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Cadmium in BC farmed oysters: A review of available data, potential sources, research needs and possible mitigation strategies

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Abstract

In response to a request by the Canadian Food Inspection Agency (CFIA) in May, 2000, 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 market for being in excess of their 2 ug Cd/g (ppm) wet weight limits. 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 in the form of this report.

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. Recommendations include the holding of a Cadmium and Oysters Workshop to exchange information with oceanographers, geologist, geochemists, oyster growers, toxicologists, biochemists and biologists; the objective being to define fruitful avenues of research and possible mitigative strategies. A culture materials Cd leaching experiment, additional sampling of beach vs previously suspension cultured oysters, and a 1-2 year grow-out experiment using the same genetic stock of oyster distributed to geographically distinct locations on the BC coast are also suggested.

Maps showing the relationship of BC coastal geology and existing stream sediment Cd data to oyster growing areas are provided 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 have been gleaned from the literature and potential applications to the BC situation are suggested.

Résumé

À la suite de la demande de l'Agence canadienne d'inspection des aliments (ACIA) datant de mai 2000, le Ministère des Pêches et Océans (MPO) de la région du Pacifique a entrepris d'étudier les raisons possibles de la présence de concentrations visiblement élevées de cadmium dans les huîtres creuses *Crassostrea gigas* qui y sont cultivées. Plus tôt dans l'année, l'ACIA avait signalé que plusieurs chargements d'huîtres d'élevage de la Colombie-Britannique, dont la teneur en cadmium dépassait la limite de 2 ug/g de poids humide, avaient été rejetées par le marché de Hong Kong. Une étude documentaire préliminaire a été effectuée, des relations ont été établies avec des éleveurs d'huîtres et des transformateurs de mollusques, des chercheurs du gouvernement et universitaires ont également été consultés. Le présent rapport fait une synthèse de l'information obtenue.

Il n'existe pas de données de référence historiques sur les résidus de cadmium dans les huîtres cultivées de la Colombie-Britannique. On a donc comparé des données rassemblées par Environnement Canada et le MPO, de 1973 à 1999, sur les résidus de cadmium dans les huîtres intertidales sauvages. Ces données ont été cartographiées et comparées aux dernières données (2000) de l'ACIA sur les huîtres. Elles ont révélé que 27 ans plus tôt, les concentrations de résidus de cadmium frôlaient déjà 2 ppm dans le Nord du détroit de Georgia. En l'absence de sources anthropogéniques apparentes de cadmium, on peut supposer que ce dernier est disponible naturellement dans certaines eaux de surface où l'on élève des huîtres, faisant partie de la composition géologique locale des dépôts de minéraux ou du transport des sédiments provenant de bassins hydrographiques ou des extrémités amont. La faible salinité peut favoriser la biodisponibilité du cadmium dissous.

Sur la côte Ouest de l'île de Vancouver, le cadmium qui s'ajoute aux éléments nutritifs, tels que les phosphates remontant des eaux profondes, pourrait aussi contribuer à augmenter la concentration. On recommande entre autres d'organiser un atelier sur le cadmium et les huîtres, regroupant des océanographes, des géologues, des géochimistes, des ostréiculteurs, des toxicologues, des biochimistes et des biologistes, dans le but d'orienter les recherches et de concevoir des stratégies correctives. On suggère aussi d'effectuer une expérience pour vérifier si les matériaux utilisés pour l'élevage dégagent du cadmium, de continuer l'échantillonnage comparé des huîtres cultivées à plat et en suspension, et de faire une expérience de culture s'étendant sur une ou deux années à partir du même stock génétique d'huîtres dispersé à divers endroits le long de la côte de la Colombie-Britannique.

Des cartes illustrant la relation entre la répartition des zones d'élevage d'huîtres et la géologie des côtes de la Colombie-Britannique ainsi que les concentrations de cadmium présent dans les sédiments fluviaux sont présentées. Le ministère des pêches de la Colombie-Britannique voudra peut-être tenir compte des caractéristiques géochimiques locales avant d'approuver l'octroi d'un bail pour l'ostréiculture.

Plusieurs hypothèses quant aux voies suivies par le cadmium provenant des sources marines et terrestres ont été tirées de la documentation, et leurs applications potentielles à la situation de la Colombie-Britannique sont proposées.

Background

In March, 2000 the Canadian Food Inspection Agency (CFIA) contacted Dr Richard Addison at the Institute of Ocean Sciences, Department of Fisheries and Oceans (DFO) for Science Branch input on the issue of apparently elevated cadmium (Cd) levels in BC oysters.

Several shipments of BC farmed oysters had recently been rejected by the Hong Kong (HK) market for being in excess of their 2ug Cd/g (2 ppm wet weight basis) import limit. CFIA were looking for additional information that DFO might have on Cd residue levels in BC oysters and subsequently possible causes for this situation.

Concern was expressed about the viability of this export market. Dr Addison's contact with the US Food and Drug Administration (FDA) Office of Seafood Safety indicated that agencies such as the European Union (EU), United Nations Food and Agriculture Organization (FAO)/World Health Organization (WHO), Codex Alimentarius Commission (CODEX) and Australia New Zealand Food Authority (ANZAF) are considering lowering the limit to 1 ppm.

In May, after an additional four shipments were rejected by HK, CFIA issued a communique to BC Molluscan Shellfish Processors and Brokers that as of May 8, 2000 export product certificates would only be issued if oysters were certified to be less than (<) the 2ppm standard.

Because of the potentially serious impact on marketability of BC and Canadian oysters and implications for Canada's negotiations on this issue during deliberations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) to be held in Geneva in June 2000, a Briefing Note was prepared for the Assistant Deputy Ministers of Science and Oceans.

DFO agreed to investigate the potential reasons for these apparently elevated cadmium levels with the aim of identifying possible mitigative strategies to growers. This report summarizes the results of data gathering, a limited literature search, discussions with researchers in a variety of disciplines, BC Ministry of Fisheries, the BC Shellfish Growers Association (BCSGA), and individual oyster growers. It identifies a number of possible hypotheses for the current situation and suggests research to address some of these issues.

Summary

1) There are no historical data that would permit comparison of temporal changes in Cd residues in oysters as currently cultured.
2) Historical beach oyster survey data suggest that in certain locations in the central and northern reaches of the Strait of Georgia, there were already elevated Cd levels in the early 1970's. At these sites, even a small increase in Cd residue would have been sufficient to exceed the 2 ppm level of current concern.
3) It is unlikely that anthropogenic inputs are responsible for current Cd residues in oysters on the West Coast of Vancouver Island. Some ideas on potential sources of Cd in the Strait of Georgia are presented.

4) Experiments have not been conducted to determine whether materials used in culture may be contributing Cd.
5) CFIA 2000 data were meant as a snapshot of the current situation. Only 3/39 samples passed the < 2 ppm standard. However because of differences in culture techniques, lack of stock and farm identity for many samples, comparisons among sites with the aim of determining cause are not possible.
6) Culture practices are so varied that direct comparisons among sites are not warranted. A small-scale sampling effort is underway (DFO/BC Fisheries) to attempt to compare Cd in wild beach-raised to previously suspension-cultured and now beach-hardening oysters.

