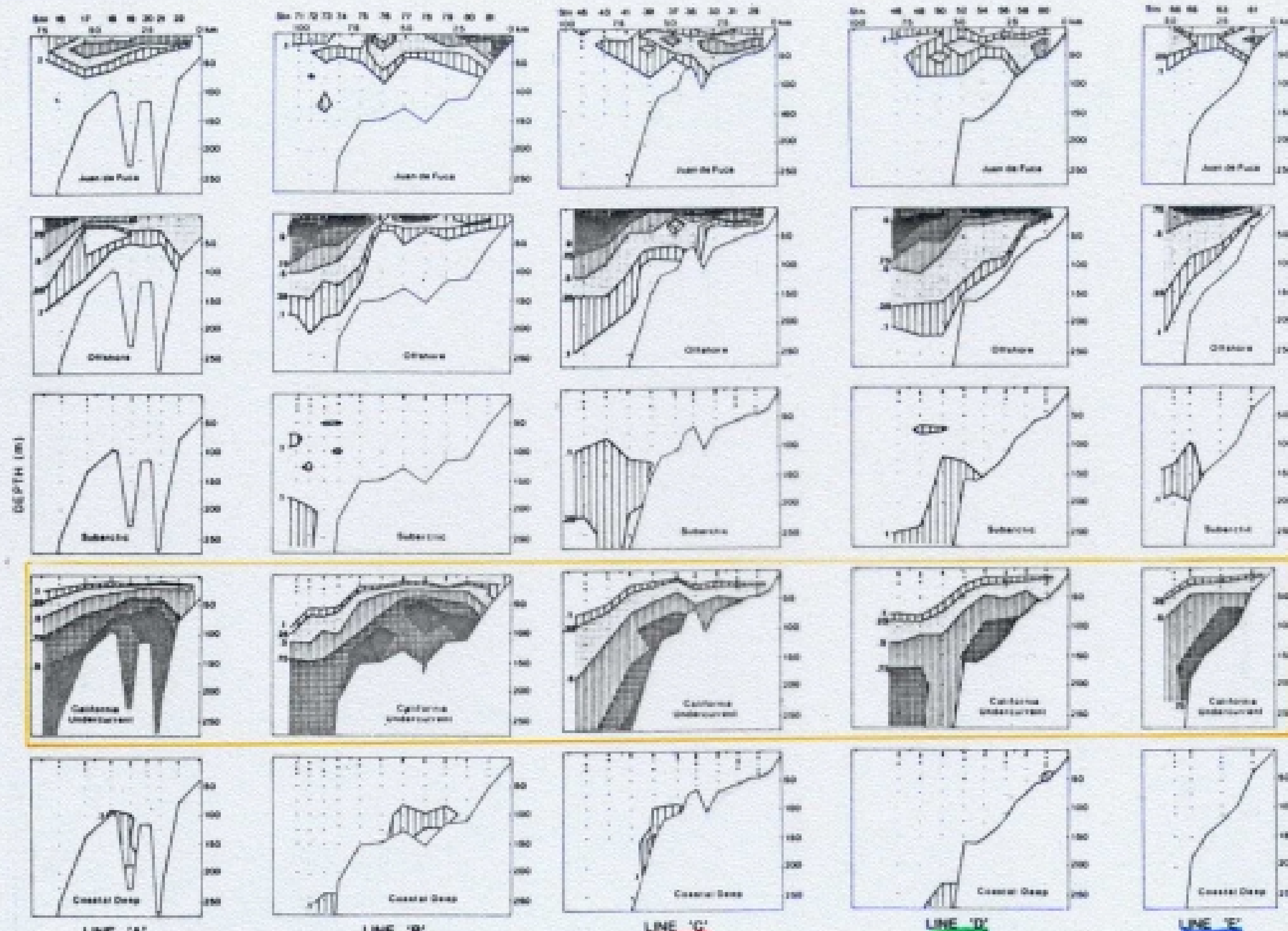
Figure 1



Cadmium (nM·kg⁻¹)
0.2 0.4 0.6 0.8 1.0
Depth (m)
0 500 1000 1500 2000 2500 3000 3500 4000
North Atlantic
North Pacific
BRULAND + FRANKS '83
Cd nmol l⁻¹
0.0 0.1 0.2 0.3 0.4 0.5 0.6
DEPTH km
1 2 3
0 20 40 60
Cd ng l⁻¹
ARCTIC
(LOMONOSOV R.)
MOORE '83

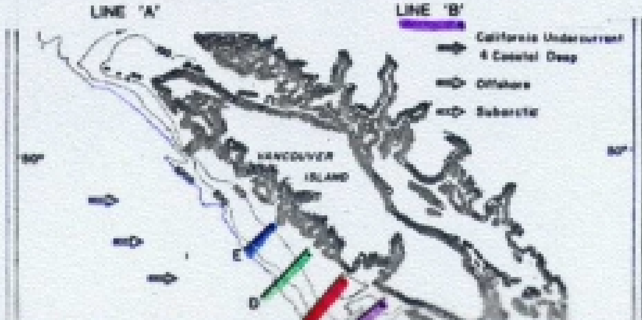
5 W

Figure 2



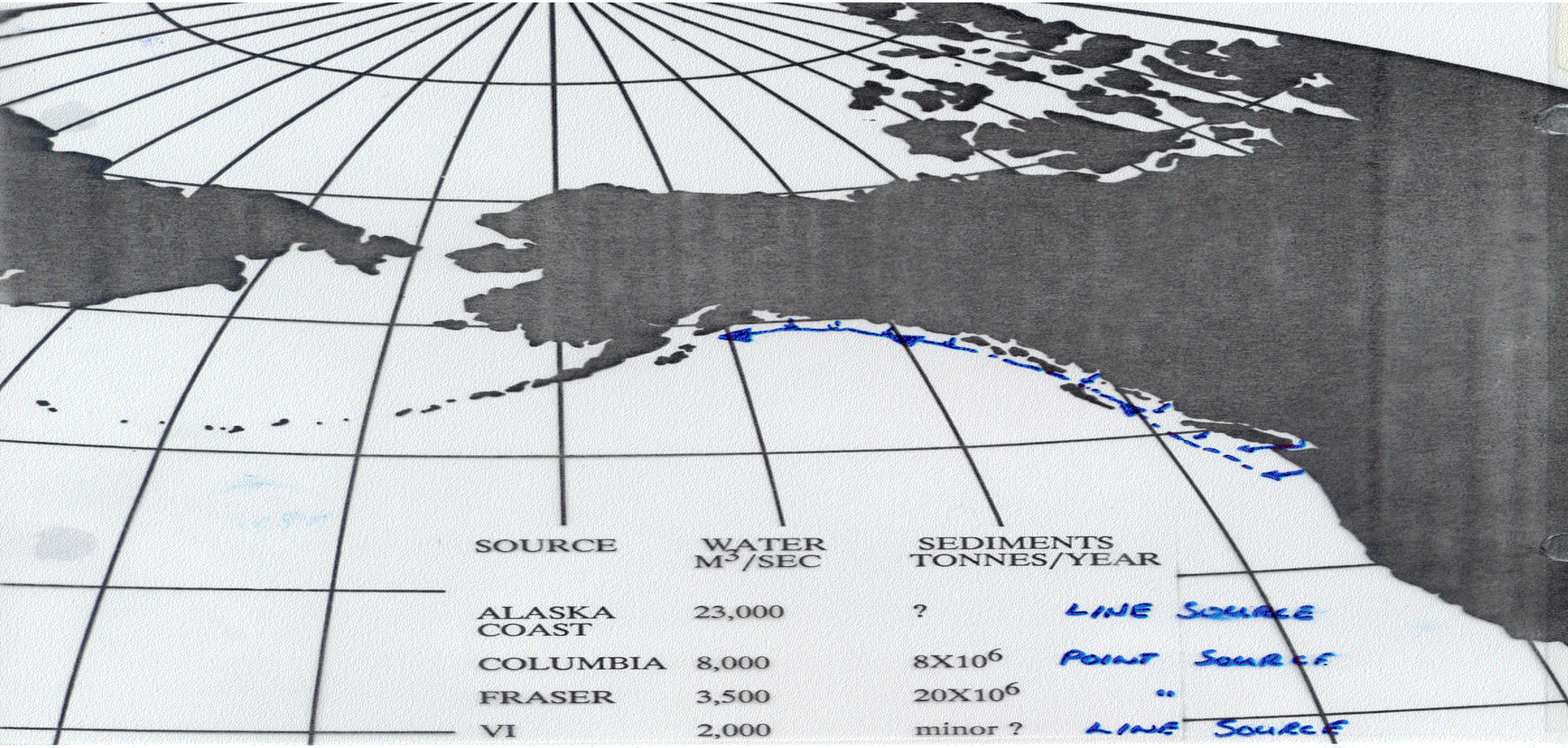
	Juan de Fuca	Offshore	Subarctic	California Undercurrent	Coastal Deep
Temperature, °C	9.84	8.75	4.70	6.90	5.10
Salinity	31.55	32.62	33.57	33.90	34.10
Nitrate, μmol	24.68	7.63	29.00	33.40	40.00
Phosphate, μmol	2.19	1.11	2.30	2.65	3.20
Silicate, μmol	41.76	12.55	48.00	52.00	90.00
Oxygen, mL L^{-1}	5.26	6.20	4.65	2.10	0.50

Mackas *et al.*, 1987



- No conditions of water column anoxia; < 1 ml L^{-1} possible.
- Fairly narrow T,S ranges; little potential for sediment flushing
- California undercurrent is a supply of nutrients.

Figure 3



SOURCE	WATER M³/SEC	SEDIMENTS TONNES/YEAR	
ALASKA COAST	23,000	?	LINE SOURCE
COLUMBIA	8,000	$8X10^6$	POINT SOURCE
FRASER	3,500	$20X10^6$	"
VI	2,000	minor ?	LINE SOURCE

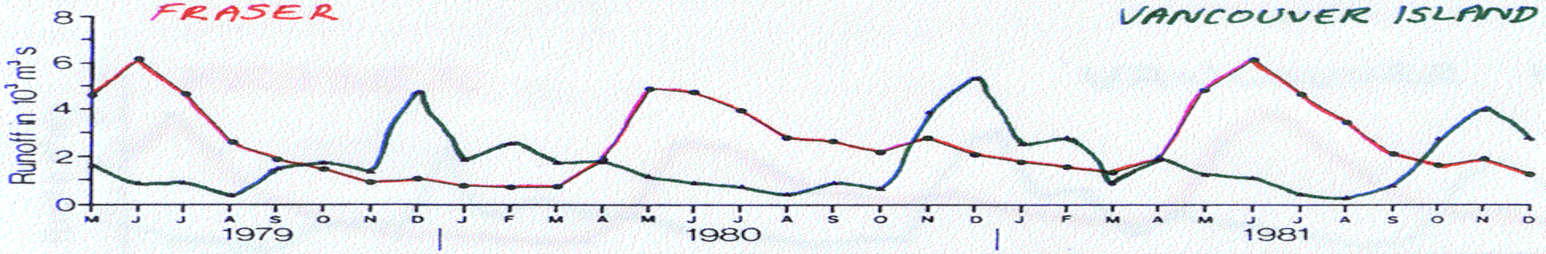


Fig. 9 Freshwater outflow from the Fraser River (solid line) and estimated run-off from the west coast of Vancouver Island (dotted line).

Freeland *et al.*, 1984

Figure 4

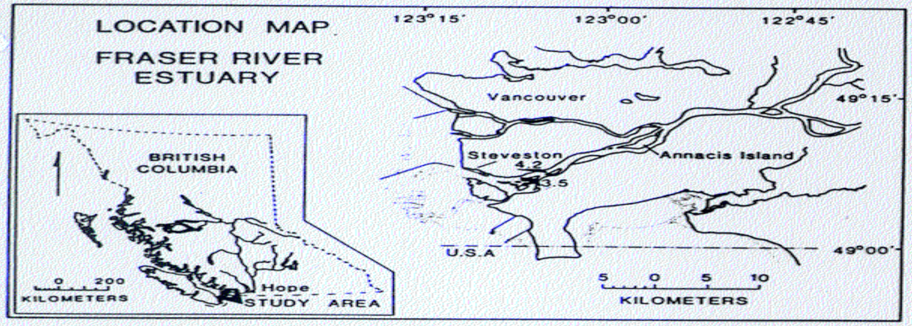


Fig. 1. Fraser River catchment (insert) and estuary with location of stations 3.5 and 4.2.

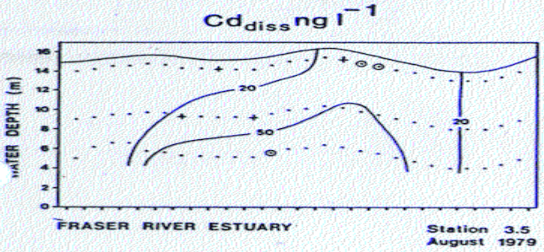


TABLE I

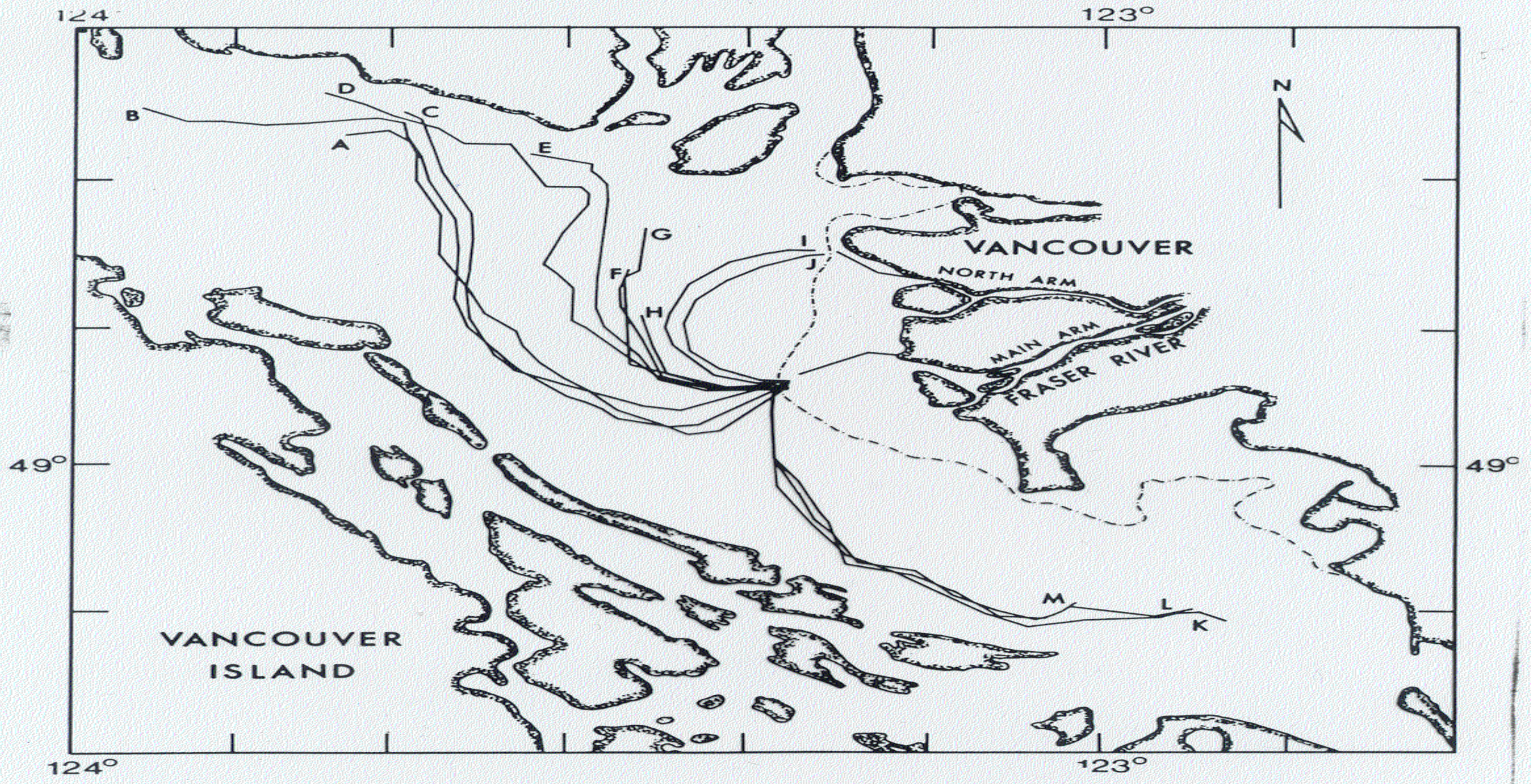
Dissolved versus particulate metal in surface and bottom waters between 1600 and 0400 hours at station 3.5

Element	Surface water (1 m)[a]			Bottom water[b]			
	Dissolved	Particulate	%[d]	Dissolved	Particulate	%	E.F.[c]
Fe $\mu g\ l^{-1}$	8.1[e] 5.4—12.1	175 106—251	95	6.4 1.1—20.0	73 43—126	92	13.6
Mn $\mu g\ l^{-1}$	2.8 1.5—5.5	6.4 4.1—9.0	70	—	2.5 1.4—4.2	—	2.4
Cu $\mu g\ l^{-1}$	0.9 0.39—1.52	0.40 0.26—0.55	30	0.46 <0.10—0.72	0.15 0.10—0.21	24	1.28
Co ng l^{-1}	35 13—159	150 90—210	81	56 <10—99	74 <10—138	57	3.17
Pb ng l^{-1}	95 61—215	140 80—250	60	44 <10—119	8 5—57	15	2.38
Cd ng l^{-1}	18 5—64	4 2—9	18	71 48—107	2 1—5	3	1.11
Suspended load mg l^{-1}	—	8.5 5.2—12.3	—	—	8.9 5.8—13.3		

[a] Salinities < 1‰. [b] Salinities > 20‰. [c] E.F. = enrichment factor calculated as $(C_{swp} - C_{bwp} + C_{swd})/C_{swd}$ where C_{swp} is the concentration in surface water particulates, C_{bwp} in bottom water particulates and C_{wsd} is the concentration of dissolved metal in surface waters. [d] % of total metal (dissolved + particulate) associated with particulates. [e] Two values $> 70\ \mu g\ l^{-1}$ omitted.

FLETCHER et al 1983

Figure 5



Crean et al., 1988

TRACKS OF SURFACE (1 m) DROGUES

- ABC 30h Interval (7,800 m^3/s; winds 2.5-8m/s SE)
- DEFGH: 22h Interval (2,700 m^3/s; winds 5-9 m/s SE)
- IJ: 8h Interval (2,700 m^3/s; winds negligible)
- KLM: 16h Interval (7,800 m^3/s; winds 8-13 m/s NW)

Figure 6

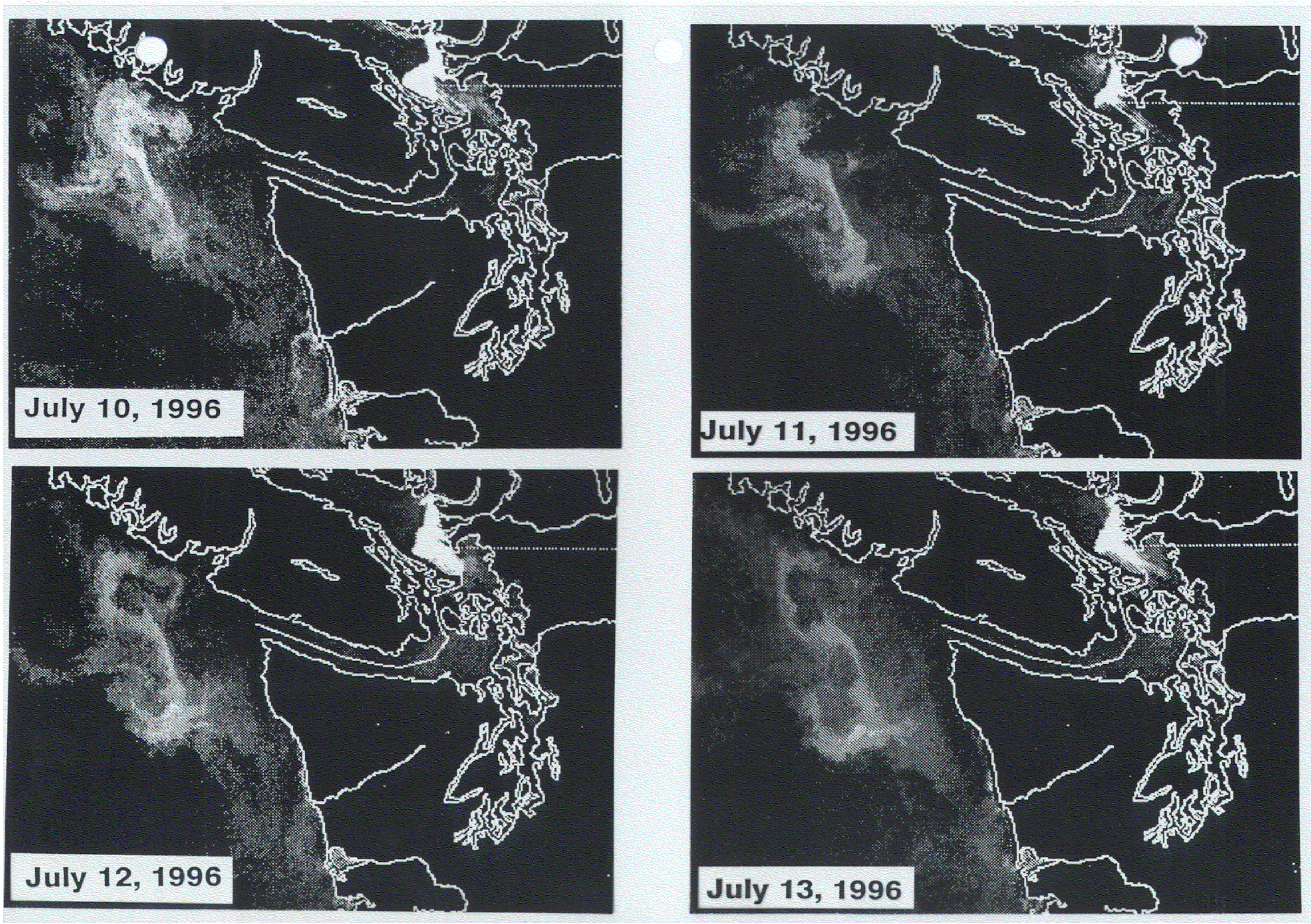
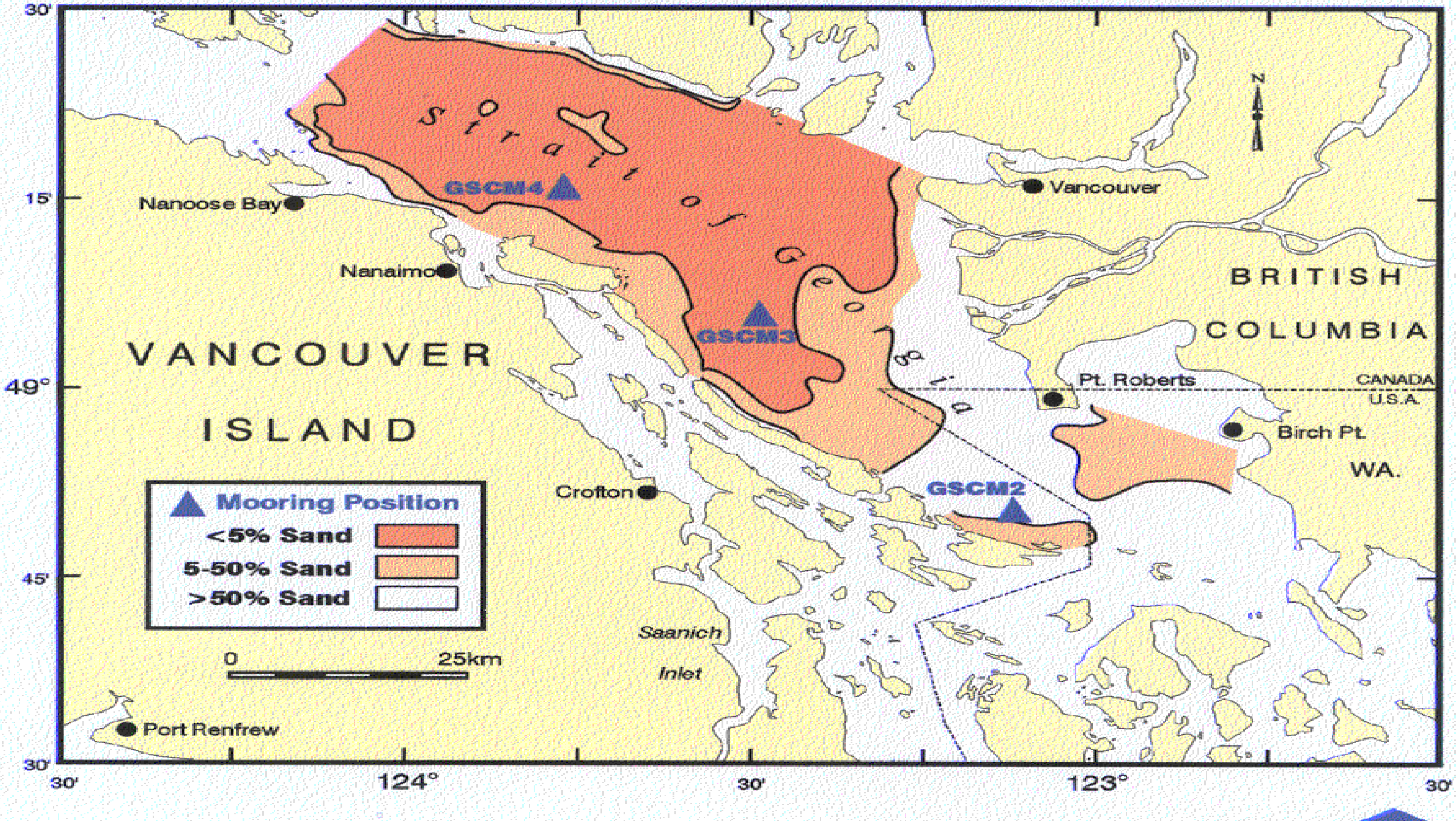


Figure 7

Surface Sediment Grain Size Distribution



from Pharo and Barnes, 1976

IOS

Figure 8

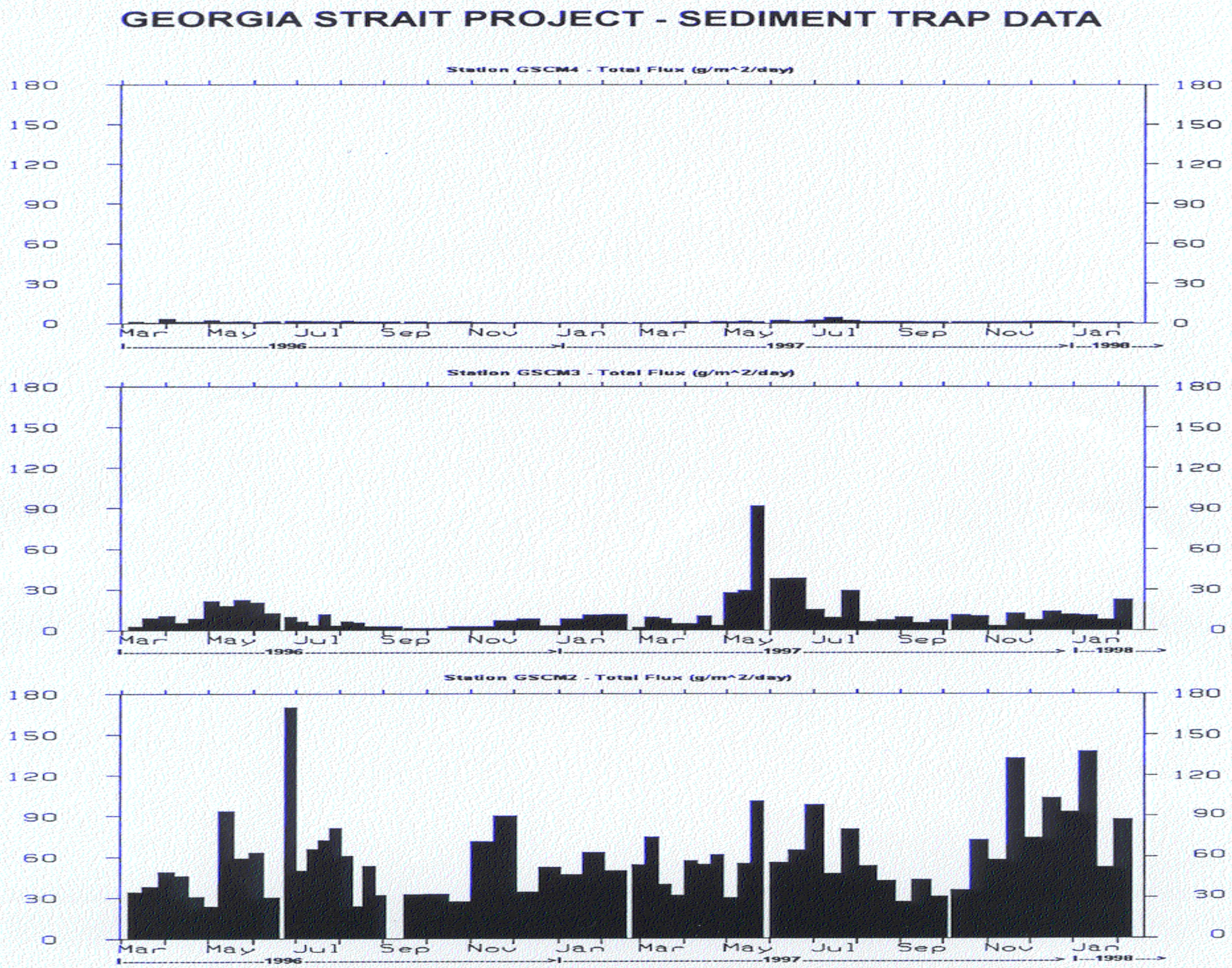

GEORGIA STRAIT PROJECT - SEDIMENT TRAP DATA
Station GSCM4 - Total Flux (g/m^2/day)
Station GSCM3 - Total Flux (g/m^2/day)
Station GSCM2 - Total Flux (g/m^2/day)
0
30
60
90
120
150
180
Mar
May
Jul
Sep
Nov
Jan
1996
1997
1998

Figure 9

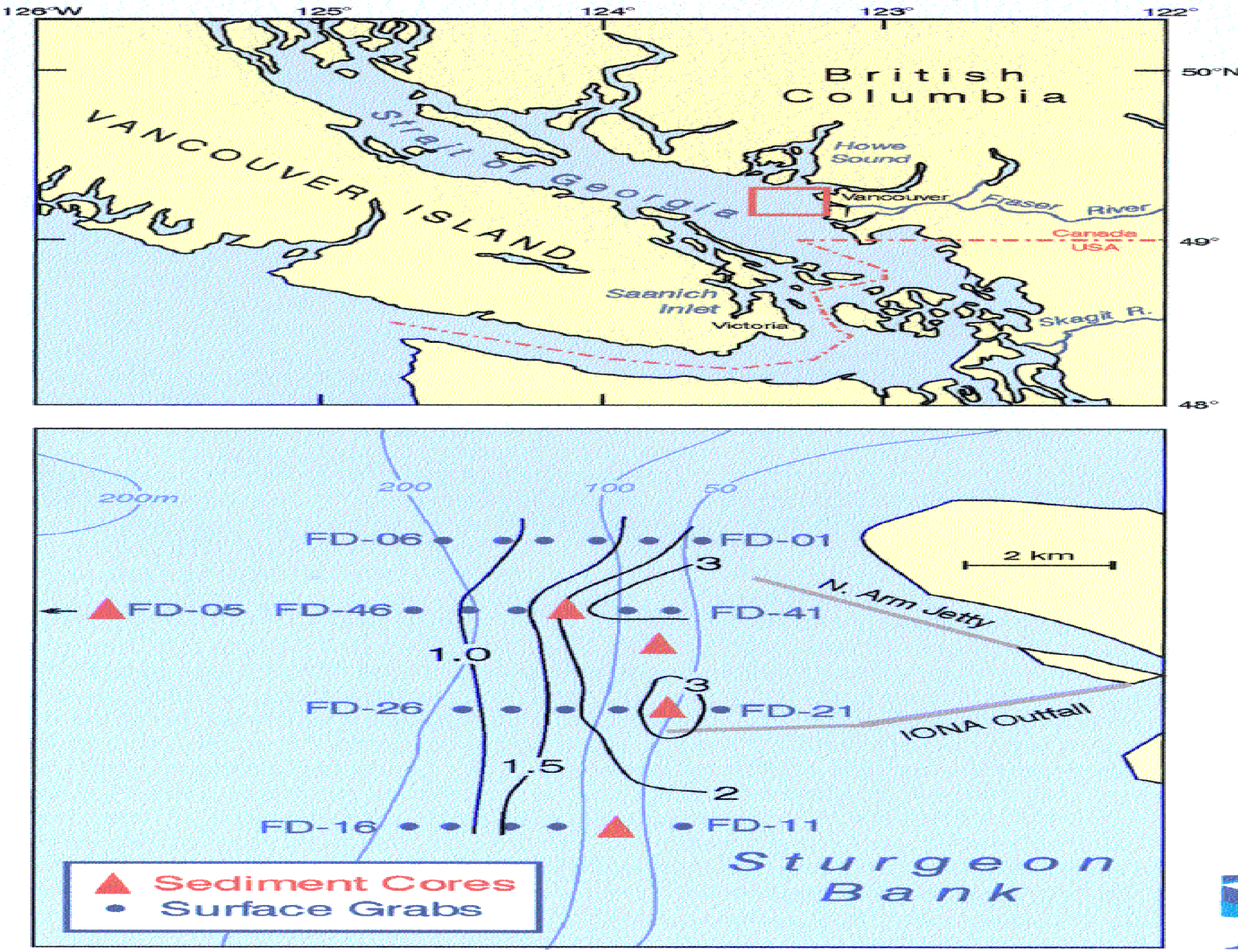

126°W
125°
124°
123°
122°
50°N
49°
48°
British Columbia
VANCOUVER ISLAND
Strait of Georgia
Howe Sound
Vancouver
Fraser River
Canada
USA
Saanich Inlet
Victoria
Skagit R.
200m
200
100
50
FD-06
FD-01
FD-05
FD-46
FD-41
FD-26
FD-21
FD-16
FD-11
1.0
1.5
2
3
2 km
N. Arm Jetty
IONA Outfall
Sturgeon Bank
Sediment Cores
Surface Grabs

Figure 10

TABLE 5

Metal fluxes and residence times

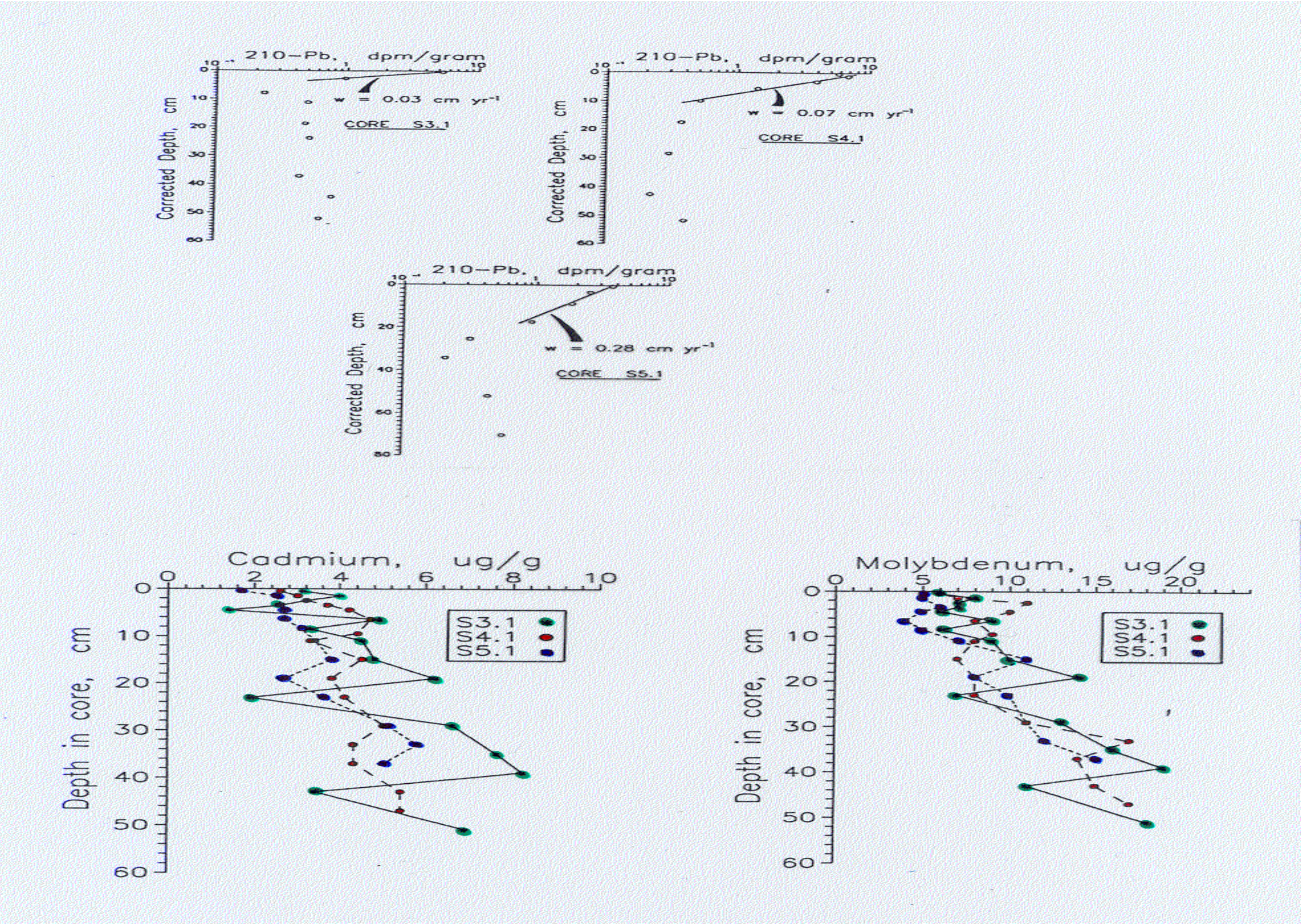
Element	Flux ($\mu g\ cm^{-2}\ year^{-1}$)					Seawater[a] concn. ($ng\ kg^{-1}$)	Water column residence time
	JV-7	BC-1	BC-2	Bal-2	Bal-4		
Pb (natural)	1.8 ± 0.3	9 ± 2	3.6 ± 0.8	4.2 ± 0.6	4.7 ± 0.6	1.1	3–4 days
Pb (cultural)	2 ± 0.4	9 ± 2	3.8 ± 0.9	5.9 ± 1.3	6.9 ± 1.4	20–35	40–130 days
Cu (natural)	7 ± 2	40 ± 6	13 ± 3	15 ± 2	15 ± 1	500–600	0.5–1.7 years
Cu (cultural)	3 ± 2		4 ± 2	5 ± 2	7 ± 2		
Zn (natural)	18 ± 2	90 ± 10	33 ± 6	45 ± 6	47 ± 4	600	0.2–0.7 years
Zn (cultural)	9 ± 3		15 ± 6	15 ± 4	47 ± 8		
Cd		0.2 ± 0.04	0.10 ± 0.02	0.10 ± 0.01	0.10 ± 0.01	70–80	10–40 years

Error terms for the cores are ±95% CI estimated from propagation of error formulae. Natural concentrations were assigned from values deep in the core; for BC-1, background was not reached so values were estimated. Cultural inputs were estimated by subtracting natural concentrations from the highest concentrations near the top of the core.

[a]Waldichuk (1983).

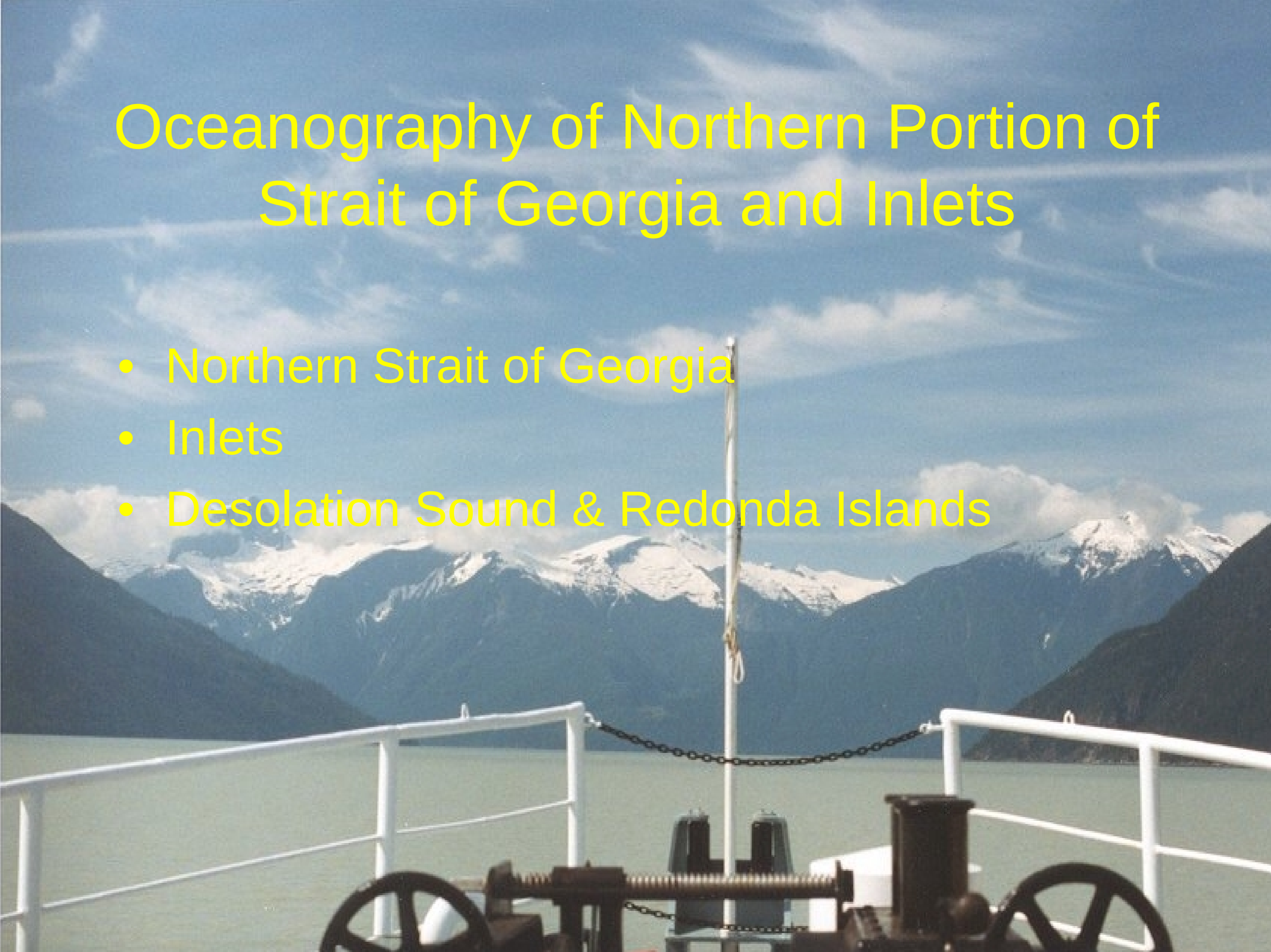
MACDONALD et al 1991

Figure 11


210-Pb, dpm/gram
Corrected Depth, cm
w = 0.03 cm yr⁻¹
CORE S3.1
210-Pb, dpm/gram
Corrected Depth, cm
w = 0.07 cm yr⁻¹
CORE S4.1
210-Pb, dpm/gram
Corrected Depth, cm
w = 0.28 cm yr⁻¹
CORE S5.1
Cadmium, ug/g
Depth in core, cm
S3.1
S4.1
S5.1
Molybdenum, ug/g
Depth in core, cm
S3.1
S4.1
S5.1