Organization

A preliminary literature search was followed by contacts with shellfish growers, their associations in BC and Washington State, specialists and researchers in Federal, Provincial and State organizations, as well as University researchers in BC, the USA, Australia, New Zealand and Chile. This information has been synthesized and applied to the current issue of Cd in BC-farmed oysters. An outline of the potential influence on this situation of numerous, frequently interrelated factors is presented by topic. Many questions are identified and suggestions for potentially fruitful avenues of research are made. It is clear that this is a complex, multifactorial and multidisciplinary problem. Cooperative application of current knowledge by specialists in the field, would help clarify or discount some of the ideas or hypotheses. An informal workshop bringing all parties together would be worthwhile. Appendices provide maps and relevant background information.

Why the concern

Cadmium is classified as a cumulative toxin that accumulates preferentially in the human renal cortex with a half life in the range of 16-30 years. Main sites of exposure are via the gastrointestinal (g.i.) tract and lungs, with lungs being much more efficient at 15-30% absorption vs 4-6% by the g.i. tract. Assuming that all exposure was dietary, FAO/WHO established a provisional tolerable weekly intake (PTWI) of 400-500 ug Cd for the average Caucasian. This was based on a critical 200 ug Cd /g wet weight of kidney, a 5% absorption through the g.i. tract, and daily excretion at 0.005% of the total body burden. For populations of smaller mean body size, the PTWI is lower e.g. 325 ug Cd for Japanese. This corresponds to 1 ug Cd/kg body wt/day. In the EC, diet contributes 126-336 ug Cd per week; of which only 5% is from the water (Jackson and Alloway, 1992).

According to CFIA, Canada has no import standard for Cd in oysters. Cheung and Wong, (1992) report that the import limits for the USA are 11.0 ug/g dry (~ 1.7 ppm wet); Hong Kong and Australia (2 ppm) and 1 ppm in New Zealand. The USA figure may be in error as other sources quote the USFDA limit as 3-4 ppm wet.

To put this in context, a meal of six good-sized BC oysters (~40 g wet) each at the 2 ppm limit would contribute 480 ug Cd at one sitting. This constitutes the FAO/WHO tolerable weekly intake of Cd from all sources. For cultures where oysters might comprise a significant proportion of the weekly intake, concern is clearly warranted. However, McKenzie et al (1985) report on a situation in a New Zealand town where the population has historically had an elevated seasonal intake of Cd from oysters (*Ostrea* *lutaria)* without demonstrating health consequences as indicated by conventional measures of kidney function.

Note: Most of the literature reports Cd on a dry weight basis. The conversion factor of wet/0.15 = dry weight was used by EC, CFIA and the US NOAA in their Mussel Watch Program. Although this relationship can vary seasonally, for the purposes of this discussion, where large difference are being considered, this error is considered minor. This has been applied to all data that were originally reported on a wet weight basis. **All data below are expressed on a dry weight basis unless otherwise specified.** (See Figs. 1 and 2 for conversion table).

Geology

Local geology is perhaps the most likely non-anthropogenic factor that could influence Cd availability in nearshore waters where oysters are being farmed. Some historical intertidal oyster Cd data (Environment Canada (EC) and DFO) can be correlated with known areas of mineralization (Fig. 3) . Examples in the mid Strait of Georgia are Texada and Lasqueti Islands and further south Gambier Island in Howe Sound (Fig. 1). Texada has been mined for iron ore, gold, copper marble and limestone. Adjacent Lasqueti Island has had historical copper and gold prospects. Gambier Island has a similar geology to that of the Britannia Mine deposit. In 1973, oysters collected from three sites on Gambier had ~ 19, 29 and 25 ug Cd/g ; samples from Lasqueti had 17 and 19 ug Cd/g and one from Texada had 13 ug Cd/g.

Consultation with Dr. C. Dunn, (NRCAN Natural Resources Canada, Scientist Emeritus) indicates that where there are mineral deposits identified as Cu/Zn, one can expect cadmium enrichment. Cadmium is frequently associated with copper/zinc ores with most zinc ores containing 0.2-0.4% Cd (Greenwood and Earnshaw, 1984). Some limestone deposits can also have Cu/Pb/Zn. There are limestone deposits on Texada and extensive mining has occurred on Nelson Island (Fig. 1g) .

While we have no CFIA data for the above locations, there is corroboration of elevated Cd levels in oysters sampled by EC in 1987/88 in the Sechelt, Nelson Island and Hotham Sound area with 5/7 in excess of the 13 ug Cd/g dry limit. Current CFIA data for oysters taken from two leases in Hotham Sound (28.3 and 21.1 ug Cd/g) are very close to the 26.3 collected by EC in 1987/88 (Fig. 1g). Unlike the situation in the Vancouver Island Baynes Sound area, there may already be elevated Cd available to oysters in Jervis Inlet. This could be from local mineralization (extensive Zn/Cu deposits) as indicated on the geological map (Fig. 3), perhaps input from glaciers at the head of the fjord, or a combination of suspended sediment and reduced salinity which has been shown to increase Cd uptake by oysters. This possibility should be investigated if data are available (e.g. Cd in glacial flour) or preferably tested experimentally by planting oysters at the head of such inlets; Jervis, Toba and Knight.

One grower was implicating the Powell River pulp mill as a source of Cd but could not provide any corroborating data to support this contention. The 1976 EC survey was designed to gather baseline data on Zn in oysters after discontinuation of the use of zinc hydrosulfite as a bleaching agent in groundwood newsprint production. Fortunately, their samples were analyzed for a suite of metals including Cd. This data set comprises the only historical record that we have to compare current data against. Interestingly, Cd levels in intertidal oysters were lower close to the mill. However the pulp mill Environmental Effects Monitoring (EEM) program does not include a requirement for measuring metals in effluents, so while pulp and paper mill processes generally are not expected to be a large Cd source, this should be confirmed. There are mills in proximity to current areas of concern e.g. Powell River and Campbell River.

During the 1976 survey, there were only two samples generated for the west coast of Vancouver Island; Barkley Sound (3.3 ug Cd/g) and Sooke (2.9 ug Cd/g). If these data were representative of the situation on the West Coast of Vancouver Island, current CFIA data for Barkley Sound indicates a 5-10 fold increase in Cd levels in cultured oysters. Our current DFO survey will be visiting this area in early August, 2000. Geological maps indicate considerable mineralization in this area (Fig. 3) but that should have been reflected in the 1973 data. On the other hand if there occurred major interventions such as extensive watershed logging, coastal areas with very high rainfall and acidic soils may be subjected to more erosion. Previously forested watersheds may now have mineralized areas that have been rendered more readily available for leaching by acidic rain. As soils become more acidic, Cd becomes increasingly mobile and may increase translocation to estuarine waters where it becomes available to plankton and oysters (Butler and Timperley, 1996).

The BC Ministry of Energy and Mines, routinely uses metals analyses of stream-transported sediments (< 177 uM) as an aid in exploration of watersheds for promising areas of mineralization and ore bodies (G. McArthur, Mgr. Exploration Science and Information, BC. Geological Survey, Victoria). This data base is available on the web and would be a fruitful avenue to pursue as an indicator of local Cd enrichment in streams. An example of such Regional Geochemical Survey (RGS), Cd data for Vancouver Island and the Mainland coast have been included in the Appendix (Fig. 4).