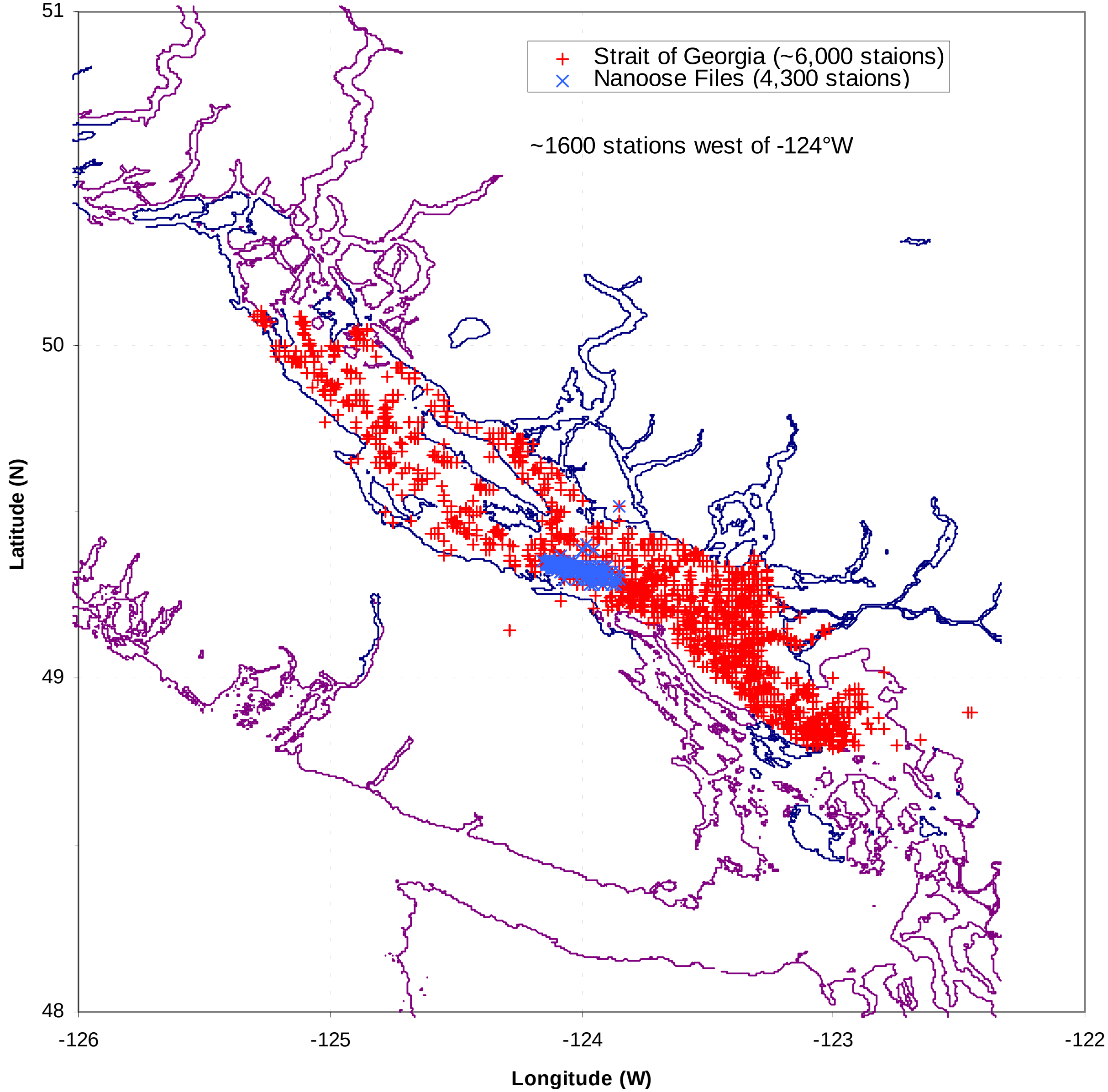
Oceanography of Northern Portion of Strait of Georgia and Inlets

- Northern Strait of Georgia
- Inlets
- Desolation Sound & Redonda Islands

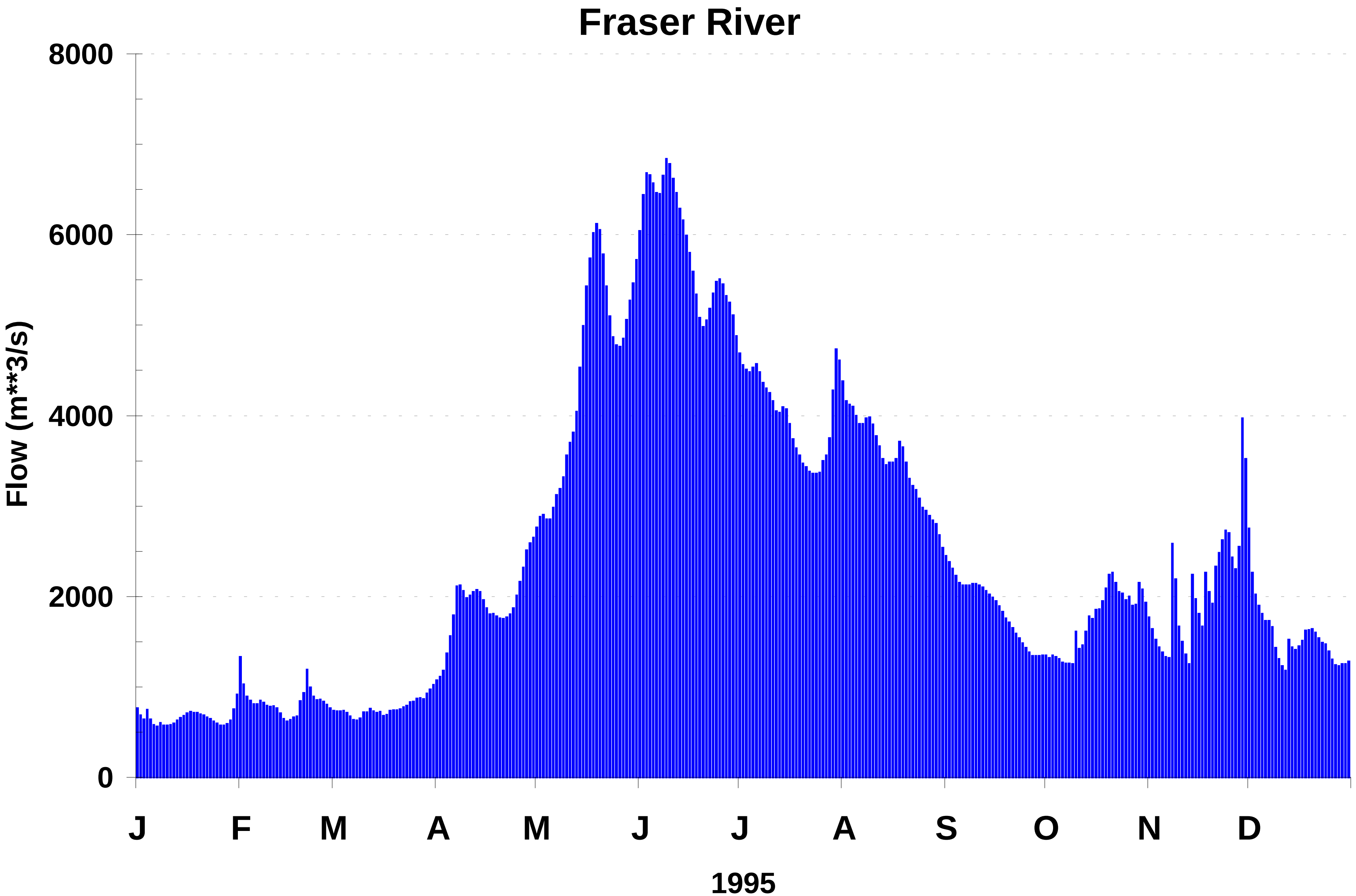


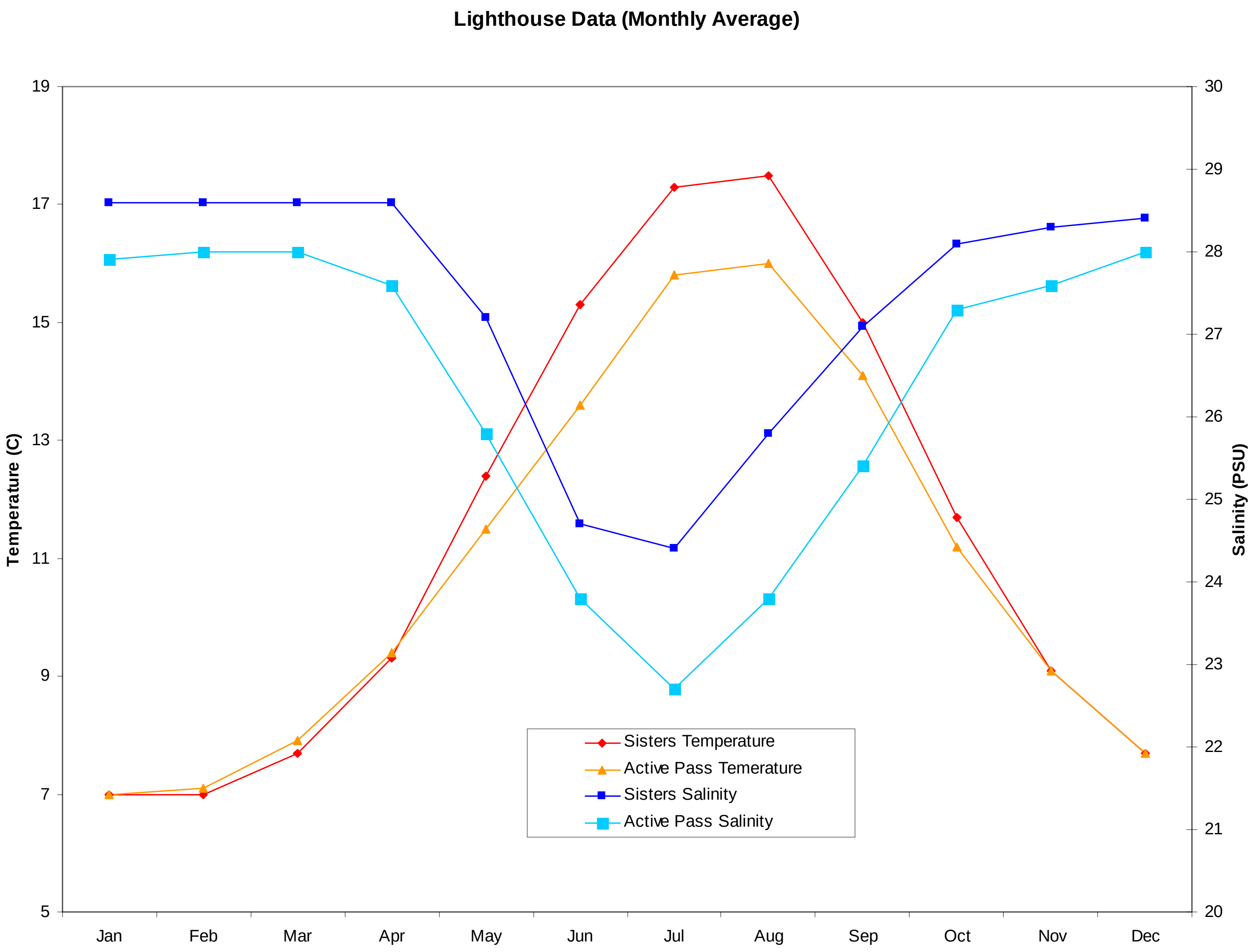
Physical Processes Forcing Circulation
&
Water Properties

- Tides
  - neap - spring variation
  - mainly semi-diurnal
- Freshwater
  - highly seasonal (Fraser River)
- Mixing
- Winds
  - sea breeze (diurnal)
  - winter outflows
  - storm
- Insolation
- Offshore or external forcing (e.g. upwelling)

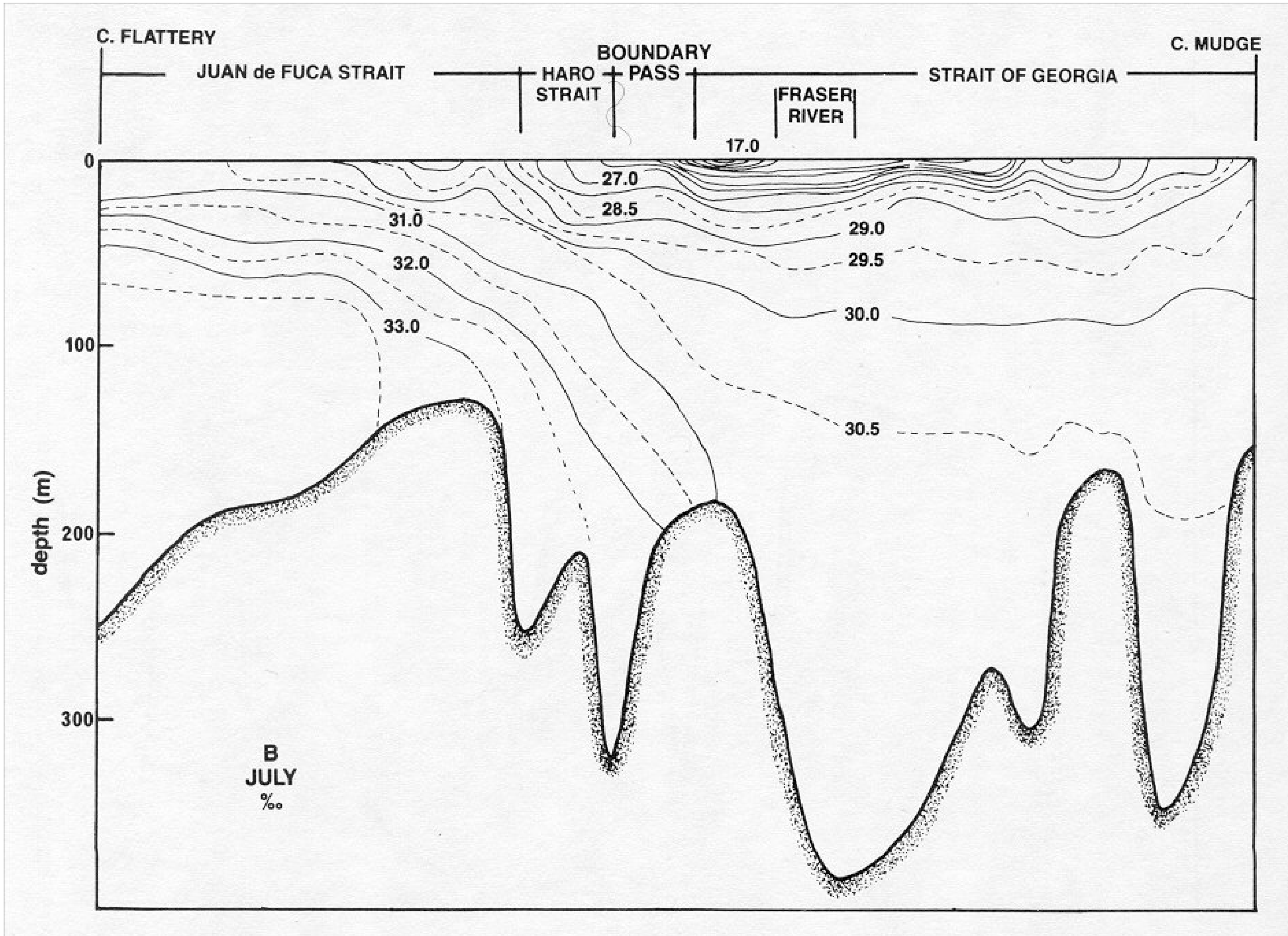


Strait of Georgia (~6,000 staions)
Nanoose Files (4,300 staions)
~1600 stations west of -124°W
Latitude (N)
Longitude (W)
51
50
49
48
-126
-125
-124
-123
-122

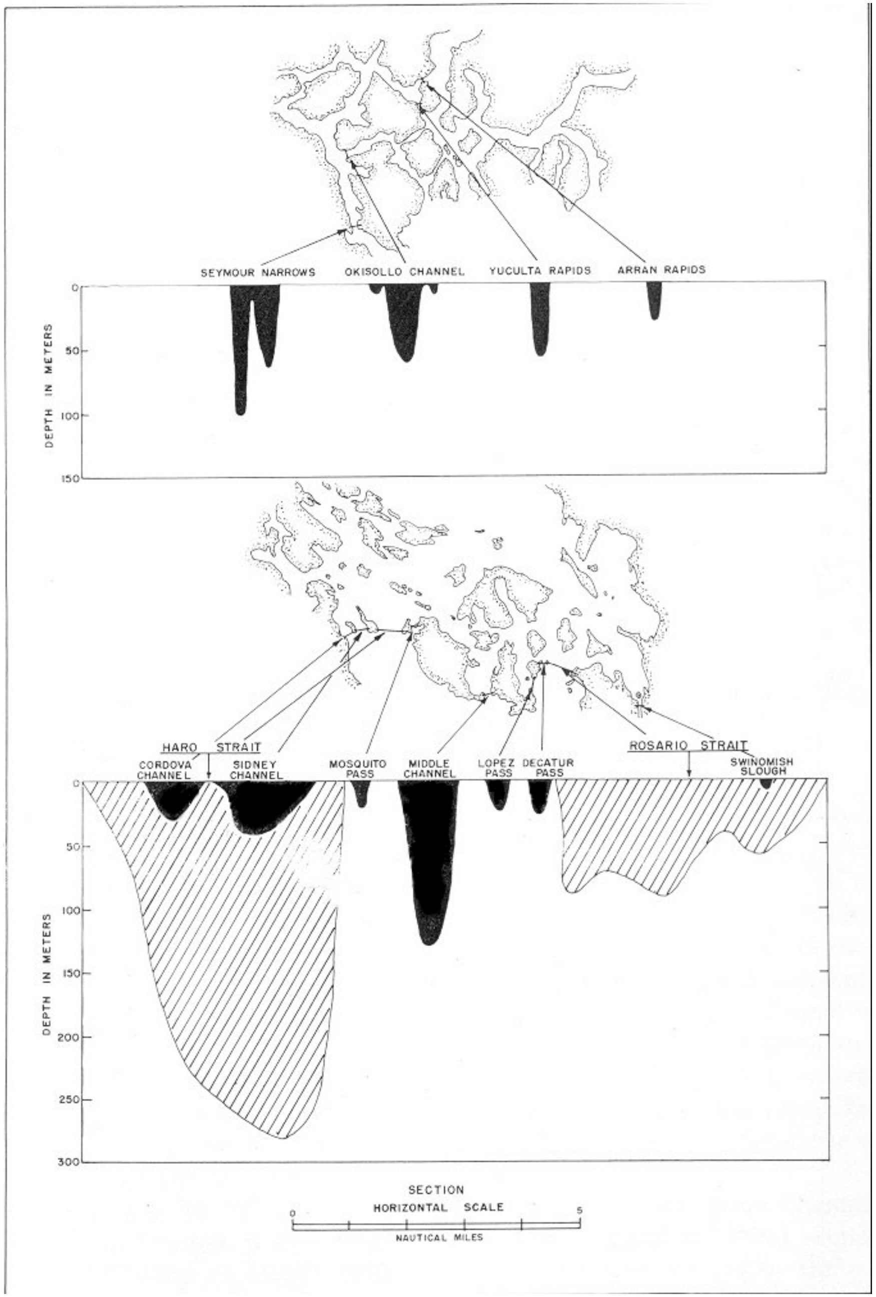

Fraser River
8000
6000
4000
2000
0
Flow (m**3/s)
J
F
M
A
M
J
J
A
S
O
N
D
1995


Lighthouse Data (Monthly Average)
Temperature (C)
Salinity (PSU)
19
17
15
13
11
9
7
5
30
29
28
27
26
25
24
23
22
21
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Sisters Temperature
Active Pass Temerature
Sisters Salinity
Active Pass Salinity

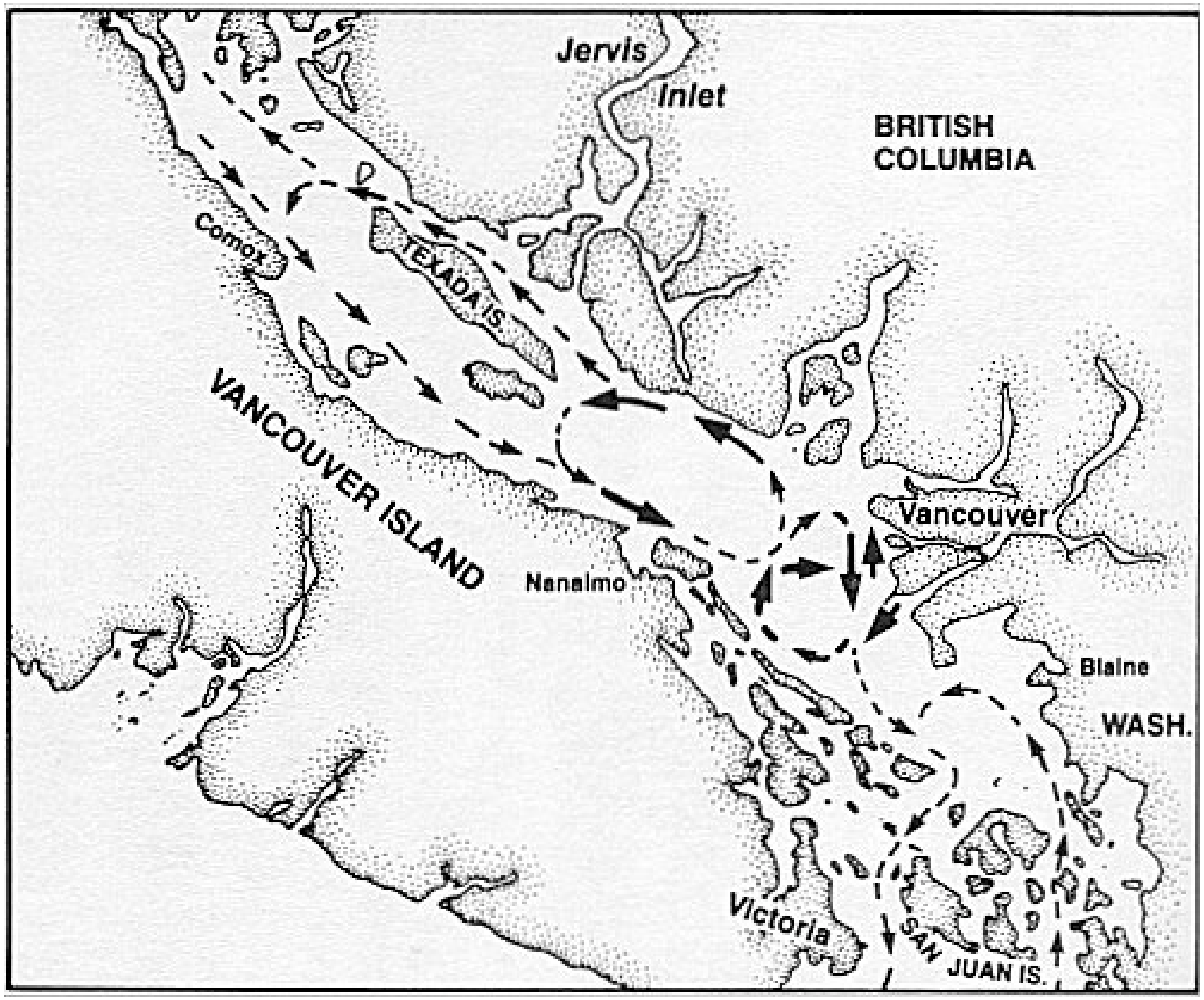
Salinity Section



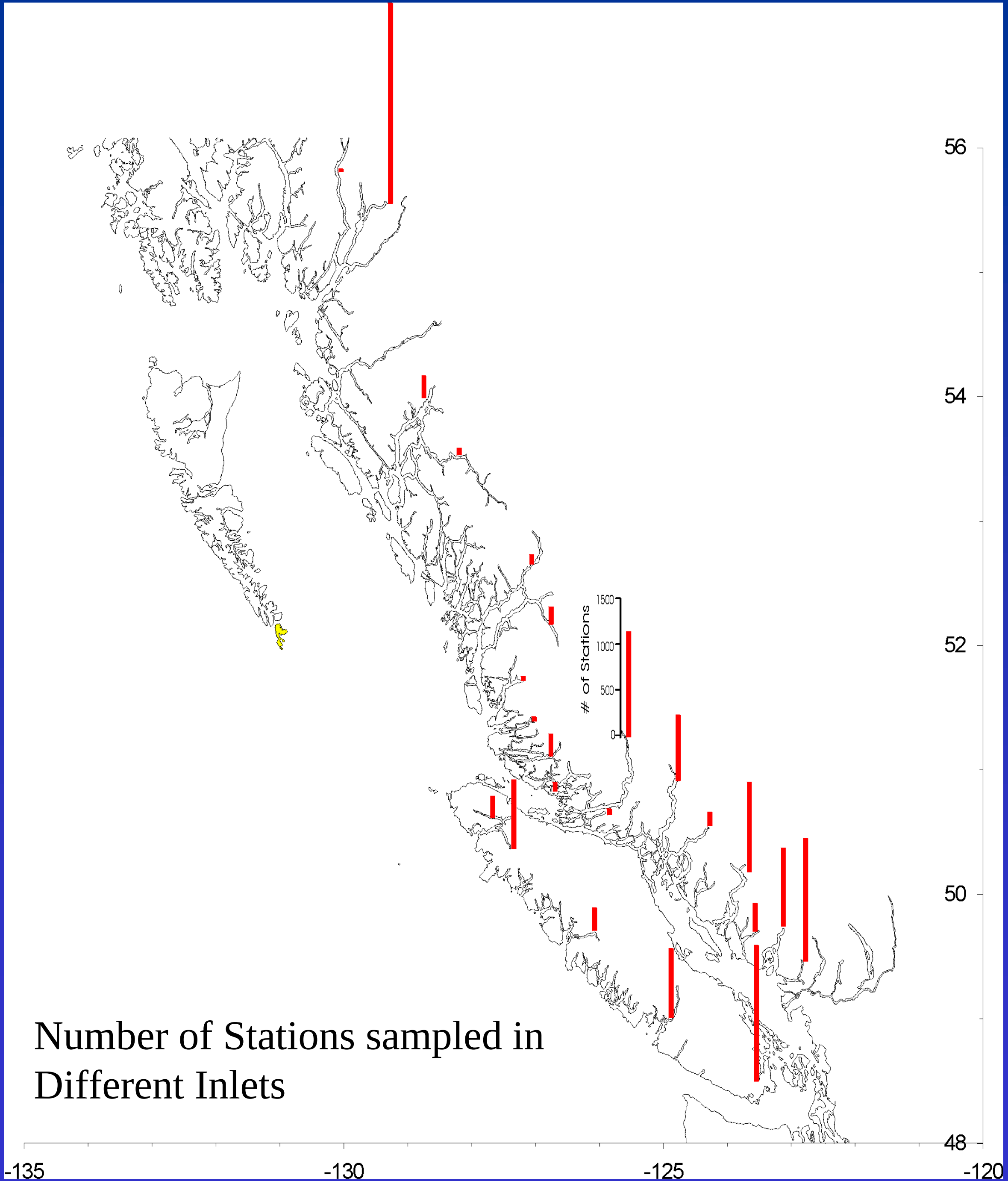
Crean and Ages (1971)