Discussions with specialists in geological exploration with the BC Geological Survey indicate that detailed large scale maps are readily available on their web site. A concerted effort to explore this possibility may help define areas of the coast that might be draining naturally enriched (in Zn/Cd) watersheds to oyster growing areas. Considering that the concentration of Cd in Georgia Strait is in the range of 75 ng/L (Waldichuk, 1983) it is conceivable that local inputs to surface waters could suffice to increase bioavailability to oysters rearing in such areas. It would therefore seem prudent for BC Fisheries to include consideration of such data when determining the suitability of new areas proposed for oyster farming.

An effort was made to follow up in the literature on potential effects of clearcut logging on the mobility of metals (H. Herunter, T. G. Brown, DFO Pacific Region). Extensive logging effects data collected by DFO on Carnation Creek, Vancouver Island contained no data on Cd. Contact with Dr. Max Bluow at the University of Northern British Columbia, Prince George, did not prove fruitful and Dr. M Feller (UBC Forest Sciences) was not aware of any such studies having been performed. Lepp (1992) reports that some soil bacteria and sporophores of fungi are capable of accumulating very high levels of Cd (40% dry weight and 3% dry weight respectively) so that in areas of accelerated soil erosion, there might be significant contributions of Cd to receiving waters.

Municipal Waste

Data provided by GVRD (Greater Vancouver Regional District) indicates a median daily loading of 0.3 kg of Cd in effluent as discharged from the Iona Sewage Treatment Plant (STP) to Georgia Strait (Bertold and Stock, 1999). This corresponds to ~ 110 kg Cd per year. Cadmium has been reported to bind preferentially to colloids and small < 1uM particulates (Lead et al., 1997) which would tend not to settle out in near-field sediments and thus have an equal probability of deposition over the whole transport environment (McLaren et al. 1993). This together with the dissolved phase, could be a source of widespread Cd distribution. When sediment in transport becomes so fine (fine silt and clay) that size sorting no longer occurs, contaminants have no preferred location for deposition, but rather have an equal probability of deposition over the whole transport environment. In a study of erosional transport of Cd from soils to the estuarine food chain, Butler and Timperley (1996) found that 75% was contained in fractions < 58 uM.

Iona diffuser effluent plume dispersion modelling indicates that the bulk of the effluent will be carried up the Sunshine Coast and that intermittent upwelling is expected in freshet, summer as well as in winter conditions (Seaconsult, 1999). This possibility should be explored by a more detailed consideration of available data and known oceanographic circulation of the mid and upper part of the Strait of Georgia.

The CFIA 2000 survey data contain only one sample 10.6 ug Cd/g from the southern Strait of Georgia (Thetis Island) and 7 from mid-Strait (Baynes Sound /Denman Island); all in excess of the 13 ug Cd/g dry weight limit. A comparison of the Baynes Sound data with those collected nearby (Comox Harbor) by EC in 1999, may support the idea that culture conditions are contributing to elevation in Cd. The Cd residue in oysters collected intertidally in Comox Harbor was 2.8 ug Cd/g vs 13.8 and 14.7 ug Cd/g 15 km to the South for cultured oysters (Fig. 1f). We will be visiting Denman in the current DFO/BC Fisheries survey to collect both wild and cultured oysters for comparison.

There may also be local inputs in relatively remote areas. Discussions with an oyster grower on Cortes Island indicated that a local farm had stockpiled communal septic sludge that exceeded the BC provincial limits for agricultural application. Data provided by the farmer indicated composted septage containing 5.4 ug Cd/g dry weight. It is conceivable that on a small scale, discharges of domestic sewage could contribute some cadmium to oyster growing areas. Domestic septic tank pump-out and STP sludge disposal practices may contribute to additional Cd loading. Contact with GVRD indicates that the Iona STP has ~ 30 years' accumulation (~ 500,000 metric tonnes) of sludge stockpiled near the plant. Because of the apparently elevated Cd levels in the vicinity of Cortes Island, data on Cd in sewage effluent discharged in that region (Campbell River) coupled with oceanographic considerations could shed some light on this issue.

Natural Enrichment

There have been two documented occurrences of natural enrichment of Cd in BC marine sediments. One in Indian Arm sediment cores (Pedersen and Waters, 1989) and one in Ucluelet Harbor (Pederson et al 1989). In both cases the mechanism was one of sequestration of Cd from ambient sea water at the anoxic sediment/water interface where the Cd was fixed as CdS and precipitated out. In Ucluelet, Cd was present at levels (dry weight) of up to 8 ug Cd /g. Organically enriched sediments were present in

Ucluelet and some contribution would have been from sewage discharge. While this mechanism may explain local elevations in sediment Cd, it is unlikely that oysters would rear successfully under anoxic conditions. However in intertidal areas where a moderate degree of anoxia may be reached at some stage of the tidal cycle, it is conceivable that subsequent oxygenation during flood tides could free up bound Cd and render it available to oysters rearing under these conditions. This could be in the dissolved, colloidal or particulate phase, whether filtered directly or made available to phytoplankton and then translocated to oysters. However oysters collected in a 1999 EC survey of Comox Harbor and Cowichan Bay, where one would expect some degree of eutrophication and organic enrichment, found very low levels of Cd in oysters (2.0 and 8.3 ug Cd/g dry respectively). Sediment Cd levels were 1.0 or < 0.8 ug Cd/g dry at all ten sites sampled (Kooi and Walker, 2000). Comparison with historical (1973) EC data indicates that there has been no increase in intertidal oyster Cd residues since 1973. In contrast, CFIA data for oysters cultured at Denman Island leases had 4x the level of Cd in the above survey. Similarly, oysters taken from a Thetis Island lease had Cd levels 6 times higher than those sampled intertidally by EC in 1997/98 from nearby Ladysmith Harbor. These data indicate that local cadmium enrichment, due to mechanisms described above, is not supported by sediment data for these environments and that other factors, perhaps related to culture methods are responsible.

Agricultural Input and the Fraser River Plume

Inorganic phosphate fertilizers used in agriculture have long been known to contain high levels of cadmium. Phosphate rock varies in Cd content depending on origin, ranging from 6-15 ppm USA (Florida) to 42-80 for Togo, 66-90 Senegal to 40-340 ppm from Idaho (Anonymous, 1989).

Butler and Timperley (1996) linked elevated (2.8 ug Cd/g wet) levels of Cd in estuarine Pacific oysters to application of inorganic superphosphate fertilizers to agricultural land upstream. In this study, two samples from different sources contained 26.6 and 33.6 ug Cd/g. Cadmium leached by rainfall from acidic soil and erosion, was transported on fine particulates to the estuary where it was desorbed and accumulated by phytoplankton. Selective ingestion of nutrient (and Cd)-rich algae and rejection of inorganic suspended sediment was demonstrated to be responsible for accumulation of Cd in oysters. Since most of the Cd was in stomach contents, depuration was suggested as a possible treatment to reduce Cd concentrations in whole oysters. Reference is made to the (1973) Australian 2 ug Cd/g import limit and concern was raised about compromising marketability of oysters reared under these conditions.

With the Fraser Valley heavily farmed, this may be a potential source of Cd to the Strait of Georgia. Since Cd can be present in dissolved, particulate, colloidal or adsorbed to very fine particles, it is conceivable that the northward movement of the Fraser River plume could enhance Cd availability (whether to phytoplankton or oysters directly) over a wide area, perhaps up the Sunshine Coast and the Northern Strait. Some continuous centrifuge data do exist with Environment Canada and should be followed up in concert with oceanography to determine the loadings from this potential source.

In a study of trophic transfer of metals, Reinfelder et al (1997) determined assimilation efficiences of four marine bivalves after a 40-60 minute exposure to the phytoplankter (*Isochrysis galbana*) which had been exposed to radiolabelled Cd for 40 minutes. Wide differences in retention and excretion occurred, and after a rapid initial clearance of the gut, oysters (*Crassostrea virginica*) retained 65% of the initial dose after 16 days in clean sea water. This indicates that under these laboratory conditions, unassimilated Cd is efficiently egested, but that which is retained longer than one day is nearly all assimilated. Elements enriched in the cytoplasmic fraction of ingested food are assimilated more efficiently than those not concentrated in this fraction. These data support the concept that if Cd is made available in the Fraser plume and/or in GVRD STP discharges as discussed earlier, this could comprise a significant trophic transfer of Cd to farmed oysters rearing in areas under influence of the plume.

Oceanographic Factors

Preliminary discussions with oceanographers at IOS, UBC, NZ, Australia, Washington, and Alaska have been held. Because of the known correlation of cadmium and phosphorus occurrence in sea water (Bruland et al 1978) and the possibility of upwelling of phosphorus-rich deeper waters bringing Cd up to surface, this mechanism could be contributing to elevated Cd levels in farmed oysters in areas such as Barkley Sound. CFIA data indicate that one grower, practicing suspension-only culture, with no beach hardening, (Fig. 1c) had 30.4 ug Cd/g in 2-year old oysters. There are no obvious anthropogenic inputs to that relatively remote area which, according to the grower, was chosen for that reason.

Growers in Nootka Sound (Fig. 1a) also have Cd levels in excess of the 13 ug/g limit. The potential contribution of upwelled water is an attractive hypothesis under these conditions. Communication with Dr. Alan Mearns of the US NOAA (National Oceanic and Atmospheric Administration) indicates that as far back as 1978, there appeared to be an increasing northward gradient of Cd residue in groundfish muscle. In the US Mussel Watch program, there are no data for Oregon or Washington state for oysters. However, it is reported that mussels taken from Cape Flattery (entrance to the Strait of Juan de Fuca; bottom tip Fig.1) had the highest Cd levels of any Washington site on the exposed coast (1986-1998), though no temporal increase is obvious.

We have only two historical (EC 1973) data points for intertidal oysters from the West Coast of Vancouver Island; Sooke Harbor and Alberni Inlet: 2.9 and 3.3 ug/g dry respectively. We have 1987/88 EC data from Clayoquot Sound (8.0 and 12.3 ug/g) implying that there may have been an increase or simply that this is part of the suggested northward trend. Unfortunately we have no data from Alaska, although recent correspondence with Dr. Sathy Naidu at University of Alaska, Fairbanks indicates that, as a result of our enquiries, they are about to embark on a survey of Cd in oysters. Alaska is planning a major development of oyster culture and appear to be keenly interested in our problem. Their results will help determine whether this northward trend in Cd availability does in fact exist.

Because of total lack of historical data on farmed oysters on the West Coast of the Island, we cannot say whether this is a new problem or has always been that way. On the assumption that it is a recent occurrence, the upwelling scenario was discussed with oceanographers F. Whitney, L. Miller, T. Parsons, and D. Mackas at IOS. The consensus seems to be that evidence is to the contrary. Nutrient supply via upwelling has dropped significantly over the last decade and stratification (FW/SW) has increased because of the reduction in summer upwelling of deeper more saline SW. Now that site locations have been plotted, the DFO Ocean Science and Productivity (OSAP) data base should be consulted to look for nutrient/phytoplankton trends in the vicinity of selected oyster growing areas. Interestingly, Lares and Orians (1997) reported very rapid upward and downward changes in *Mytilus californianus* Cd residues during periods of late summer upwelling in 1991 at Amphitrite Point (the entrance to Ucluelet Harbor, Fig. 1) and concurrent elevations in dissolved Cd, phosphorus and drops in temperature. The previously-discussed ability of some mussel species to regulate Cd may account for the rapid responses observed.

Current culture practices result in oysters being completely submerged and therefore feeding 24h a day, unlike intertidal oysters which rest between tides. Pumping rate has been measured at ~20 L/h, so very large volumes of water are passed over the gills. If there were only slightly increased Cd availability or slightly elevated temperature, it could be that accumulation would be accelerated. On the other hand, productivity is generally thought to be down off the West Coast of Vancouver Island, so appropriate phytoplankters may not be readily available. Consultation with growers has indicated no clear trends in growth. This is likely because of the complex interaction of factors that determine growth performance in oysters. One important factor may be that of salinity. Wang et al (1996) reported that in *Mytilus edulis*, a drop of salinity from 34 to 20 ‰, increased Cd influx by 1.7. However a further drop to 15 ‰ had no effect. Cunningham (1979) observed higher uptake of Cd in *Mytilus* in less saline surface waters. Denton and Burdon-Jones (1981) found the same for Cd uptake in black-lip oyster *Saccostrea echinata.*

Data collected by a grower in Effingham Inlet (Barkley Sound) indicates a steady salinity gradient decreasing up inlet. There are several oyster farmers along its length. This would seem to be an excellent opportunity to test the hypothesis that decreased salinity results in enhanced Cd uptake.

Biological Factors
Questions and Considerations

Uptake is complex. Assimilation efficiency, total concentration in the water column, and seston load are all major parameters that determine metals accumulation. Uptake and retention rates are affected by the mixture of metals in water, by changes in salinity and by temperature and therefore are likely to be site specific. Several studies report a ~50/50 ratio for food vs dissolved, others, plankton (0.03%), particulates (8%) and from solution(92%) respectively; others indicate that virtually all uptake is via plankton.

Cd is a non-essential metal which exerts its toxic action by interference with protein synthesis and metabolism. However very recent (April 2000) evidence indicates that it may be incorporated into the enzyme carbonic anhydrase when Zn availability is limited. Preferential sequestration of Cd could perhaps occur under these conditions. Preliminary discussion with F. Whitney and L. Miller (IOS) and P. Harrison (UBC) suggests that Zn depletion is unlikely to occur in coastal waters but cannot be ruled out in view of recent changes in nutrient upwelling on the Pacific Coast. A more comprehensive investigation of this possibility should be pursued.

Can gut content comprise a significant proportion of the body burden of Cd ?
NZ research indicates that gut contents and lining is high (>2 ug/g wet) in Cd. Cd concentration was two orders of magnitude higher than in sediments. Selective ingestion of the nutritious (and contaminated) fraction was responsible for uptake. If the situation

were similar here, depuration by clearing gut contents might help. However if Cd is bound to metallothionein (MT) this may not be relevant. We should determine proportion of residue attributable to gut contents.