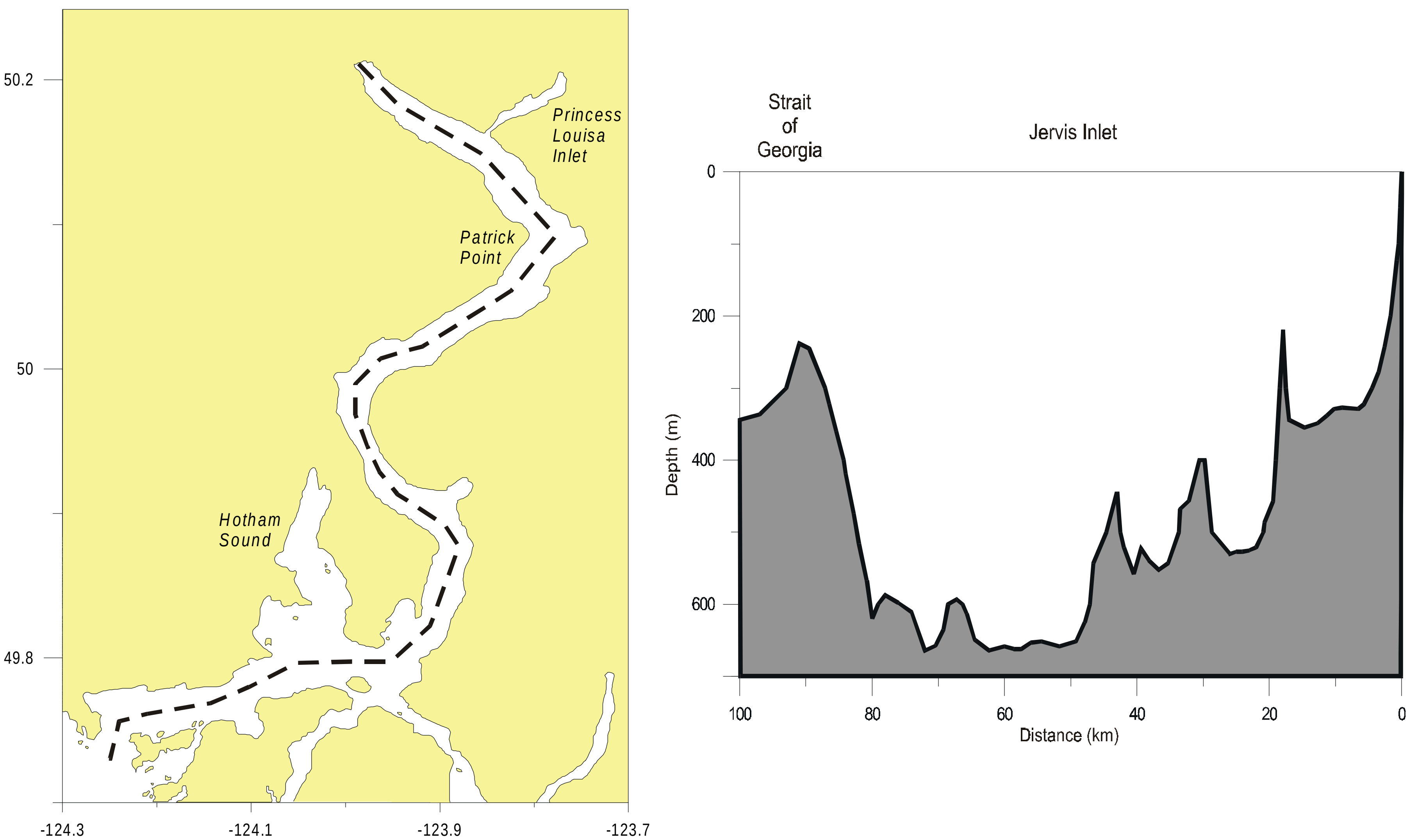
Waldichuk (1957)



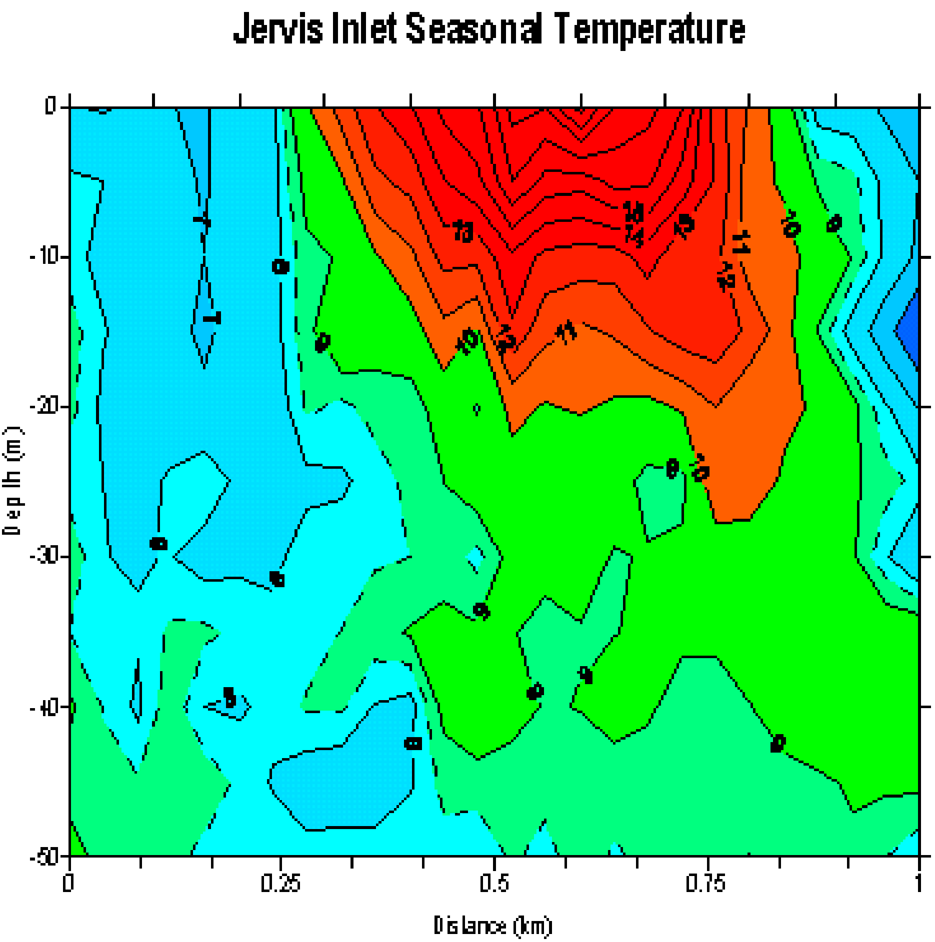
Thomson (1981)

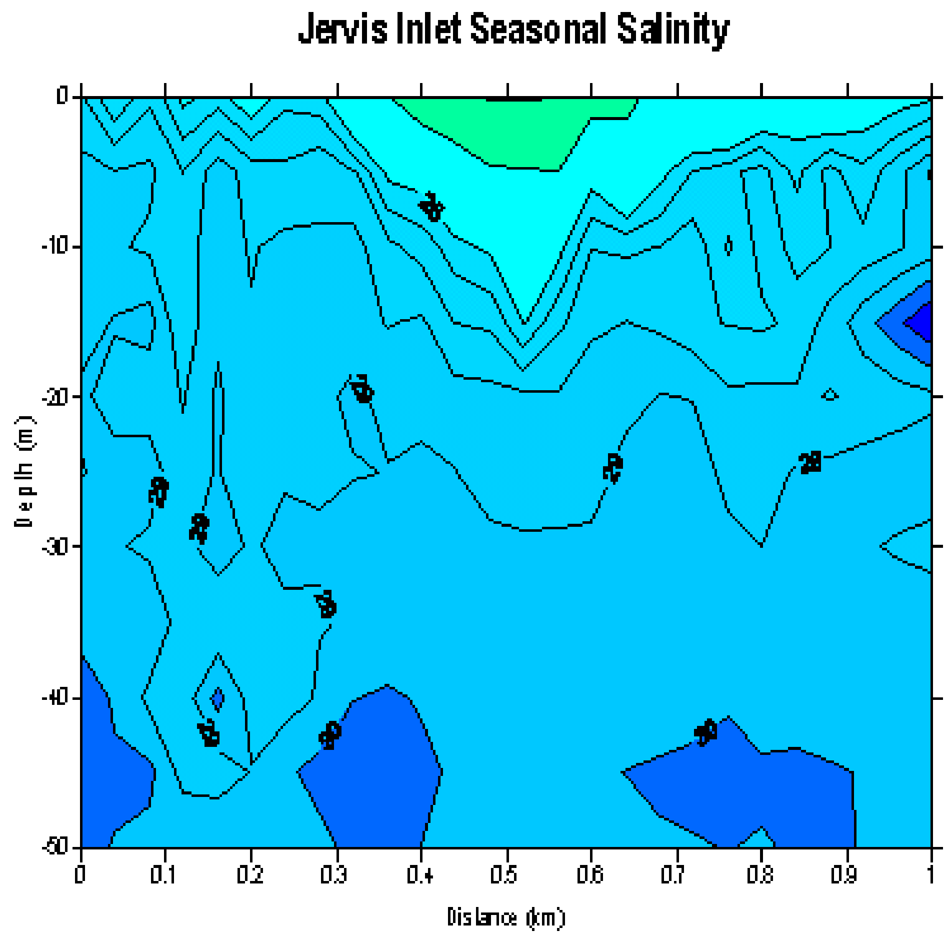


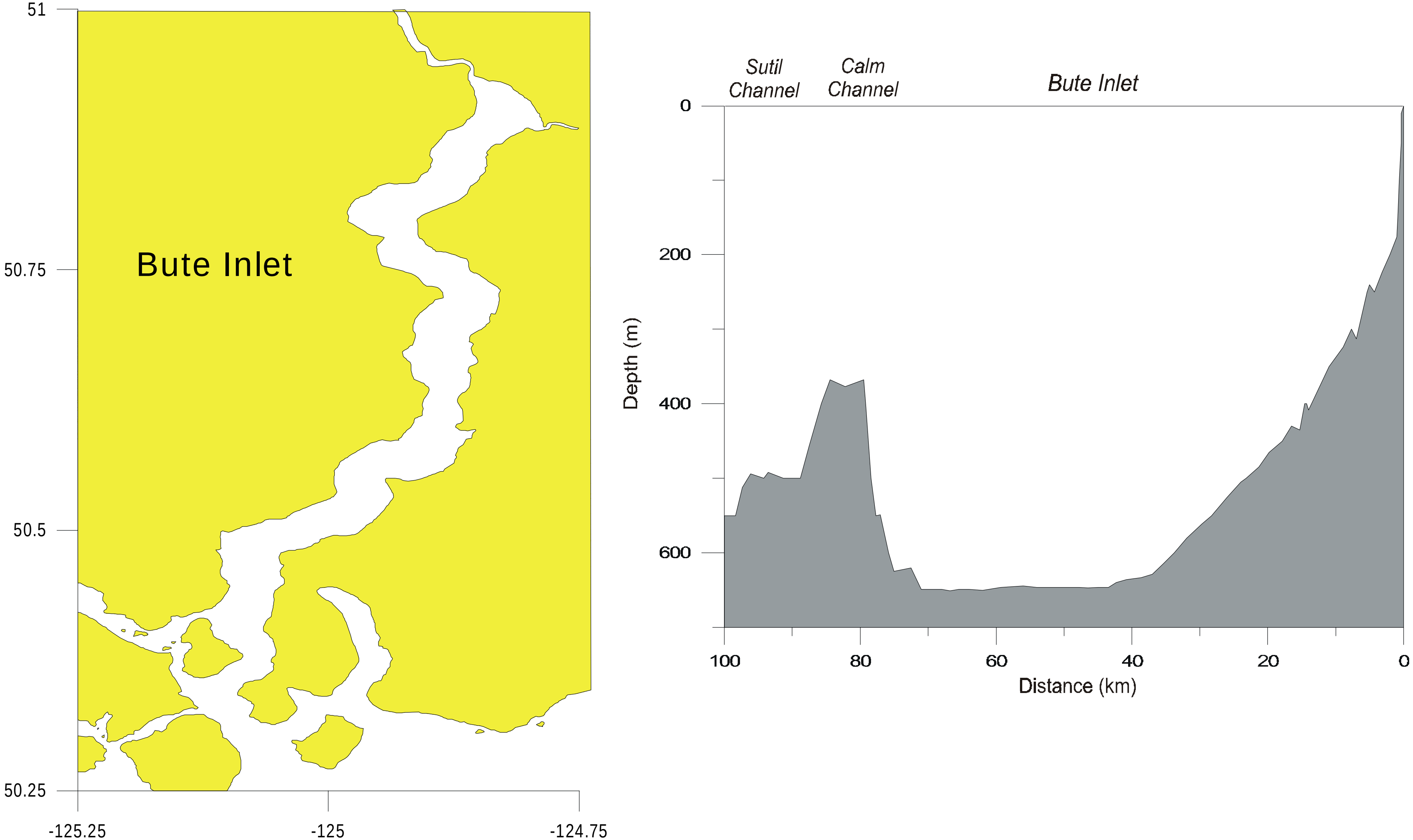
Number of Stations sampled in Different Inlets



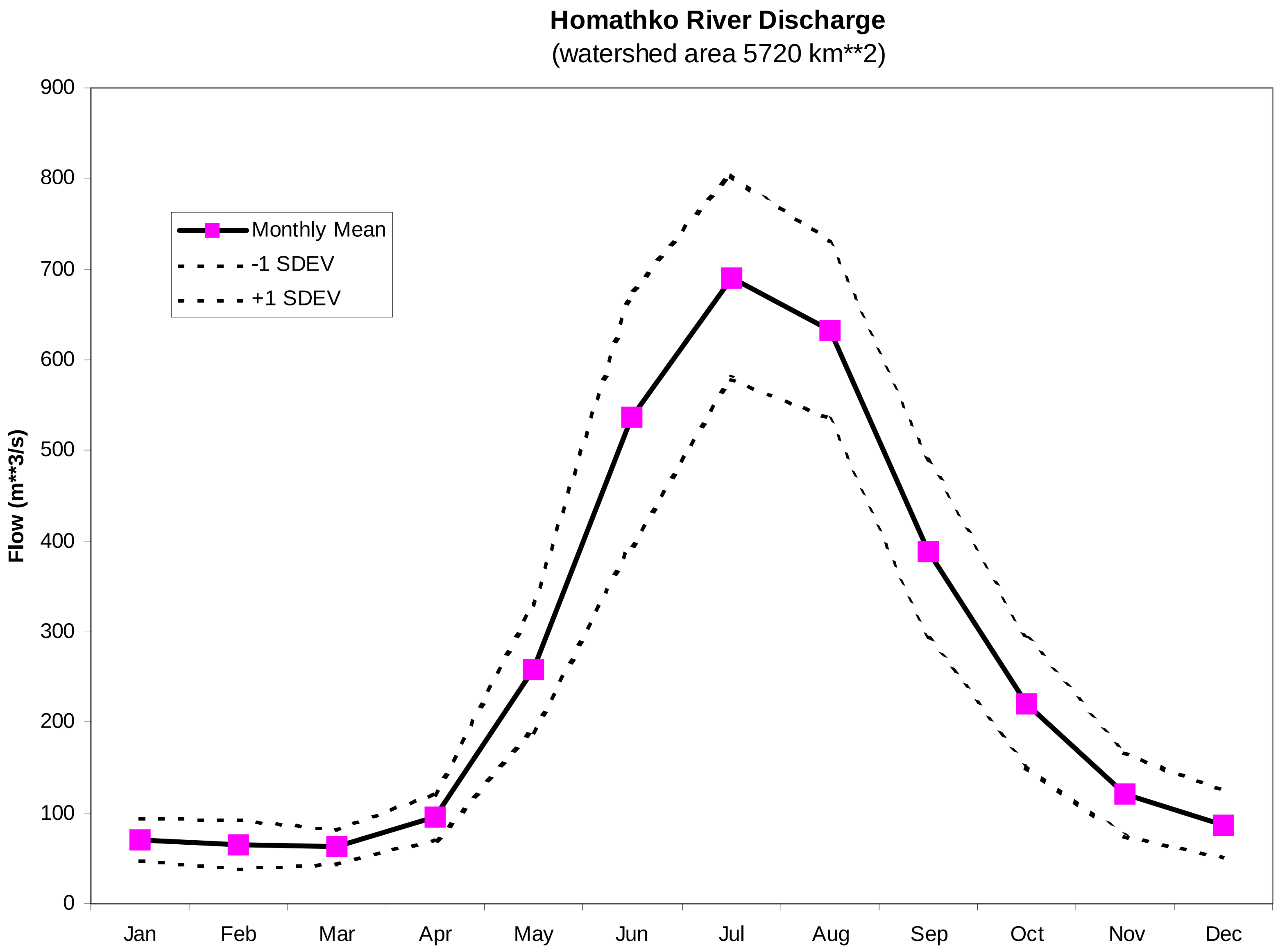
50.2
50
49.8
-124.3
-124.1
-123.9
-123.7
Princess
Louisa
Inlet
Patrick
Point
Hotham
Sound
Strait
of
Georgia
Jervis Inlet
0
200
400
600
Depth (m)
100
80
60
40
20
0
Distance (km)


Jervis Inlet Seasonal Temperature
Depth (m)
Distance (km)
0
-10
-20
-30
-40
-50
0
0.25
0.5
0.75
1


Jervis Inlet Seasonal Salinity
Depth (m)
Distance (km)
0
-10
-20
-30
-40
-50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

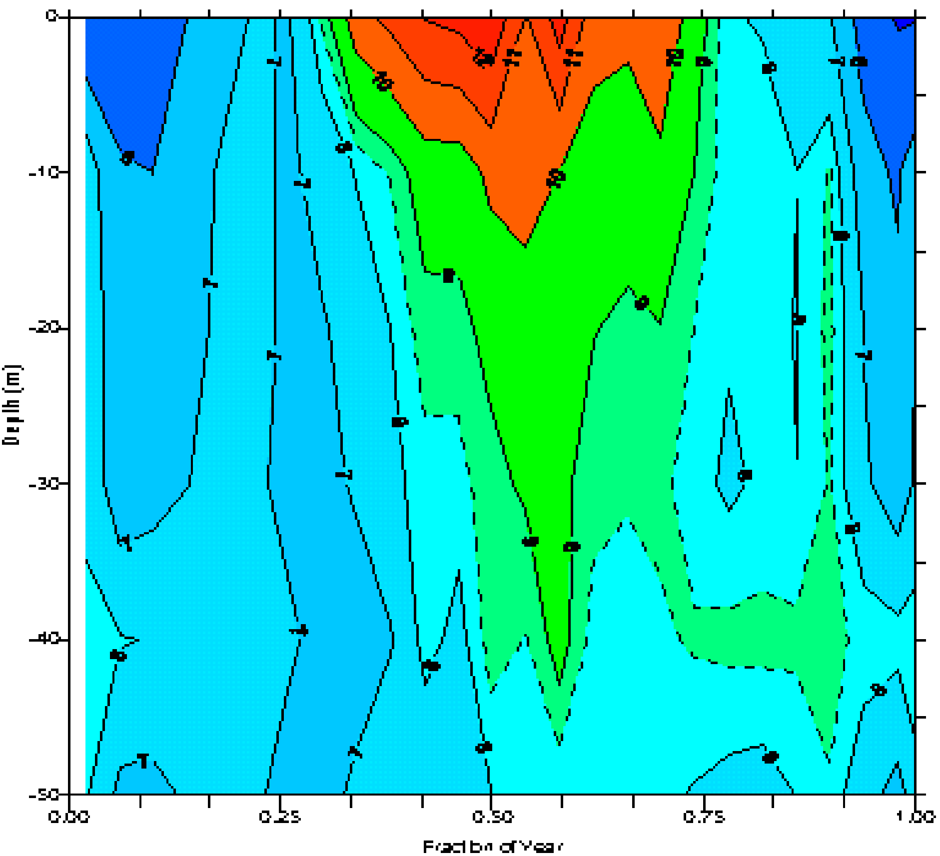


51
50.75
50.5
50.25
-125.25
-125
-124.75
Bute Inlet
Sutil Channel
Calm Channel
Bute Inlet
0
200
400
600
Depth (m)
100
80
60
40
20
0
Distance (km)