Cd is tightly bound by a metallothionein-like protein. This would account for its slow depuration rate and probably preclude efforts to depurate oysters in Cd-reduced SW, were that technologically possible. However Dr. B. Olafson (UVIC) suggested that perhaps if MT were flooded (saturated) with Zn through administration in diet, it may be possible to exchange the MT bound Cd with Zn. MT dynamics in oysters may differ from those in mussels. This topic warrants a literature investigation.

Culture Equipment

Cadmium pigments are utilized as a stable inorganic coloring agent and UV inhibitor in plastics as well as a liquid stabilizer constituting 1-3% of the total weight of polyvinyl chloride (PVC) plastics. Solid stabilizers contain 4-12% Cd by weight and are also present in PVC. In order to be certain that the materials utilized in current oyster culture practices (as described on the BC Shellfish Growers' Site)
http://www.island.net/~bcsga/bcsgirs/oysters/oyster.htm
we propose to sample a selection of representative materials and subject them to acid leaching to determine any potential Cd residues from this source. Since oysters are very good at sequestering Cd from ambient water, any addition from materials which contain them for periods of up to 2 years, could contribute to contamination.

Batteries

The Canadian Coast Guard is currently involved in a project to recover batteries that were discarded overboard from light stations or aids to navigation. Leaching tests indicate that these may be local point sources of Hg and Cd contamination, in the case of NiCad batteries. A request had been made to CCG to provide a list of locations where NiCad batteries may have been dumped. Since the Cd content of such batteries ranges from 5-20%, depending on size, (Llewellyn, 1994) if there were aids to navigation in proximity to an oyster growing area, this could constitute a local input.

References

Some are annotated, all except those marked with an asterisk * have been obtained as copies. Comments in *italics* are pertinent to the BC situation. Not all are cited in the text but have been included as part of information gathering. Cd concentration is abbreviated as [Cd].

Anonymous, 1989. Cadmium in phosphates: one part of a wider environmental problem. Phosphorus Potassium 162: 23-30.
Reviews sources, absorption, metabolism, half-life, contribution of smoking and derivation of WHO limits of dietary intake limits of 400-500 ug Cd/week. In polluted estuaries, Cd can accumulate to ~ 120 ppm wet weight in shellfish without apparent ill effects. Contribution of Cd accumulated in vegetables, in sewage sludge applied to agricultural lands, and in phosphate rock fertilizers is discussed. Cd in inorganic fertilizer is not as well retained in soil as that originating from manure or aerial transport. Process changes that would reduce Cd in fertilizers are detailed.

Bertold, S.E., and Stock, K.P. 1999. Final report GVS & DD municipal wastewater treatment plants 1997 monitoring program. Wastewater chemistry- data evaluation. pp.130 + Appendices. Contains trace metals and organics concentrations and loadings data for five GVS & DD Sewage Treatment Plants.

Bruland, K.W., Knauer, G.A., and Martin, J.H. 1989. Cadmium in northeast Pacific waters. Limnol. Oceanogr. 23(4): 618-625.
Provides equations that should allow the calculation of Cd levels from phosphate data. *Phosphate data may be available from cruises up the coast of Vancouver Island. If this relationship is still valid, it may be possible to generate historical data on Cd levels. IOS oceanographers should be able to accomplish this.*

Butler, C.A., and Timperley, M.H. 1996. Fertilised farmland as a source of cadmium in oysters. Sci. Total Environ. 18: 31-34.
Cadmium as a contaminant in superphosphate agricultural fertilizers was found to be leached by rainfall from acidic soil and erosion and transported on fine particulates to the estuary where it was desorbed and accumulated by phytoplankton. Selective ingestion of nutrient-(and Cd) rich algae and rejection of inorganic suspended sediment was demonstrated to be responsible for accumulation of Cd in (Pacific) oysters. Estimate for filtration rate (20 L/min). Since most of the Cd was in stomach contents, depuration was suggested as a possible treatment to lowering [Cd] in whole oysters. Reference is made to the (1973) Australian 2 ug/g [Cd] import limit and concern is raised about compromising marketability of oysters reared under these conditions. Phosphate fertilizers can contain very high levels of cadmium

Cheung, Y.H., and Wong, M.H. 1992. Trace metal contents of the Pacific oyster *Crassostrea gigas* purchased from markets in Hong Kong. Environ. Manage. 16(6): 753-761.
Dissected oysters to define which tissue contained the highest residues including Cd. Sorted by length of shucked whole oyster. For Cd the accumulation was gill >mantle>visceral mass>adductor muscle. Interprets low level in viscera as a result of gut depuration procedures by retailers. *This could be one strategy for BC oysters close*

to the limit. However whole body depuration is not a viable option as Cd is largely bound by metallothionein. Table 2 gives results for size vs Cd residues (dry weight) . Minor differences 3.98 ug/g; 3.66 ug/g; 3.09 ug/g …down to 3.04 ug/g for the largest of the 7 groups. Smallest 5.1-6.0 cm; largest 10.1-10.7 cm. *Largely academic for the BC situation because of our high residues. However we can test using the same metrics on the August 2000 Lasqueti Island sample. Methodology is of some concern as they washed shucked tissue in tap water and blotted dry before weighing. Other literature suggests that the pallial fluid should be included in the wet weight of the shucked oyster. Refers to metals loss via translocation to eggs but checking the original reference does not corroborate this assertion. Also suggests that higher Cd levels in the winter may be due to higher salinities. Most other literature indicates decreased uptake as salinity rises.*

Cossa, D. 1988. Cadmium in *Mytilus* spp.: worldwide survey and relationship between seawater and mussel content. Mar. Environ. Res. 26: 265-284

Cunningham, P.A. 1979. The use of bivalve molluscs in heavy metal pollution research. *In* Marine pollution functional responses. *Edited by* W. B. Vernberg, A. Calabrese, F. P. Thurberg and F. J. Vernberg. New York, Academic Press. pp. 183-221.

Review Paper. Discusses intrinsic and extrinsic factors that control uptake and depuration of metals. Among these are age, size, weight, reproductive condition, sex including depuration during spawning. Variability in reversible and irreversible uptake into various body compartments contributes to conflicting results of depuration studies. Extrinsic factors: temperature, salinity, chemical speciation and interactions with other metals, concentration and duration of exposure as well as position in the water column affect uptake rates. In *Mytilus*, greater uptake of Cd, Pb and Zn was observed in less saline water stratified over more saline water, resulting in higher uptake near the surface. (*This may be pertinent to our situation*). Distribution among organs and intracellularly are detailed. For Cd, kidney accumulates the highest residues. The interactions of extrinsic and intrinsic factors determine uptake and retention kinetics, rendering difficult extrapolation between sites. Procedures to be followed in field collections to minimize variability are discussed. *Salinity and temperature especially important for Cd.*

Denton, G.R.W., and Burdon-Jones, C. 1981. Influence of temperature and salinity on the uptake, distribution and depuration of mercury, cadmium and lead by the black-lip oyster *Saccostrea echinata*. Mar. Biol. 64: 317-326.