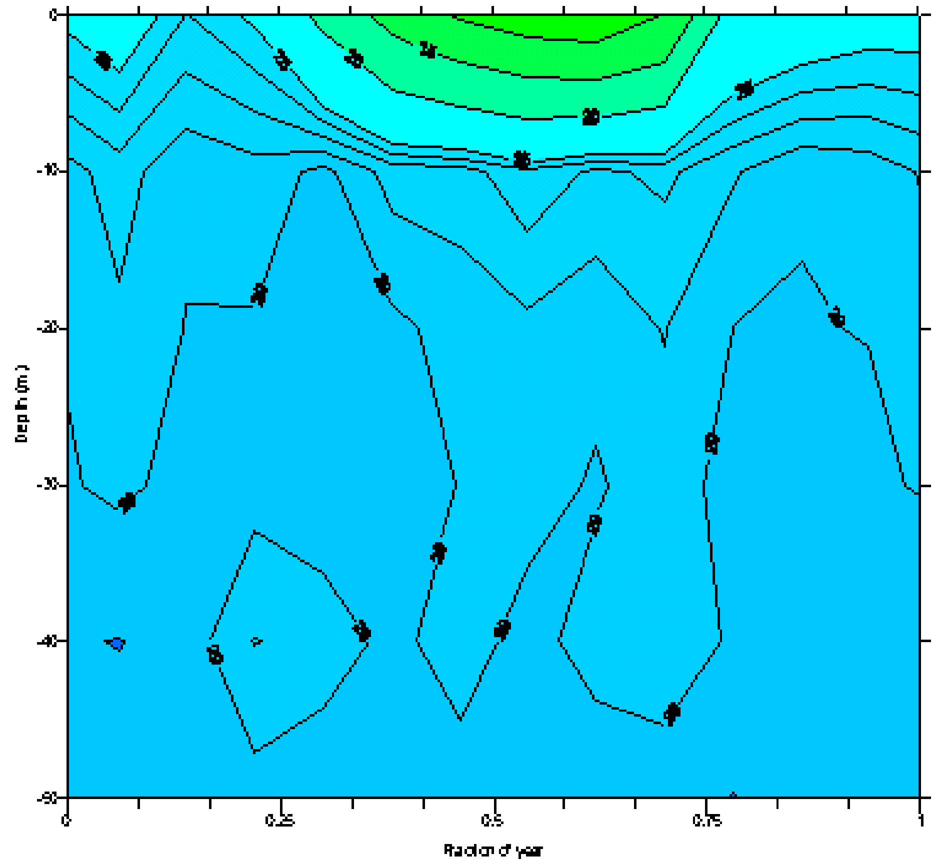


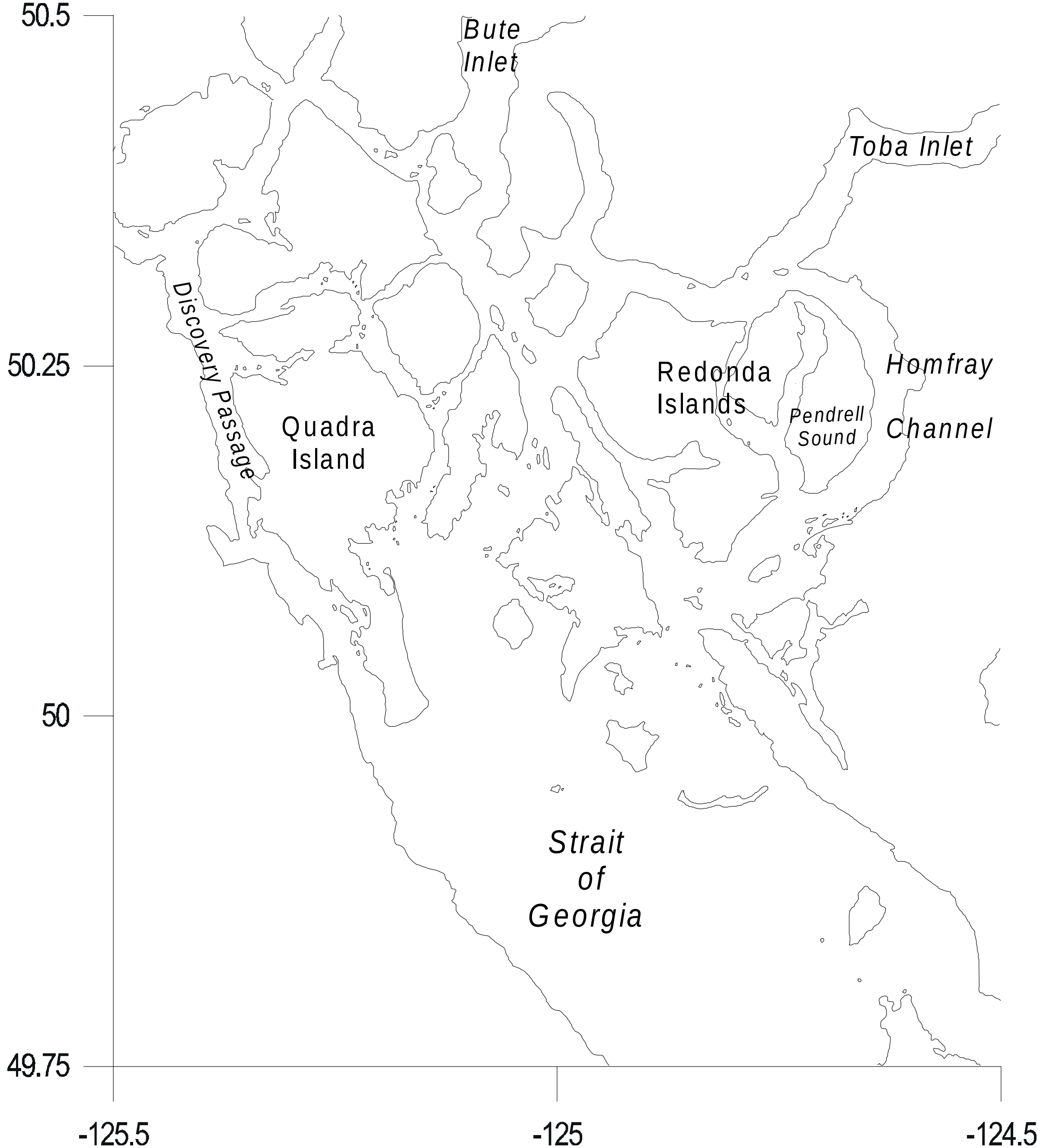
Homathko River Discharge
(watershed area 5720 km**2)
Monthly Mean
-1 SDEV
+1 SDEV
Flow (m**3/s)
0
100
200
300
400
500
600
700
800
900
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Bute Inlet Seasonal Temperature



Bute Inlet Seasonal Salinity



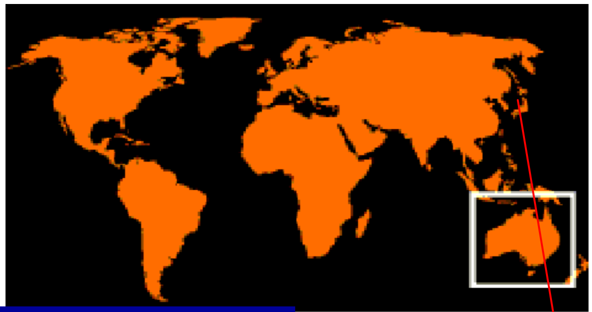


50.5
50.25
50
49.75
-125.5
-125
-124.5
Bute Inlet
Toba Inlet
Discovery Passage
Quadra Island
Redonda Islands
Pendrell Sound
Homfray Channel
Strait of Georgia

Cd in Pacific oysters

- Cd in Pacific oysters in Australia
- Selective breeding of Pacific oysters
- Cd in Pacific oysters in BC: a hypothesis

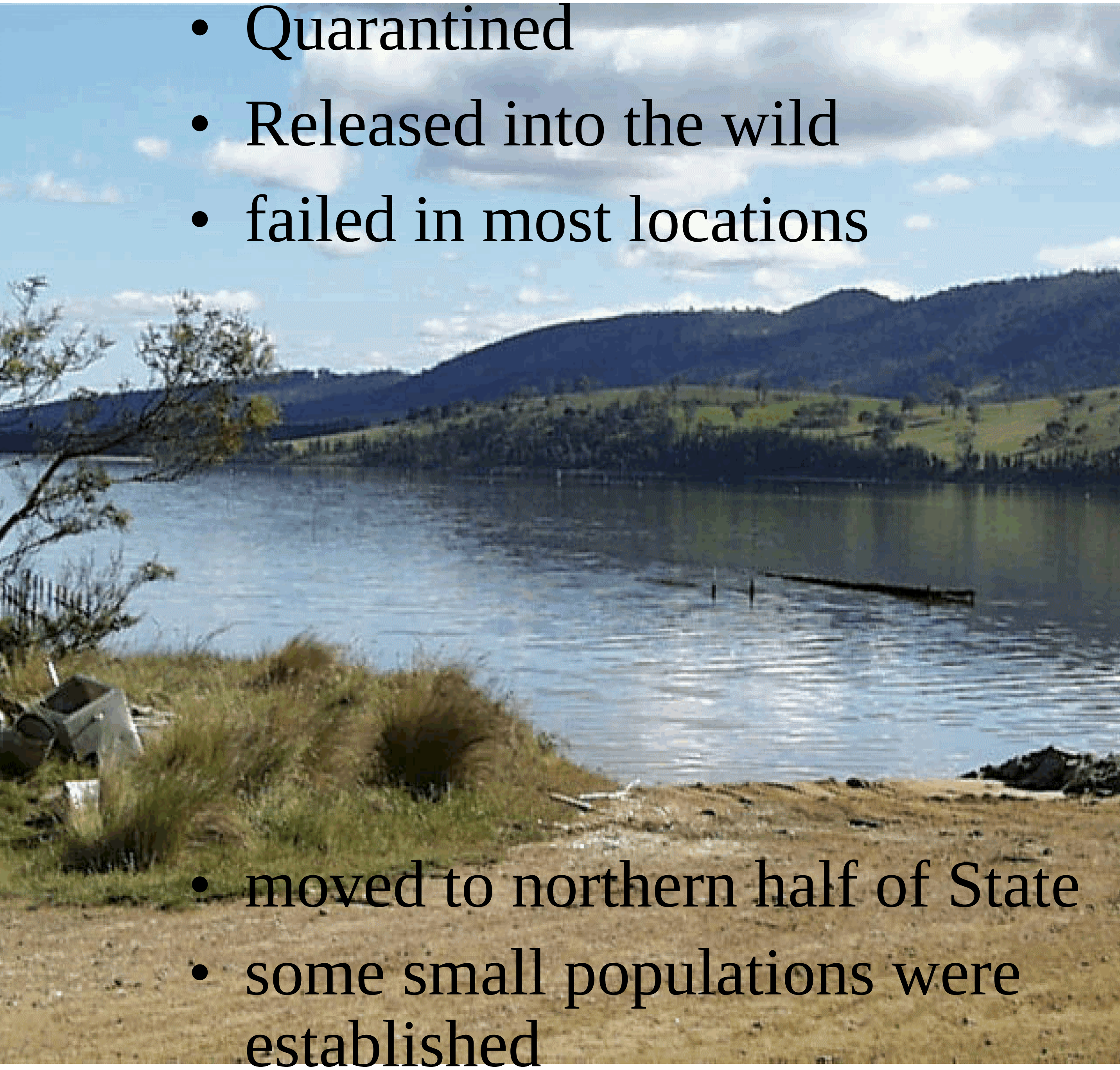
Picture by
W. Heath



Pacific oysters from Japan 1948-1952

Now farmed in two States

Pacific Oysters in Tasmania

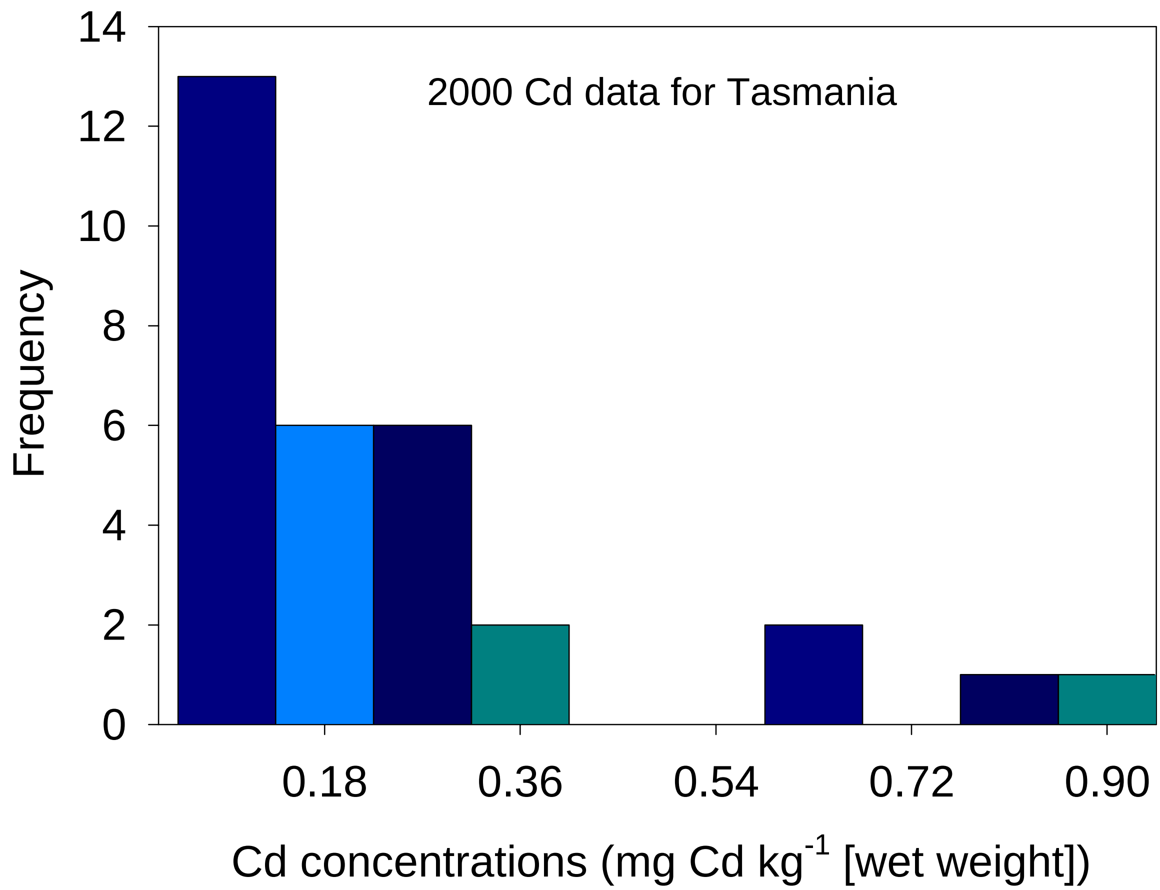


- Quarantined
- Released into the wild
- failed in most locations
- moved to northern half of State
- some small populations were established
- not very successful

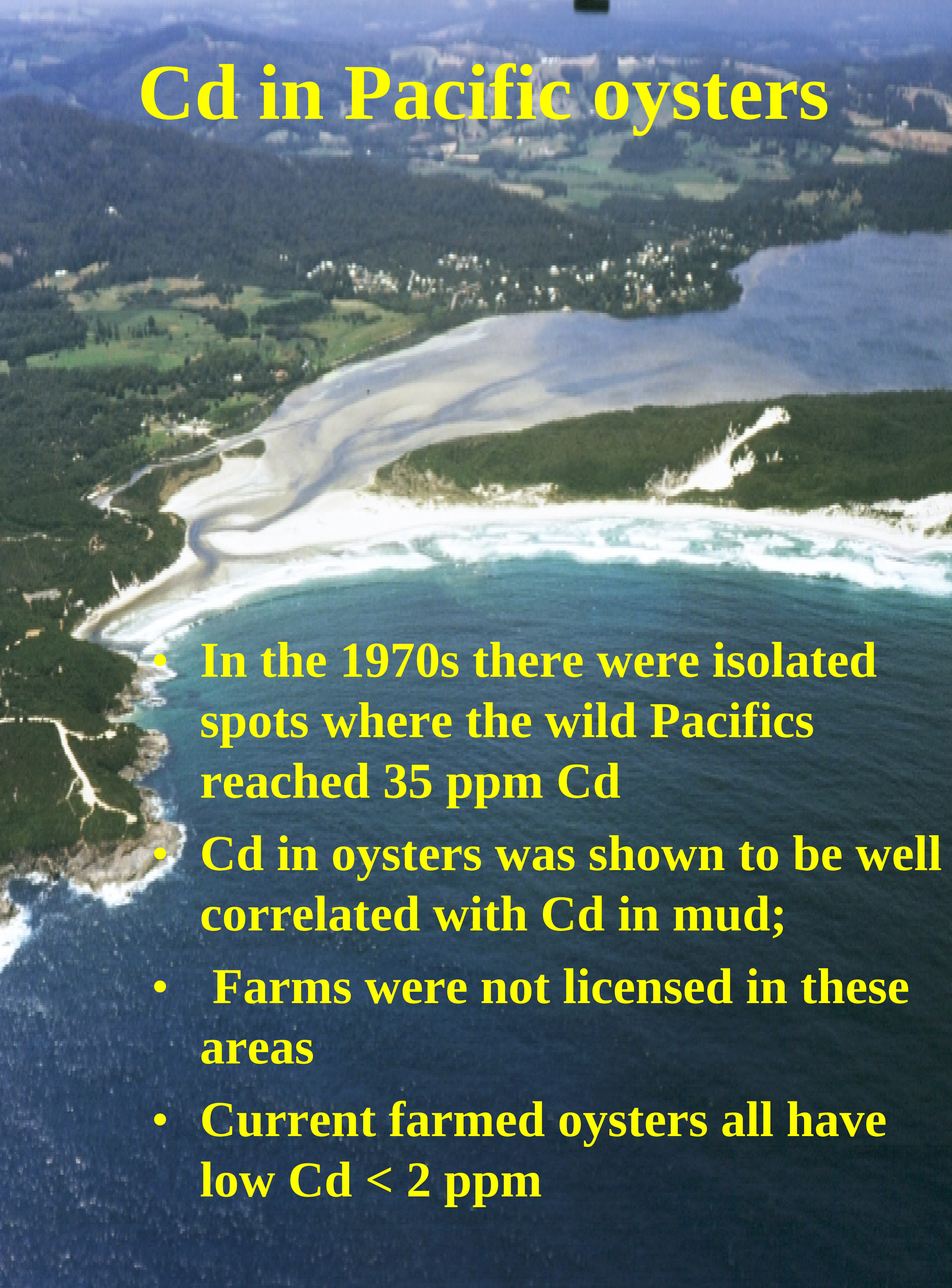
Cd in Pacific Oysters in Australia

- 1970's localized spots
  - high levels of many metals including, up to 35 ppm Cd (ww)
- Cd in oysters was highly variable
- Cd in oysters related to Cd concentrations in sediments
  - 1 ppm in mud = 4-5 ppm (ww) in oysters
- total Cd in oyster was well correlated with age & size (concentration was constant)
- 100 hours of depuration did not have any impact on Cd (dw) in oysters
- not much seasonality in Australia

Recent survey data

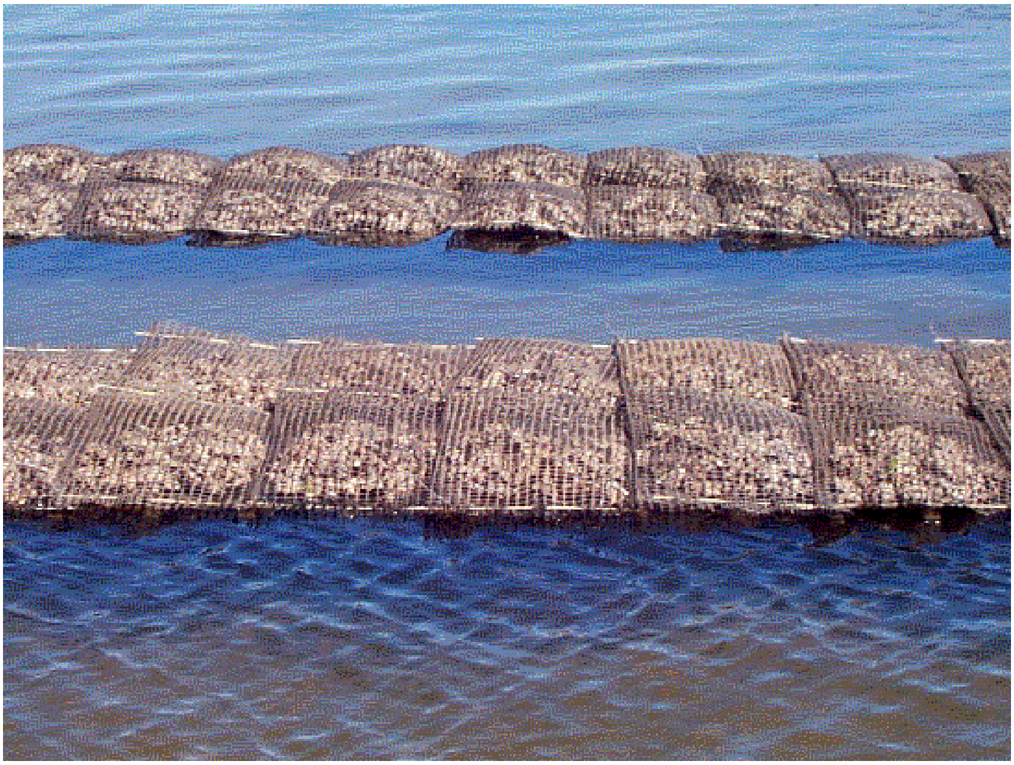


Cd in Pacific oysters



- In the 1970s there were isolated spots where the wild Pacifics reached 35 ppm Cd
- Cd in oysters was shown to be well correlated with Cd in mud;
- Farms were not licensed in these areas
- Current farmed oysters all have low Cd < 2 ppm

The current Pacific Oyster Industry in Australia



- Grown as farmed single-seed oysters
    - restaurant trade - half shell
- ~ $25 million per annum
- Full hatchery production
    - good for genetic manipulation
- limited genetic diversity?