2yr-old oysters from an experimental oyster farm were exposed to 10 ug Cd/L (10,000 ng/L) at 36 and 20 ppt at 20 and 30 C for 30 days then transferred to clean SW for depuration for a further 30d. [Cd] in the experimental tank remained close to nominal. Rates of Cd accumulation were significantly increased by temperature. Accumulation rates at both temperatures were consistently higher at low salinity. Reference is made to similar results for fiddler crab, blue crab and *Mytilus edulis*. Suggest that increase in uptake by temperature is not simply related to increased ventilation volume but also a function of deposition. Dilute SW has been shown to increase oxygen consumption in oyster tissue and may increase ventilation and uptake. Also metal speciation may change at lower salinity thereby increasing bioavailability. Cd has an extremely long biological half life. Cites other literature that no detectable Cd depuration from oysters was observed after a 1 month depuration period. Similarly, in *Mytilus edulis*, excretion rate of Cd was 18 times slower than uptake. *This fits in with the MT-binding of Cd and subsequently very slow release. Why such a high (10 ug/L) [Cd] was utilized in this study* *is not discussed…likely to simulate a heavily polluted environment. Increased uptake at lower salinity.*

Fischer, H. 1988. *Mytilus edulis* as a quantitative indicator of dissolved cadmium. Final study and synthesis. Mar. Ecol. Prog. Ser. 48: 163-174.
Developed a Cd/shell-weight index which is independent of nutritional state, spawning or tidal exposure, temperature, dissolved oxygen and salinity; factors which normally produce fluctuation in conventional soft tissue concentration data. Cd/shell weight index = [Cd] in tissue divided by weight of shell. Fig. 3 shows the relationship (log transformed data) that Cd/shell-wt index is directly proportional to dissolved Cd. e.g. mussels grown in 1 ug/L Cd would have an index of 4.85. Tested this to ~40 ng/L which is likely comparable to [Cd] in BC waters. Cd/shell weight index is inversely proportional to salinity in the range of 15-30 ppt so can correct for varying salinities. Coastal SW generally has a Zn:Cd ratio of 30:1 to 40:1 and this is not expected to vary much in nearshore SW so the rates of accumulation of Cd are unlikely to change because of variation in Zn:Cd ratios. *Check this out for our sites.* Mussels can accumulate up to 1000 ug Cd/g without effects on growth. *Consideration of binding and storage mechanisms can explain differences between generally short term lab experiments and long term field observations. Interactions with Zn and resultant effects on Cd uptake are important but we can check from ambient WQ data whether these exist. Should be able to estimate [Cd] in SW after have data on salinity and Cd/shell weight index. Suggests to use small individuals for transplant experiments so that growth is incorporated into the calculations. This approach could be applied in our case.*

Fisher, N.S., Bohé, M., and Teyssié, J.-L. 1984. Accumulation and toxicity of Cd, Zn, Ag and Hg in four marine phytoplankters. Mar. Ecol. Prog. Ser. 18: 201-213.
Accumulation by algae was rapid and equilibrium was reached with respect to metal partitioning between dissolved and particulate phases. Uptake was passive. Cellular metals content was linearly related to ambient metals concentrations.
If on site studies are undertaken, it may be useful to screen plankton samples for Cd and Zn residues concurrently with water sampling.

Frew, R.D., Hunter, K.A., and Beyer, R. 1989. Cadmium in the dredge oyster *Ostrea lutaria*- dependence on age, body weight and distribution in internal organs. Mar. Pollut. Bull. 20: 463-464.
Oysters collected from Foveaux Strait NZ (2-25 ug Cd/g wet weight) despite the absence of any known anthropogenic input. Lost ~ 20% of the wet body weight as exuded fluid soon after they were opened**.** *Important to include this in the sample to be dried/homogenized.* Suggest that because of variability related to tissue weight and age, the total amount of Cd per oyster rather than Cd concentration be used as an index of contamination. Found ~ 14 ug/year accumulated in excess of excretion. No plateau was found after 4 years of growth. Suggest that time scale for excretion is ~ 10 years. Most of Cd was found in the visceral mass not the gills and muscle implying that most of the Cd was accumulated by ingestion of food particles rather than direct absorption from the water. *Provide a regression of growth layers vs age which is counter to the information for C. gigas provided by G. Gillespie PBS and B. Heath BC Fisheries who both indicate that Pacific oysters cannot be aged accurately. Is this a species difference or are they unaware that this is possible ?*

Frew, R.D., Hunter, K.A., and Beyer, R. 1997. Cadmium in oysters and sediments from Foveaux Strait, New Zealand. Proceedings of the trace element group of New Zealand, Waikato University November 1996. pp. 23.
Analyzed 436 individual oysters from 29 sites for Cd as well as the geographical distribution of Cd in oysters and sediments. Average dry weight residue exceeded 20 ug/g Cd . Evidence is presented that Cd transport into the region is largely in particulate form and that phytoplankton uptake of Cd in the Subtropical Convergence produces this Cd-rich particulate matter. *This is a follow-up to an earlier study which suggested that high rainfall may be leaching Cd from Fjordland on the West Coast of the South Island and transporting it south and west across the Southern tip of the Island (Foveaux Strait). Correspondence has been exchanged with Dr. Keith Hunter on this topic and he might be an excellent source of additional information pertinent to conditions on the West Coast of Vancouver Island.*

Garrett, C.L. In prep. Chemical contaminants in sediments and biota from south coastal areas of B.C.- data report for surveys conducted from 1984 to 1995. Environment Canada, Shellfish Section.
Includes tabulation of data on Cd residues (dry weight) in oysters collected at 35 locations intertidal locations in the Strait of Georgia 1987/88 and two in Clayoquot Sound. Detailed site locations have been obtained and results plotted on our map (Fig. 1, yellow dots). There are some additional (not as well specified as to location) earlier EC data that could be entered.

Greenwood, N.N., and Earnshaw, A. 1984. Chemistry of the elements. Oxford, Pergamon Press. pp. 1542.*

Harbo, R.M., and Birtwell, I.K. 1983. Trace metal content for crustaceans and fishes from Howe Sound, British Columbia. Management Biology Support Unit, South Coast Division, Department of Fisheries and Oceans. 379. pp. 44.
Intent was to provide baseline data and identify local metal contamination problems. Most (1971-73) sites were adjacent to urban and industrial areas. In 1976, additional sites were sampled at Texada and Cortes Islands and Cowichan Bay however no Cd in oyster determinations were made. No information is presented on where in relation to the intertidal zone the collections were made nor what the size ranges were. *Crassostrea gigas* were reported to contain much higher levels than other shellfish 1.37 ug/g wet weight (range 0.7-3.4 ug/g); 2.9-14.0 ug/g on a dry weight basis Mean= 5.95 ug/g dry for N=42. Compare this to 0.4 ug/g wet and 2.3 ug/g dry for all other shellfish. (littleneck clam, horse clam and butter clam all ~ 0.1 ug/g wet). *Oyster data extracted: Presumably a single specimen at each location except where noted. Note that 36/42 analyzed for Cd, came from one location (Mudge/Gabriola). These data have been plotted on our map (Fig.1, blue dots).*

Hung, Y.-W. 1982. Effects of temperature and chelating agents on cadmium uptake in American oyster. Bull. Environm. Contam. Toxicol. 28: 546-551.
After 40 days exposure to (simulated polluted waters ~50 ug Cd/L) soft tissue (dry weight basis) residues were 25.2; 54.6; 85.5 and 123 ug/g at 5, 10, 15 and 20 C respectively. *There may be significant temperature differences among BC sites utilizing suspension culture, and therefore differential uptake rates due to temperature. Reference to the IOS OSAP data base and site records (if available) should identify these.*