Selective Breeding of Pacific Oysters

Peter Thompson, Tasmanian Aquaculture and Fisheries Institute, CSIRO, FRDC, $1.3 million

PhD students

Toxic algae: dinoflagellates - Naomi Parker

Toxic algae: bluegreens - Malcolm McCausland

Nutrition of Crayfish larvae - Michel Bermudes & Greg Smith

Triploidy in Sidney rock oysters - Rosalind Hand

Modeling growth in Brazilian mussels - Felipe Suplicy

Project Overview

•Produce lines in commercial hatchery (fed *I. galbana*, *P. lutheri*, *T. pseudonana* , all > 5 microns)

•TAFI supplies the nursery to > 1.8 mm

- Commercial scale: 44 families and 6000 oysters in each family
- Managed similarly to commercial stocks
- 5 farms around 2 states

Genetics work

Markers, for each chromosome

- Allozymes
- DNA
  - microsatellites
  - AFLPs

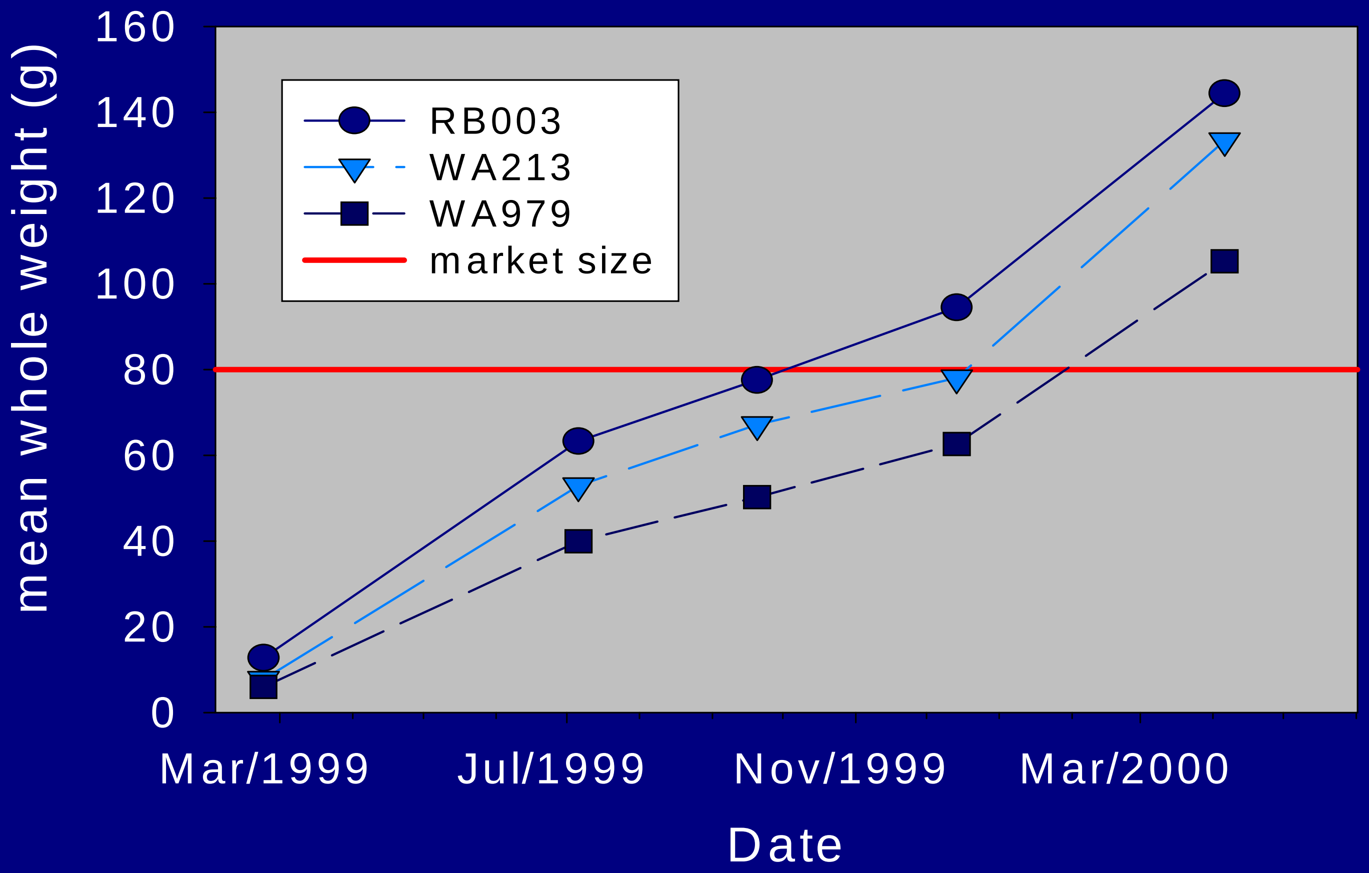
Linkage map

- Positions of genetic markers
- QTL (quantitative trait loci) plus other trait loci for several characteristics, fast growth

Results

Better families grow faster on all sites

From nursery phase to market 8-9 months



Two colour morphs within one family

Both golden and normal where produce d at classic ratios (3:1)

goldens were slower growing

Frilly shell

one dark

one light
valve

Frilly shell

two light
coloured
valves

Smooth
shell

one dark
one light
coloured
valve

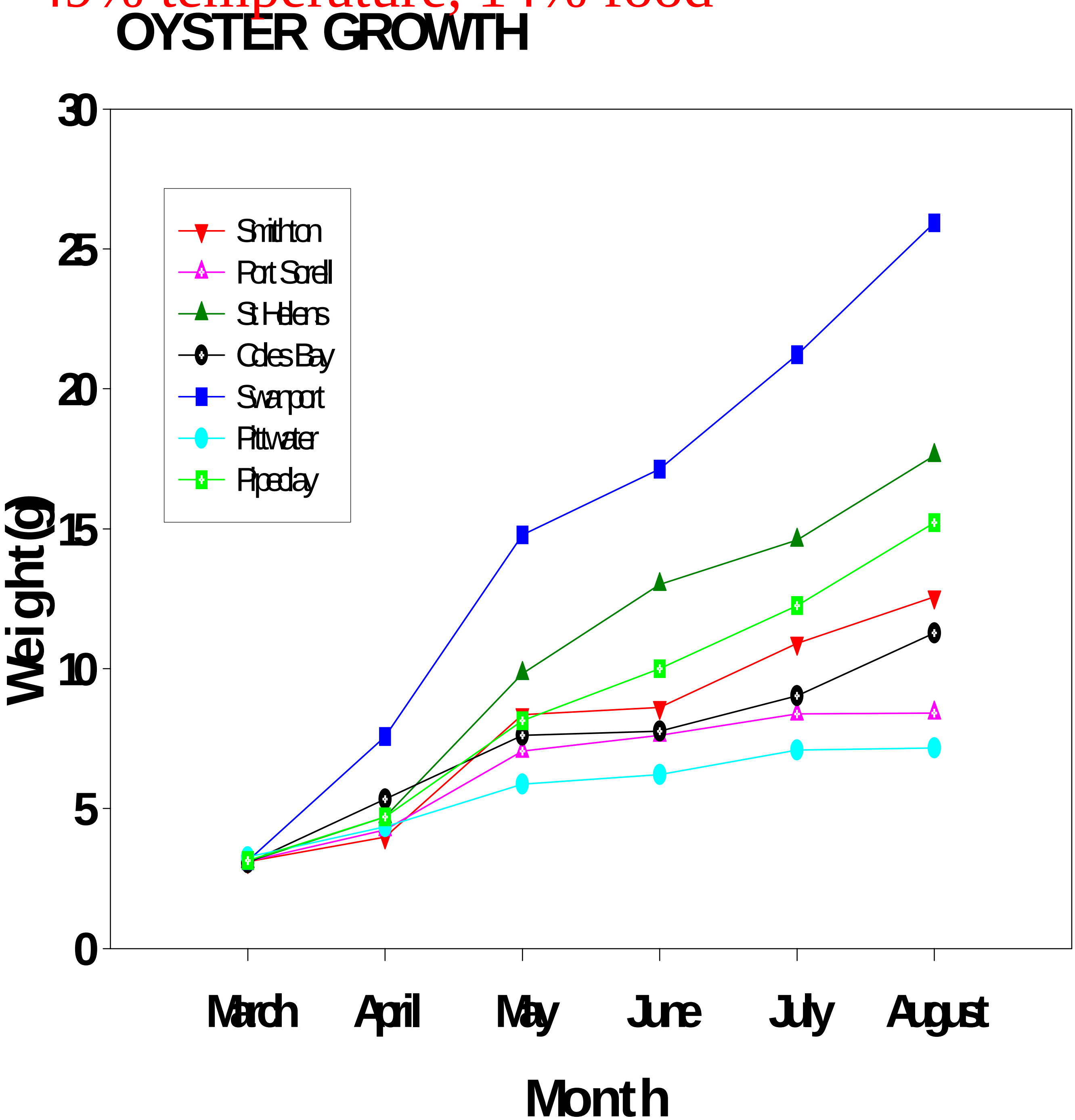
Specific shell morphologies

- Improved understanding of the genetic basis for this trait
- lines free from this defect

- Top
  - nice, deep cup
- Bottom
  - high degree of curl-back
  - undesirable trait
    - isolated
    - recessive
    - back cross

Site differences

- Same family but substantial differences between sites
- minimum 100% overwinter growth, maximum 700%
- 49% temperature, 14% food

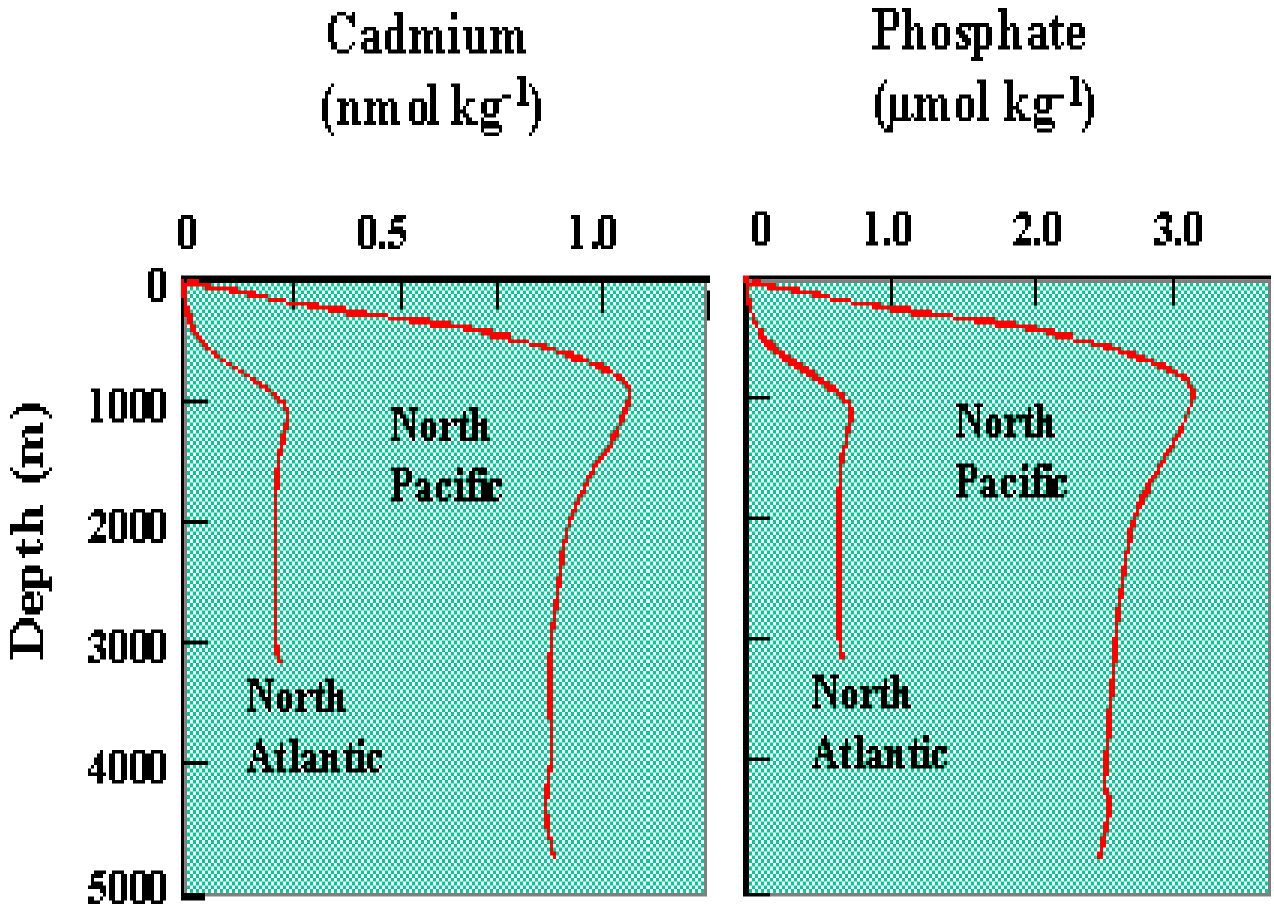


Conclusions: Selective Breeding

- Mass selected oysters grew 8% faster in generation 1 and 12% faster in generation 2.

- 96 Families with many individual traits from shell colour and morphologies to faster growth

Cd in BC waters acts like a nutrient



Data from Bruland, 1983

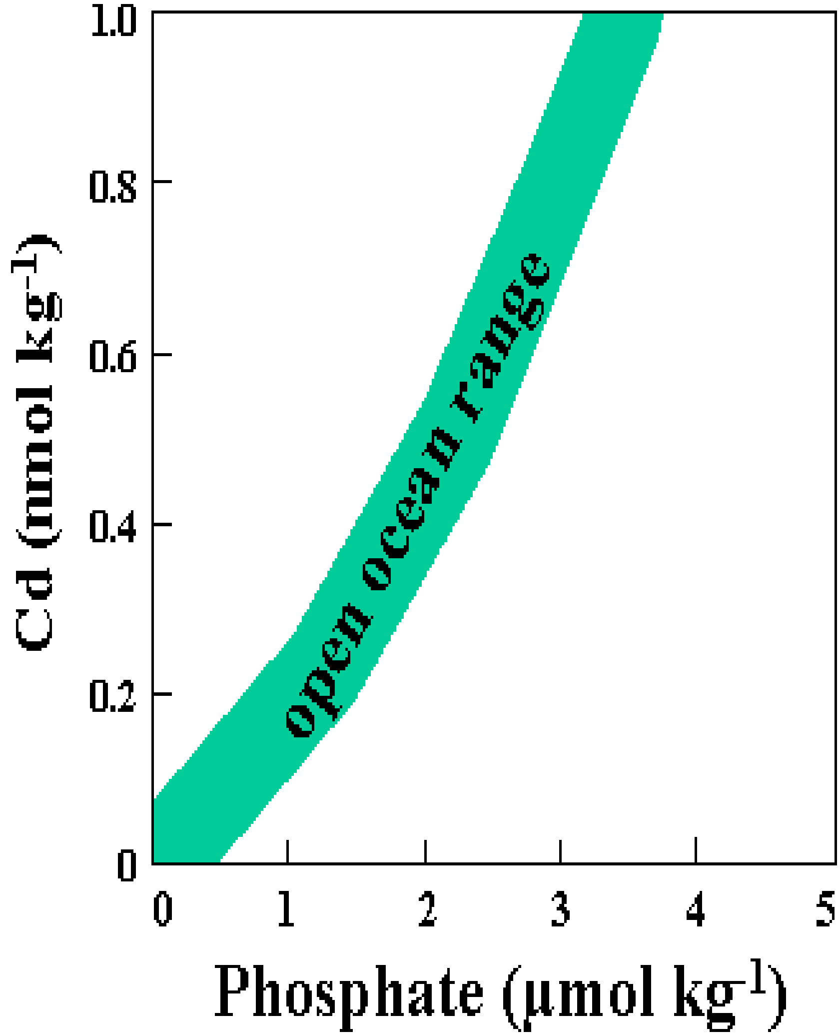
Difference between Atlantic and Pacific (P recycling faster than Cd?)

Nutrients and phytoplankton (upwelled water) Molar ratio C:N:P 106:16:1

CN:P:Cd = 318000:48000:3000:1 (see next)

Cd:phosphate ratios

(no terrestrial inputs)



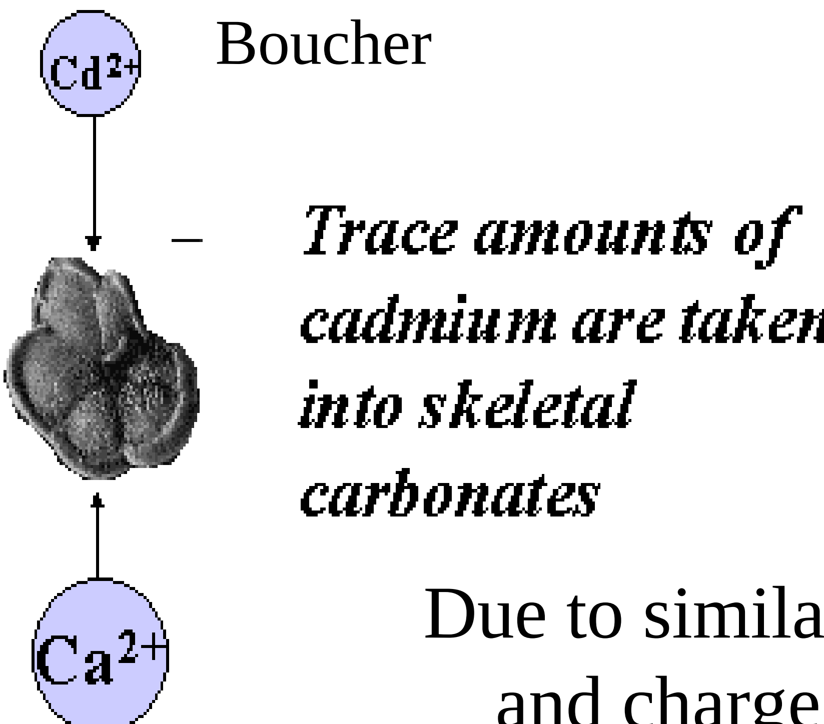
Weight ratios C:N:P:Cd = 33000:5900:850:1

assuming 2:1 dry weight:carbon ratio in phytoplankton (conservative)

Natural oyster food probably has 15 ppm Cd (dry weight)

Another possible route for Cd: with Ca

Author: J. Boucher



Due to similar size and charge Cd replaces Ca

- Foraminifera
- Coccolithophorids?

Coccolithophorids: including *E. huxleyi*

Phytoplankton are patchy in time and space

- **There should be local & regional differences, oysters will cause some integration over time and space**

Cd in BC phytoplankton

- Zn and Cd association in phytoplankton (Zn down, Cd up)
  - Lee & Morel 1995 (MEPS).
- Recent report of Cd in carbonic anhydrase (not a contaminant)
  - (Cullen et al. 1999, Nature)
  - off California

Conclusions: Cd in BC phytoplankton

- Cd in phytoplankton enzymes
- higher dissolved Cd = greater Cd in phyto
- Background Cd could be 15 ppm in phytoplankton
- Cd may be greater in coccolithophorids
- low [Zn] low [Mn] = high Cd
- interactions with growth rate

Conclusions:

- Cd in Australia: not consider to be a significant concern
  - monitored annually
  - less than 1 ppm
- **Cd in BC**
  - **2 ppm (ww) likely to be a natural phenomenon (complex)**
  - **expect it to be variable in time and space (good and bad years)**

Results of the 2000 Survey of Cadmium in B.C. Oysters.

Klaus Schallié,
Aquaculture & Molluscan Shellfish Specialist,
Canadian Food Inspection Agency

CFIA
ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Background

In December 1999 Hong Kong's Food and Environmental Hygiene Department reported that several shipments of oysters from British Columbia were found to have cadmium levels that exceeded their action level of 2 ppm (wet weight)

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Background

- CFIA staff reviewed historical data from the Environmental Contaminants Program
- Cadmium levels in approx. 39% of the samples of oysters and scallops exceeded 2ppm
- Other shellfish, < 2 ppm

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Background

Species	Mean	Range	n
SCALLOPS	2.21	0.11 - 7.76	10
OYSTERS *	1.86	0.5 - 6.0	20
MUSSELS, CALIFORNIA	0.72	0.6 - 2.0	3
SEA URCHIN ROE	0.60	0.09 - 0.86	9
GEODUCKS	0.21	0.01 - 0.9	9
CRAB, DUNGENESS	0.08	< 0.01 - 0.1	16
SHRIMP	0.06	0.02 - 0.13	11
SEA CUCUMBER	0.05	< 0.01 - 0.09	6
PRAWNS	0.03	< 0.01 - 0.05	16
CLAMS	0.02	0.01 - 0.07	40

* Data from 1993 to 1998, does not include results from special survey in 2000

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Background

- Environment Canada was contacted with a request for any data regarding cadmium in shellfish
- They provided results for oysters from their monitoring programs

CFIA
ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Background

- The EC analysis results were calculated as dry weight, crude conversion showed levels were consistent with CFIA data
- EC staff indicated that B. C. marine sediments are naturally high in cadmium

Background

- Cadmium analysis results were also obtained from CFIA on the Atlantic Coast
- Levels in oysters (*C. virginica*) ranged from 0.07 to 0.56 with a mean of 0.33 (n = 18)

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Actions Taken

When Hong Kong authorities provided us with their analysis results, CFIA informed the industry that we could no longer certify oysters for export to that market without analysis results showing Cd levels < 2ppm

CFIA ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Actions Taken

- Industry was advised that the CFIA Laboratory could do analysis for individual lots or for shellfish leases
- A few samples were submitted but all results were > 2ppm and no oyster shipments have been certified for export to HK

CFIA
ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Actions Taken

- CFIA contacted DFO Science Branch with a request for any data and information on cadmium levels in oysters
- A literature search and investigation was begun by IOS's Dr. George Kruzynski

CFIA ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Actions Taken

- CFIA, in cooperation with the shellfish industry, embarked on a survey of oysters
- Oysters were sampled from the major growing areas and also representing different sizes and culture methods

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

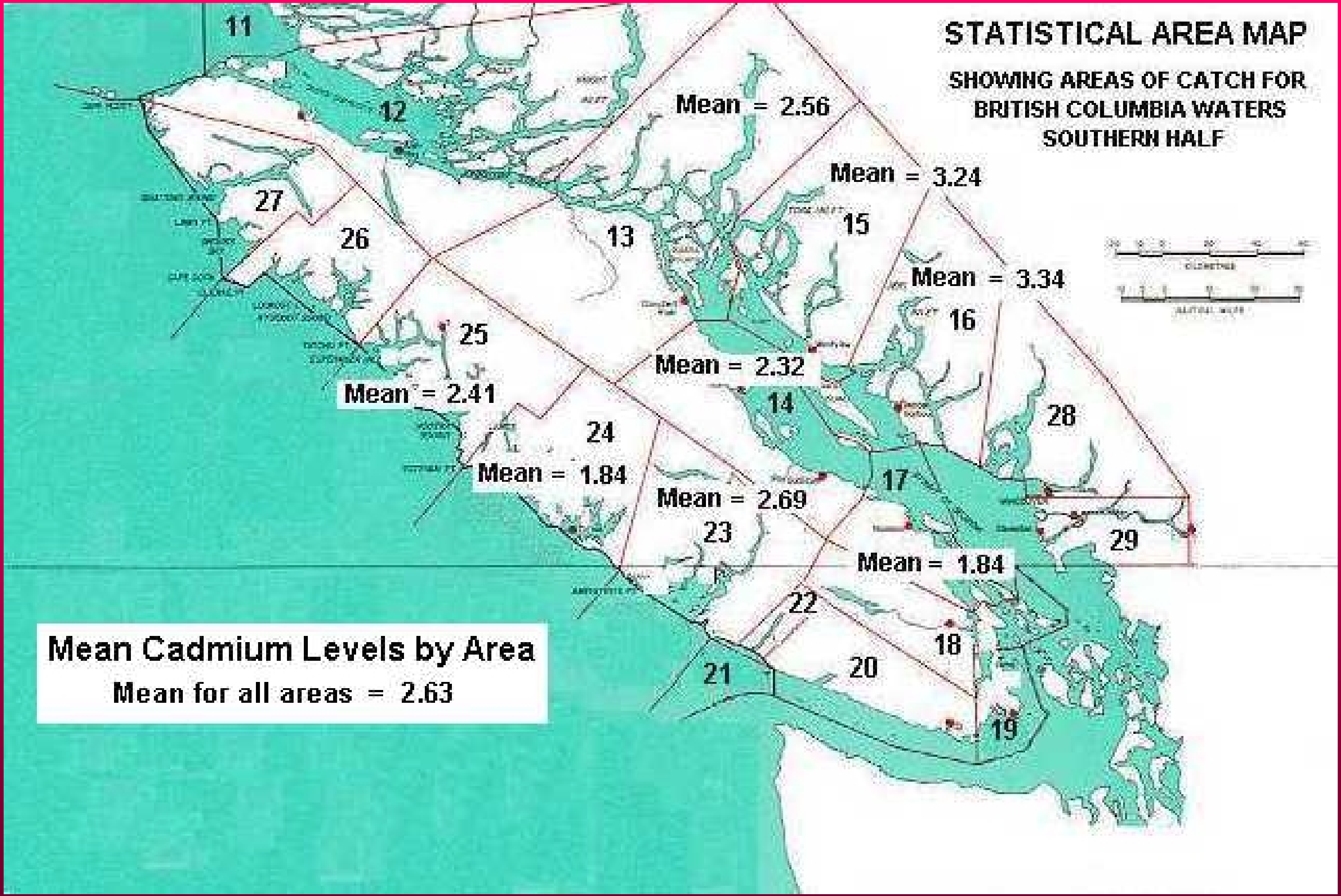
Survey Results

- More than 60% of our samples taken in 2000 had levels of cadmium over 2 ppm
- The mean for 81 samples was 2.63 ppm
- The major growing areas all had means over 2 ppm

Survey Results

- Only two areas show results that are consistently under 2 ppm
- These are the southern parts of DFO Statistical Areas 17 and 24

CFIA ACIA CANADIAN FOOD INSPECTION AGENCY AGENCE CANADIENNE D'INSPECTION DES ALIMENTS



STATISTICAL AREA MAP
SHOWING AREAS OF CATCH FOR
BRITISH COLUMBIA WATERS
SOUTHERN HALF
Mean = 2.56
Mean = 3.24
Mean = 3.34
Mean = 2.32
Mean = 2.41
Mean = 1.84
Mean = 2.69
Mean = 1.84
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Mean Cadmium Levels by Area
Mean for all areas = 2.63

Survey Results

- No relationship between size / age of oysters and cadmium levels was noted
- Likewise, for intertidal vs off bottom (long line or tray) culture

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International Standards for Cadmium in Bivalves

0.1 ppm:	Venezuela, Slovak Republic
0.2 ppm:	Austria
0.6 ppm:	Switzerland
1.0 ppm:	Czech Republic; EU Countries and CODEX - Proposed
2.0 ppm:	Hong Kong, Australia
3.7 ppm:	USA (shellfish - level of concern)

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Next Steps

The data from the 2000 cadmium survey was forwarded to Health Canada with a request for an updated risk assessment

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The End!

C’est finis!

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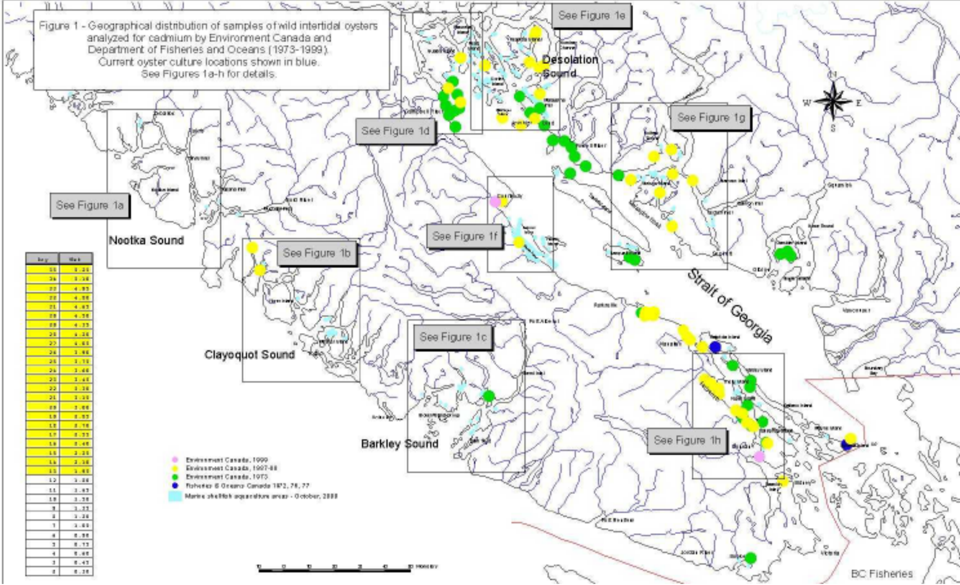
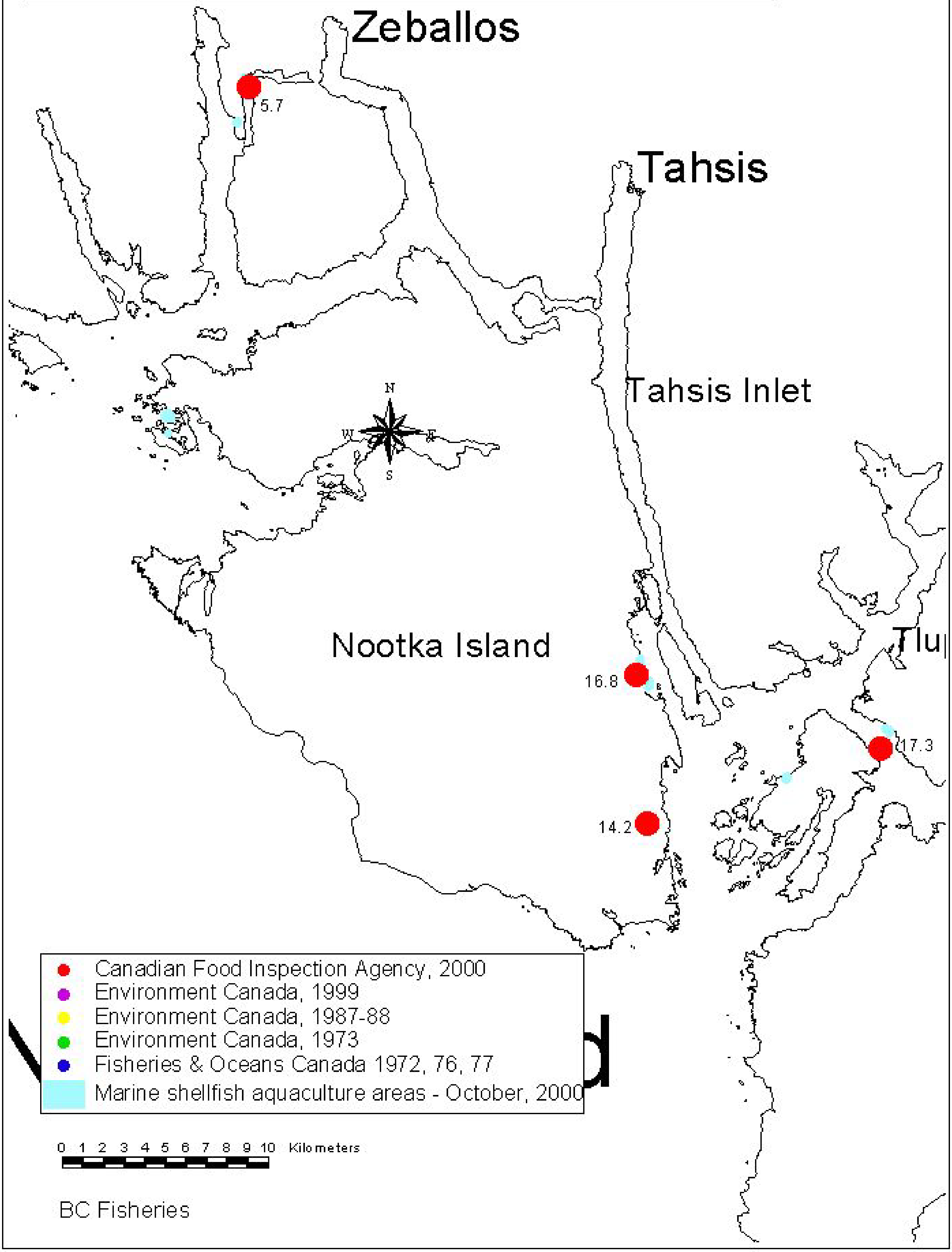


Figure 1 - Geographical distribution of samples of wild intertidal oysters analyzed for cadmium by Environment Canada and Department of Fisheries and Oceans (1973-1999). Current oyster culture locations shown in blue. See Figures 1a-h for details.

Fig. 1a - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Nootka Sound



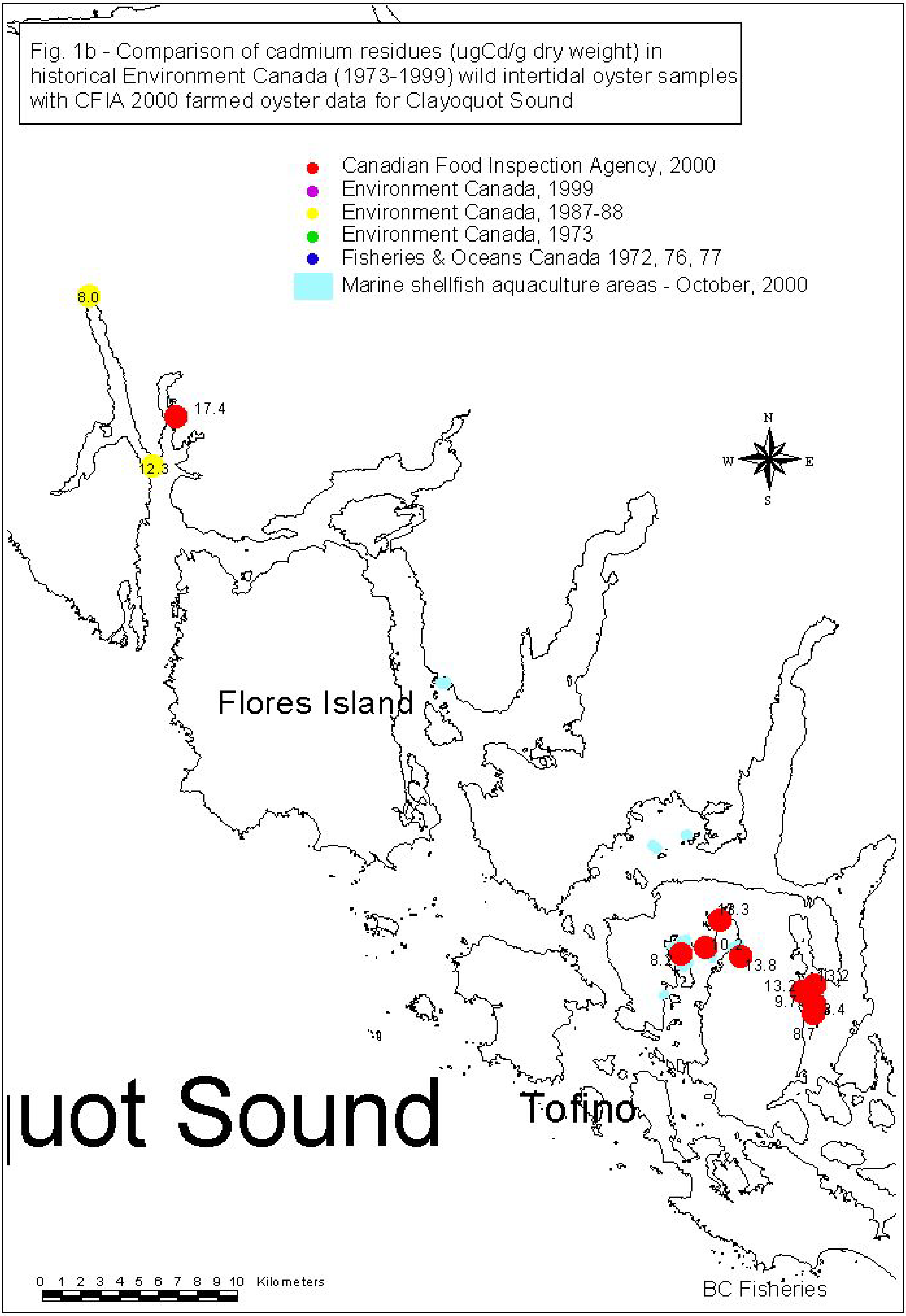


Fig. 1b - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Clayoquot Sound

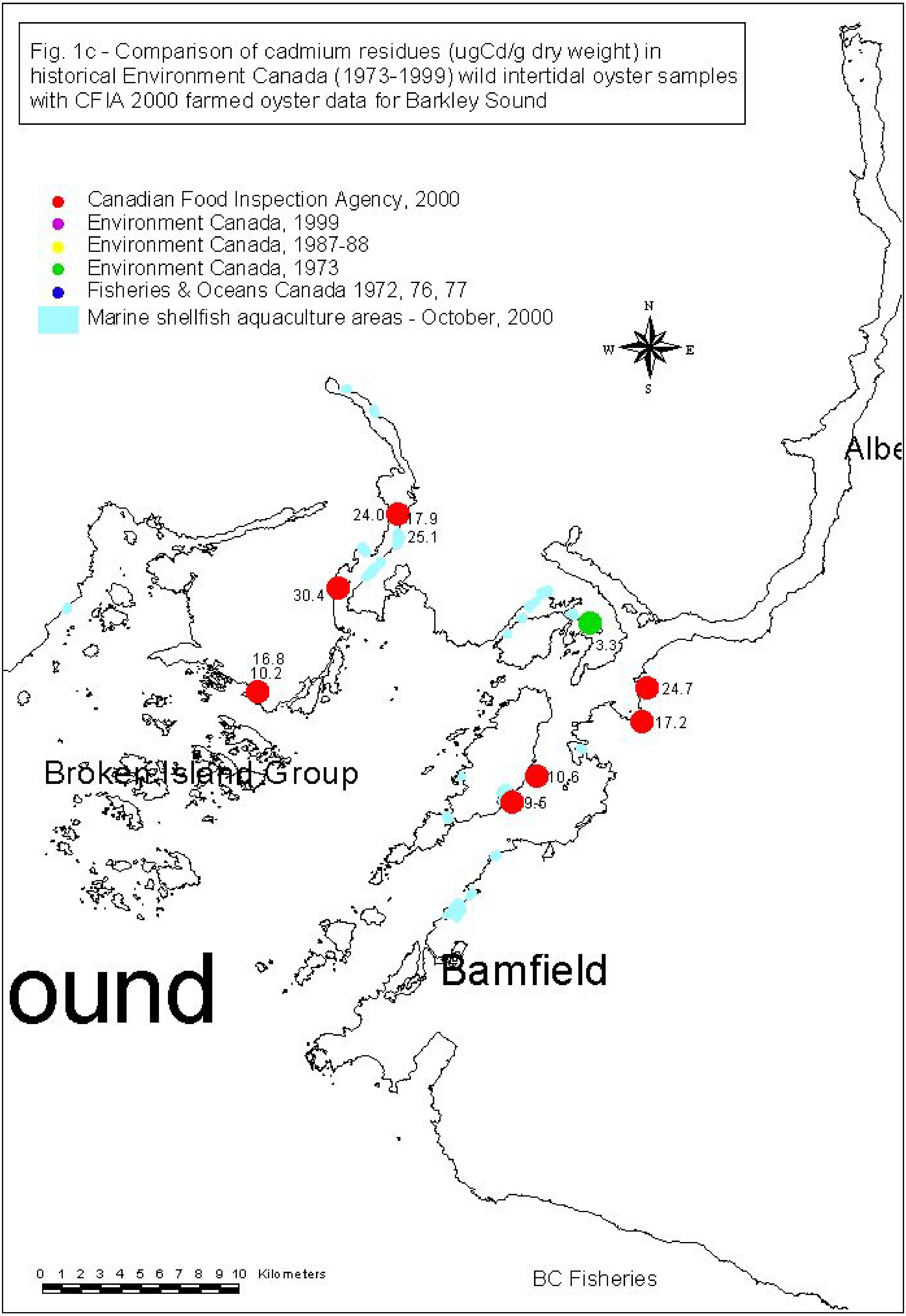


Fig. 1c - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Barkley Sound
Canadian Food Inspection Agency, 2000
Environment Canada, 1999
Environment Canada, 1987-88
Environment Canada, 1973
Fisheries & Oceans Canada 1972, 76, 77
Marine shellfish aquaculture areas - October, 2000
N
W
E
S
Albe
24.0
17.9
25.1
30.4
3.3
16.8
10.2
24.7
17.2
10.6
9.6
Broken Island Group
ound
Bamfield
0 1 2 3 4 5 6 7 8 9 10 Kilometers
BC Fisheries