Jackim, E., Morrison, G., and Steele, R. 1977. Effects of environmental factors on radiocadmium uptake by four species of marine bivalves. Mar. Biol. 40: 303-308.
In radiolabelled -Cd uptake experiments, *Mytilus edulis* (filter feeder) accumulated an order of magnitude higher Cd residues than deposit feeder *(Nucula proxima*). Marked interspecies differences in uptake rates in responses to temperature were reported, ranging from no difference @ 10 and 20 C for *M. edulis* to a 90% increase at 20 C vs 10 C for *Mulinia lateralis* (also a filter feeder). The presence of 5 ug/L zinc tended to decrease uptake in these two species and a reduction in salinity from 30 to 20 ppt at both 10 and 20 C produced a 24-400% increase in Cd uptake in *M. edulis, M. lateralis* and *N. proxima*. Feeding type was important with *M. lateralis* (an infaunal filter feeder) accumulating 5x more Cd than the deposit feeder *N. proxima. This challenges the intuitive view that shellfish living in contact with sediments would tend to accumulate more Cd than ones suspended in the water column. Influence of salinity may be very important.*

Jackson, A.P., and Alloway, B.J. 1992. The transfer of cadmium from agricultural soils to the human food chain. *In* Biogeochemistry of trace metals. *Edited by* D. C. Adriano. Boca Raton, Lewis Publishers. pp. 109-158.

Kim, Y., Powell, E.N., Wade, T. L., Presley, B.J., and Brooks, J.M. 1999. Influence of climate change on interannual variation in contaminant body burden in Gulf of Mexico oysters. Mar. Environ. Res. 48: 459-488.
Discussion of NOAA Mussel Watch data *C. virginica* trends in relation to ENSO (El Nino Southern Oscillation). Most oysters (2 yr old) reach equilibrium with local exposure conditions within 3 months for metals. Interannual changes of Cd were concordant in bays within 100 km and 600 km of each other i.e. rising and falling simultaneously from year to year (1986-1992) in the southern Gulf but not in the northern part. Overall, Cd residues declined nearly monotonically over the 7-yr period reflecting reduction in use and metals were less strongly influenced by ENSO than organics. Salinity, temperature, feeding rate and food supply were implicated as controlling factors in feeding rate and uptake of Cd. *This paper suggests that circulation patterns and oceanographic conditions may control uptake kinetics over large areas. Perhaps applicable to the mainland inlets in the upper Strait of Georgia, and the west coast of Vancouver Island.*

Köhler, K., and Riisgård, H.U. 1982. Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*. Mar. Biol. 66: 53-58.
Mussels were exposed to Cd (200 ug/L) for 40 days and residues determined. In another experiment, exposure was for 40 days to 50 ug/L followed by 30 days to 100 ug/L) under laboratory conditions (18-23 ppt SW at 4-10 C). Report a linear uptake of Cd at a rate of 3.1 ug/g/day (dry weight basis) at 50 ug/L in flow through lab sea water, 4.1 in starved, and 6.6 ug/g/day in supplementary-fed mussels in semi-static exposures. When [Cd] was low in the tissues, no MT was detected however once it appeared, MT rose concurrently with [Cd]. When mussels were transferred to clean SW for depuration, Cd-content dropped from 564 ug/g to 417 ug/g over 30 days. The % of remaining Cd bound to MT increased from 22 to 78%. Cd induces synthesis of MT. This may be due to Cd denaturing protein and stimulating new protein to be synthesized. *If this were the case, then MT would in essence become a sink for Cd until MT production were inhibited.* The observed increase in % Cd bound to MT during depuration may be due to such a mechanism. The linear uptake observed is similar to that reported for *C. virginica.*

Kooi, B., and Walker, D. 2000. 2000 survey of toxic substances in Comox Harbour and Cowichan Bay. Draft data report. Shellfish and Aquaculture Section, Environmental Protection, Environment Canada.
Most recent survey containing data on Cd levels in intertidal oysters. *Indicates no increase since earlier surveys of 1973, 1987/88 Compare to Denman and Thetis Island CFIA 2000 cultured data which are 4x higher in Cd residue.*

Lares, M.L., and Orians, K.J. 1997. Natural Cd and Pb variations in *Mytilus californianus* during the upwelling season. Sci. Total Environ. 197: 177-195.
Very low Cd residue 5.6 ug/g dry +/- 0.46 95% C.L. *Consistent with different physiology between mussels and oysters. Confirms rapid response to upwelled Cd; both up and down.*

Lepp, N.W. 1992. Uptake and accumulation of metals in bacteria and fungi. *In* Biogeochemistry of trace metals. *Edited by* D. C. Adriano. Boca Raton. FLA, Lewis publishers. pp. 277-297.

Llewellyn, T.O. 1994. Cadmium materials flow. US Department of Interior, Bureau of Mines. Information circular 9380. pp. 17.

McKenzie, J.M., Kjellstrom, T.E. and Sharma, R.P. 1985. Cadmium status in a New Zealand population group ingesting high daily intakes of cadmium. Proceedings of the fifth international symposium on trace elements in man and animals. Aberdeen Scotland. Commonwealth Agricultural Bureaux, Farnham Royal UK. pp. 526-528.
NZ dredge oysters *Ostrea lutaria* containing ~ 25 ug Cd each are consumed seasonally at rates of up to 6 dozen/week. Fecal samples were monitored for Cd excretion and urine for B2- microglobulin concentration. None of the 78 subjects demonstrated departures out of the normal range. An argument is made for reconsidering the PTWI for Cd. *This appears to be in contrast to current views of FAO/WHO CODEX and other international agencies. May represent a special case of physiological adaptation ?*

McLaren, P., Cretney, W.J., and Powys R.I. 1993. Sediment pathways in a British Columbia fjord and their relationship with particle-associated contaminants. J. Coastal Res. 9: 1026-1043.

Nelson, H., and Goyette, D. 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. pp. 57.
Objective was to determine the baseline contamination from zinc that had been used by mills for bleaching of newsprint pulp. Industry was switching to a boron bleaching process and recovery of shellfish was to be monitored. Collections were made in May, June, August and November 1973. Copper, zinc and cadmium were determined in pools of 2-5 oysters at 5 different locations along the mid-intertidal zone at each station. i.e. data for each station represent 10-25 oysters. Areas surveyed included Powell River, Campbell River, Crofton, Nanooose Harbor, Texada Island, Lasqueti Island, Gambier Island, Alberni Inlet, and Sooke Basin. *This is a key paper as the data comprise the baseline for intertidal oyster Cd residues in the region against which current levels in cultured oysters can be measured. Data (green dots) are plotted on our summary map*

(Fig. 1). Results are presented on both wet and dry weight basis and the relationship of 0.15 x dry = wet was utilized in the present review.