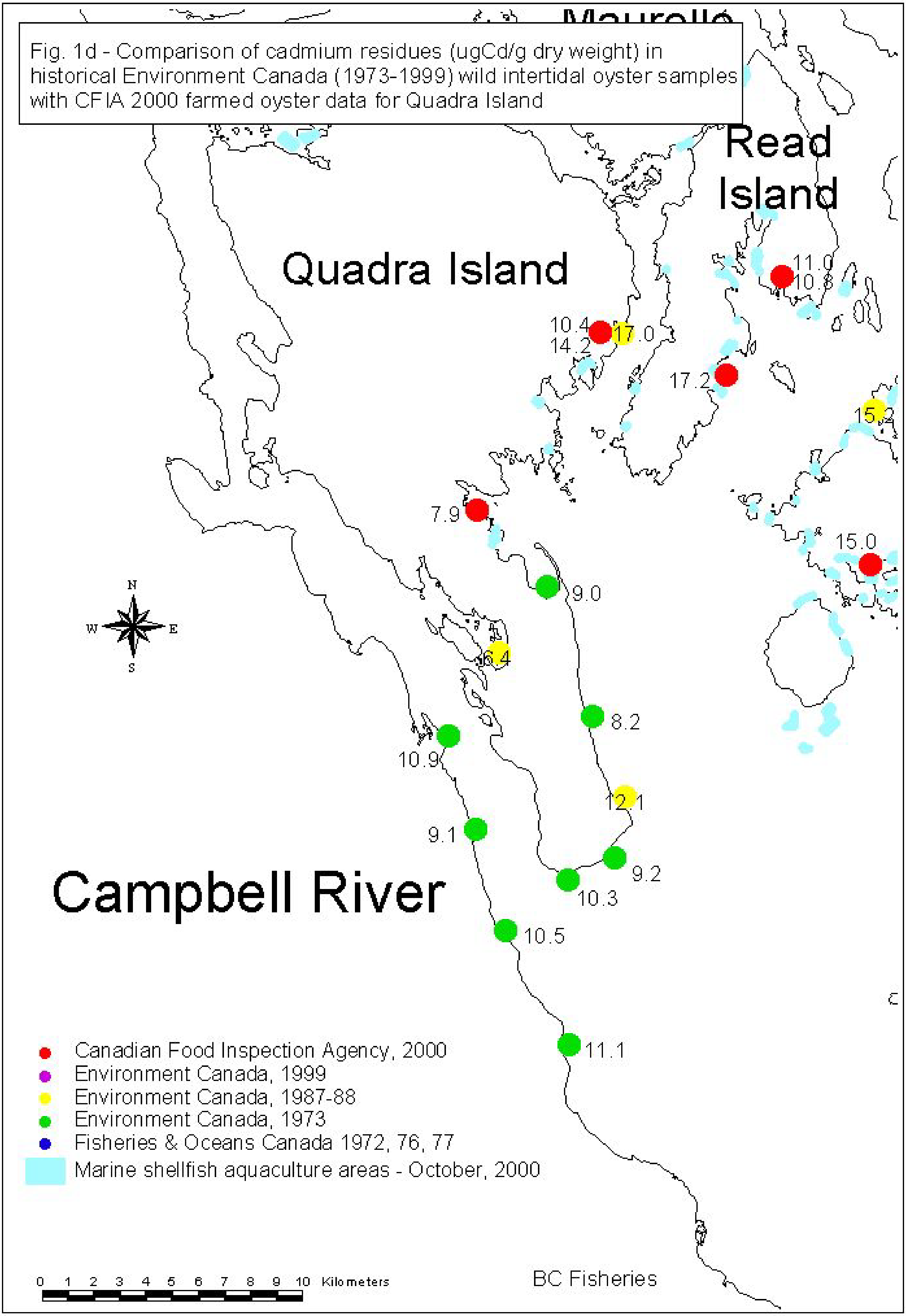


Fig. 1d - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Quadra Island

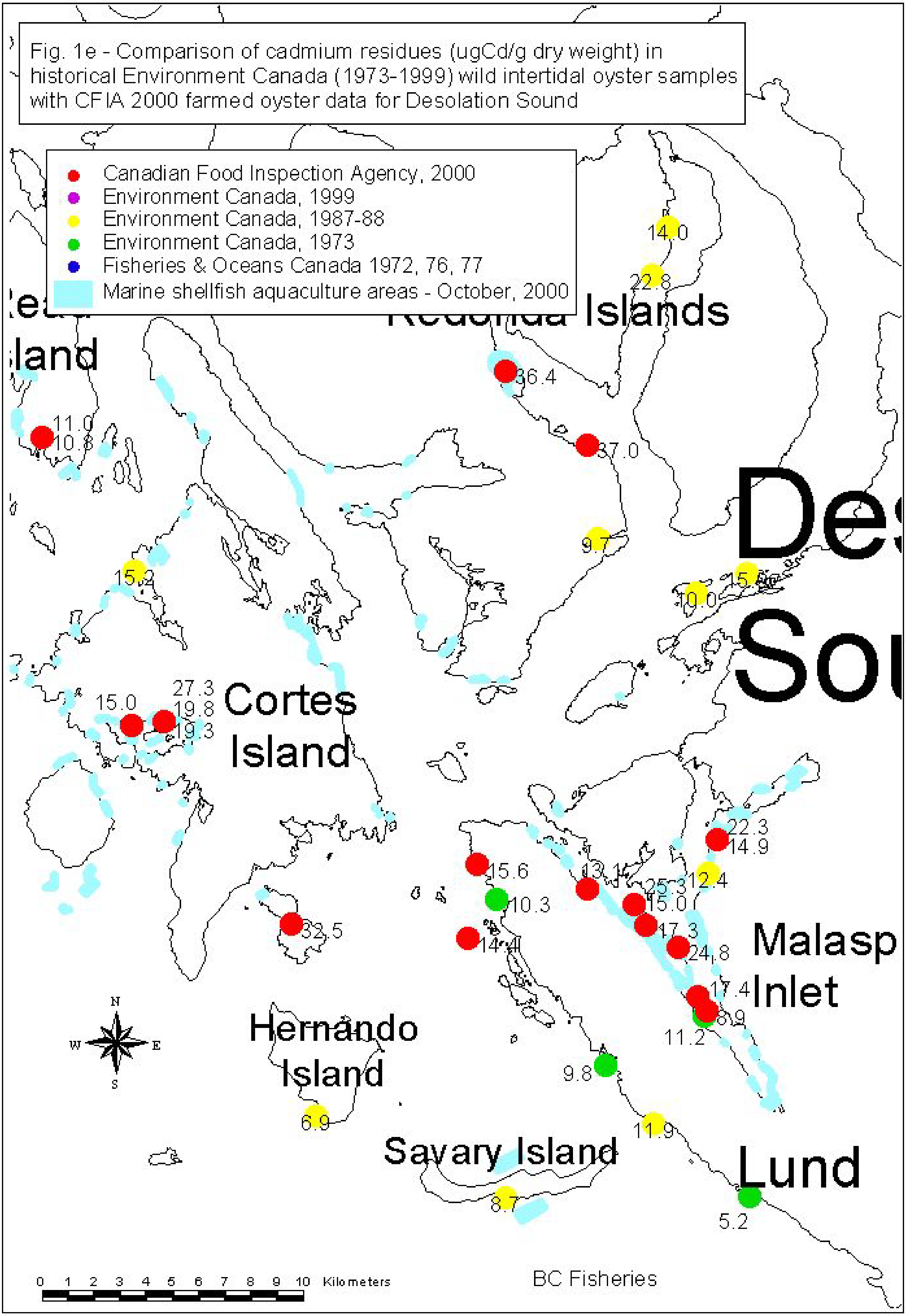


Fig. 1e - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Desolation Sound

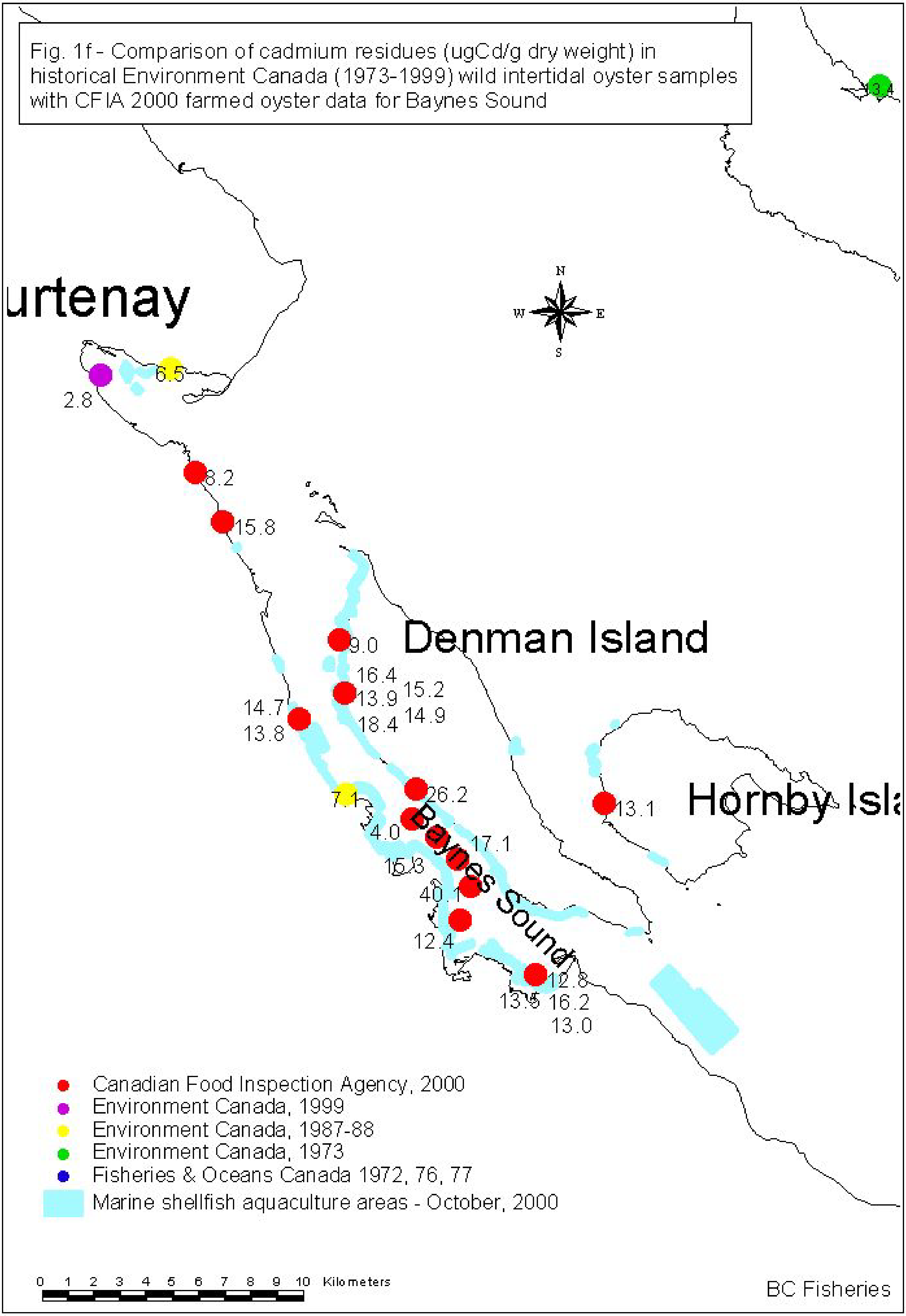


Fig. 1f - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Baynes Sound

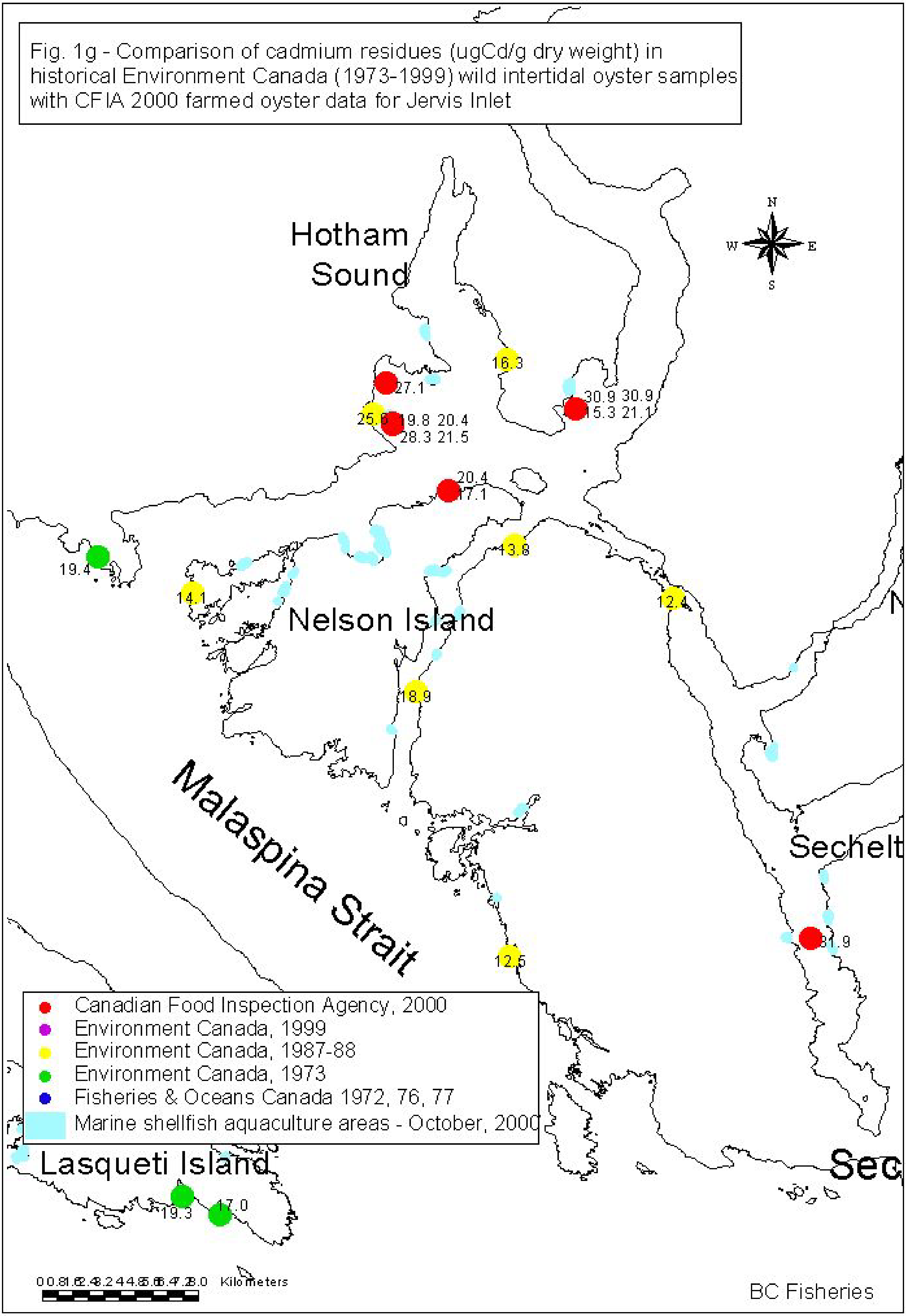


Fig. 1g - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Jervis Inlet

Fig. 1h - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for the Ladysmith Harbour area

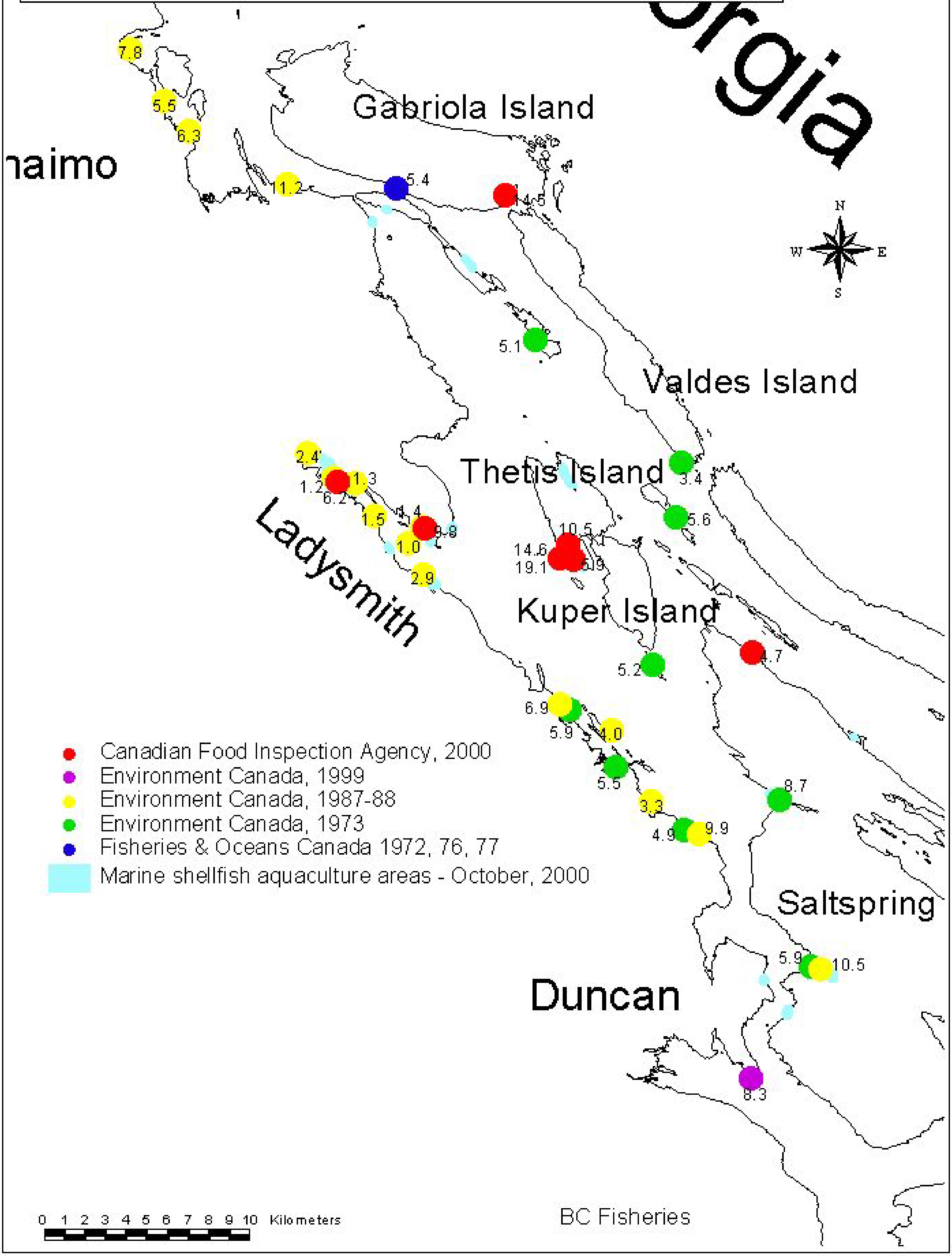
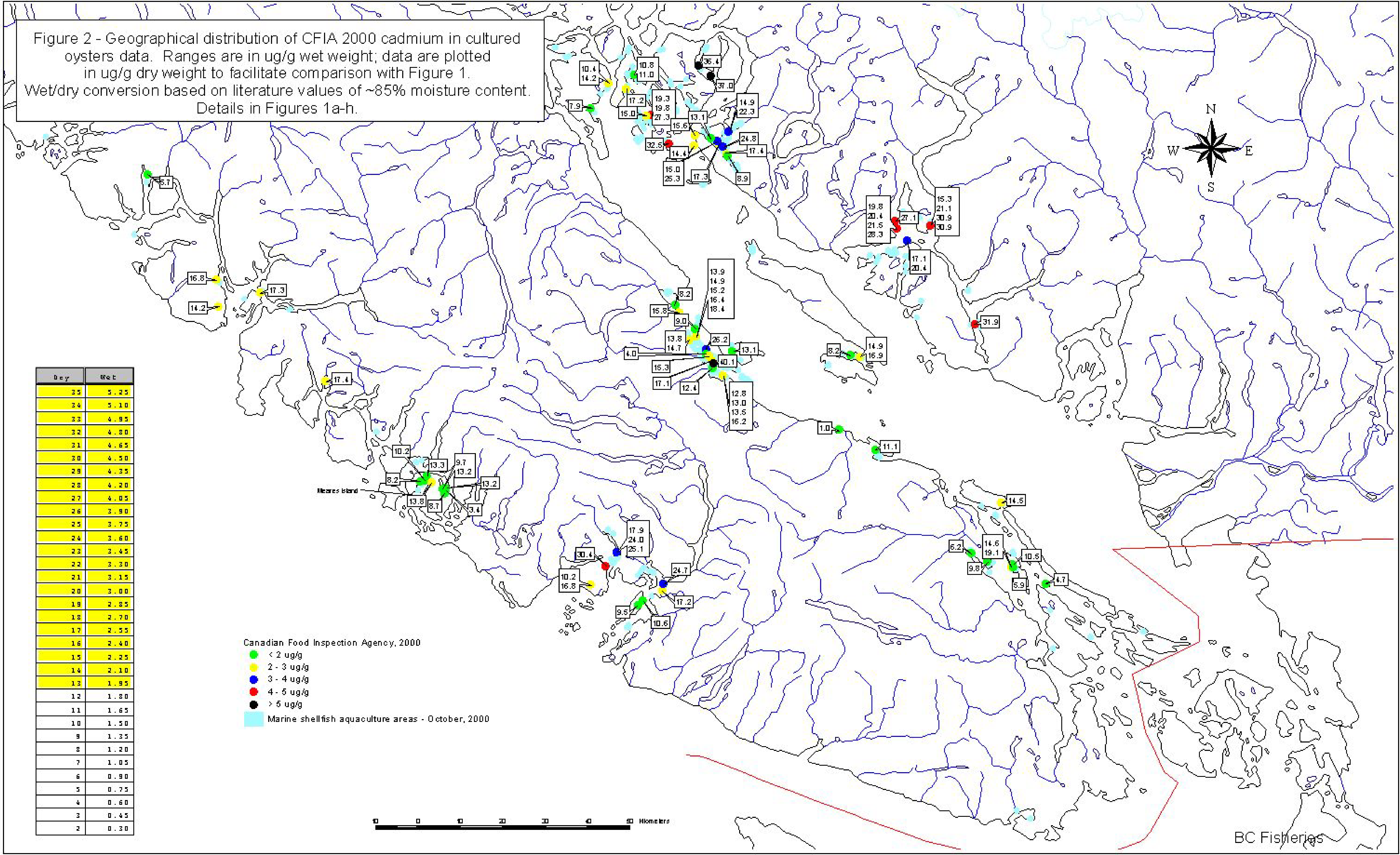


Figure 2 - Geographical distribution of CFIA 2000 cadmium in cultured oysters data. Ranges are in ug/g wet weight; data are plotted in ug/g dry weight to facilitate comparison with Figure 1. Wet/dry conversion based on literature values of ~85% moisture content. Details in Figures 1a-h.



Dry	Wet
35	5.25
34	5.10
33	4.95
32	4.80
31	4.65
30	4.50
29	4.35
28	4.20
27	4.05
26	3.90
25	3.75
24	3.60
23	3.45
22	3.30
21	3.15
20	3.00
19	2.85
18	2.70
17	2.55
16	2.40
15	2.25
14	2.10
13	1.95
12	1.80
11	1.65
10	1.50
9	1.35
8	1.20
7	1.05
6	0.90
5	0.75
4	0.60
3	0.45
2	0.30

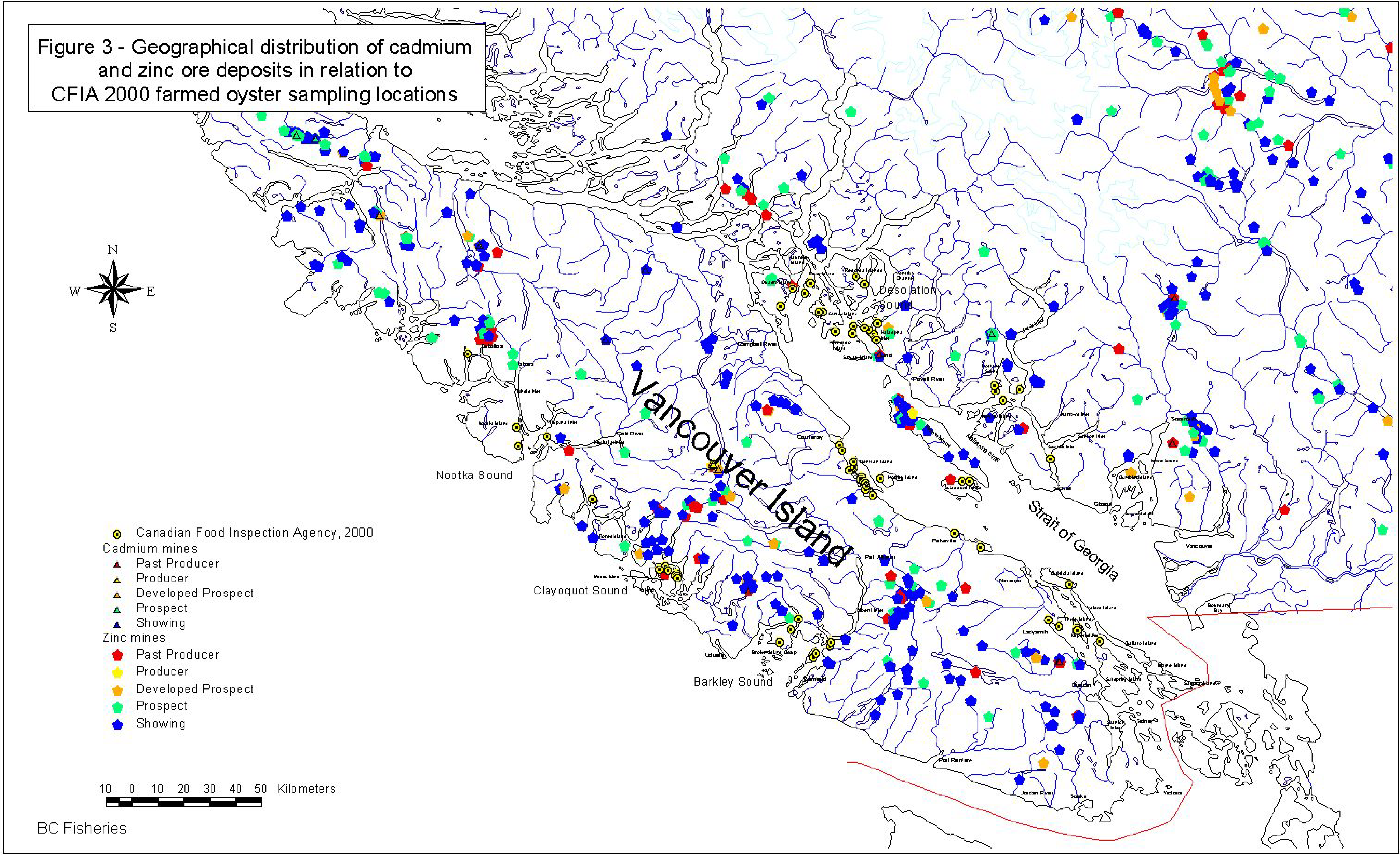


Figure 3 - Geographical distribution of cadmium and zinc ore deposits in relation to CFIA 2000 farmed oyster sampling locations

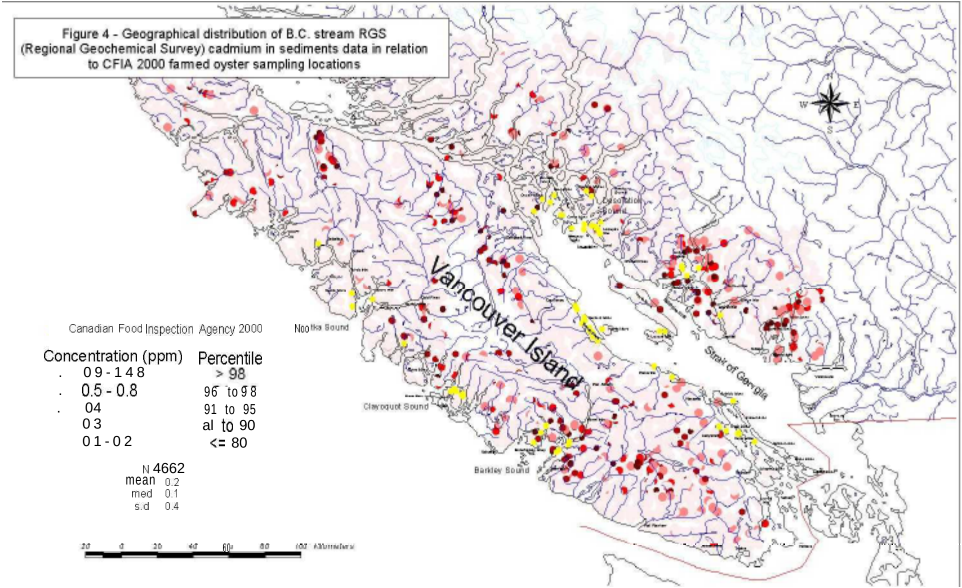


Figure 4 - Geographical distribution of B.C. stream RGS (Regional Geochemical Survey) cadmium in sediments data in relation to CFIA 2000 farmed oyster sampling locations