O'Connor, T.P. 1996. Trends in chemical concentration in mussels and oysters collected along the US coast from 1986-1993. Mar. Environ. Res. 41(2): 183-200.
Uptake rate of metals by bivalves differs among species eg. Oysters vs mussels collected at the same location. Sites on Long Island Sound where both mussels and oysters were collected, Cu and Zn were enriched in oysters by a factor of 10 relative to mussels, whereas Pb was 3x higher in mussels than in oysters. For other elements (presumably including Cd) the species differences were less than less than 3-fold. The influence of fluctuating salinity, growth, reproductive state and other natural and varying factors which determine uptake and retention rates hinder trend detection. *If salinity were to play an equally important role in Cd uptake by oysters, this might account for some of the variability in Cd values reported for BC. i.e. could there by a recent trend to lower salinities resulting in an increase in Cd uptake? A search of the data base of water properties, currents, tides and other oceanographic parameters maintained by the Ocean Science and Productivity Division (OSAP) at IOS would help address these issues.*

Pedersen, T.F., and Waters, R.D. 1989. Assessment of the enrichment of cadmium and other metals in the sediments of Port Moody and Indian Arm, British Columbia. EPS. MISC 89-1. *****
Sediment cores from the pre-industrialization era showed levels of Cd in excess of the current 0.6 ug/g Ocean Dumping limit; up to 8 ug/g dry weight. *Similar mechanism proposed to that in the Ucluelet study.*

Pedersen, T.F., Waters, R.D. and Macdonald, R.W. 1989. On the natural enrichment of cadmium and molybdenum in the sediments of Ucluelet Inlet, British Columbia. Sci. Total Environ. 79: 125-139.
Cd sequestered from overlying seawater by precipitating in form of CdS into organically enriched anoxic sediments. Up to 8 ug/g dry weight. *If this were to happen, might resuspend at high tide and make locally available to plankton and oysters. However unlikely that oysters would be living in anoxic environments, certainly not oysters being cultured.*

Reinfelder, J.R., Wang, W.-X., Luoma, S.N. and Fisher, N.S. 1997. Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels. Mar. Biol. 129: 443-452.
Interspecies comparison indicating very different physiological mechanisms of metabolism/depuration of Ag, Am, Cd, Co, Se and Zn. In oysters *C. virginica* , 65% of originally ingested Cd was still present after 16 days. Cd administration was through consumption of phytoplankton that had been briefly (40-60 minutes) exposed to radioactive Cd. Detailed turnover constants and assimilation efficiencies are provided. *Data are consistent with the general concept of the binding of the bulk of Cd in oysters by metallothionein-like proteins, rendering it unavailable for depuration. This has significant ramifications for the use of depuration as a mitigative measure.*

Roesijadi, G., Young, J.S., Drum, A.S. and Gurtisen, J.M. 1984. Behavior of trace metals in *Mytilus edulis* during a reciprocal transplant field experiment. Mar. Ecol. Prog. Ser. 18: 155-170.

Metals contents in whole body, digestive gland and gills of *Mytilus edulis* were monitored at 2, 4, 8, 16 and 24 weeks of suspension in cages 3 m above the bottom at two locations; one polluted (Tacoma) one uncontaminated (Sequim). In addition mussels were transplanted from Sequim WA < >Tacoma Harbor. Seawater was monitored for Cu, Zn, Cd, Hg and Ag as well as temperature and salinity. Zinc increased linearly in transplanted Sequim mussels whereas Tacoma- originating mussels reached a steady state after 2 weeks. Tacoma>Sequim mussels did not immediately decrease in whole body residue. There was an ~8 wk lag period before depuration (partial) occurred. Cd and Ag in whole mussels continued increasing at 24 weeks while Cu, Zn and Hg decreased. Cd increased only slightly from ~ 5.2 ug/g dry weight at day 0 to ~6.5 ug/g after 24 weeks at Sequim and to 8.5 ug/g at Tacoma. Mussels taken from the "contaminated site" at Tacoma transplanted to Sequim remained virtually unchanged in Cd residue. Interestingly the initial Tacoma whole body Cd residue did not differ from the "uncontaminated" site at Sequim. Changes in SW metals concentration (52-116 ng Cd/L at Sequim) could be associated with content in mussels but the two were not in synchrony. Zn and Hg in whole mussel exhibited an 8 wk lag before concentrations began to decrease. Gill, digestive gland and whole body Cd residues are presented and differ markedly. *If the metals dynamics in oysters are similar, a depuration period … if it were possible to implement … might not necessarily result in a reduction in Cd residues. Ambient SW Cd concentrations especially if fluctuating, many not show a clear correlation with whole body Cd residues. Because of the potential influence of Zn on Cd dynamics, it may be useful to measure (concurrently) Zn levels in SW and whole mussels.*

Seaconsult, 1999. Iona deep sea outfall 1999. Environmental monitoring program. Effluent dispersion and solids deposition modelling study. Prepared for GVRD. pp. 108.

Thomson, J.D. 1982. Metal concentration changes in growing pacific oysters *Crassostrea gigas*, cultivated in Tasmania, Australia. Mar. Biol. 67: 135-142.
Spat (stage when free swimming larvae settle out of the water column and become sessile) transferred to two growing areas one intertidal, one suspended to a depth of 9 m. Metals were monitored over one growing season. Metal content increased with time with the trend similar to that of weight growth curves. [Cd] increased from 1.5 to 13.3 ug/g dry weight (2 ug/g wet weight). Concentrations curves showed a downward trend indicating dilution by new tissue. National Health and Medical Research Council wet weight standards of 2 ug/g wet weight were exceeded at both sites. There was no significant difference in slopes of uptake regression lines between the two locations despite the fact that the intertidal oysters were submerged ~65% of the time with a tidal amplitude of 1 m. Although zooplankton metals contents were highest in the summer, growth was not matched by corresponding uptake of metals. Non-food particulates may comprise a larger fraction of ingested matter during the summer. Seasonal changes in uptake were thought to be related to lower salinities due to rainfall. *Useful information on similar uptake by same oyster stock transplanted to widely different habitats. No [Cd] in sea water is given. Higher winter concentrations may be linked to greater solubility of metal ions in lower salinity water This is consistent with other literature*.

Thomson, J.D. 1983. Short-term changes in metal concentration in the cultivated Pacific oyster, *Crassostrea gigas* Thunberg, and the implications for food standards. Aust. J. Mar. Freshw. Res. 34: 397-405.

Discusses the advisability of stipulating food standards on a dry weight basis because of inherent lower variability and the possibility of "manipulation" of concentrations based on wet weight. Placing oysters in low salinity water for 48 and 100 h diluted the metal residue by osmotic water uptake. *Pacific oysters marginal for Cd could conceivably be placed in low salinity water for a period before marketing; a perhaps effective but dubious strategy from a health protection point of view. If standards were on a dry weight basis, this loophole would be closed.*

Waldichuk, M. 1983. Pollution in the Strait of Georgia: a review. Can. J. Fish Aquat. Sci. 40: 1142-1167.
Table 1. Gives the range of Cd levels in water (70-80 ng/L) and in sediments <2.0 ug/g dry weight. These are actually from Saanich Inlet and sediment cores from the point Grey Ocean Dumping Site respectively

Wallner-Kersanach, M., Theede, H., Eversberg, U. and Lobo, S. 2000. Acccumulation of trace metals in a transplantation experiment with *Crassostrea rhizophorae*. Arch. Environ. Contam. Toxicol. 38: 40-45.
Transplants between contaminated (but not by Cd) and uncontaminated sites in Brazil. Measured metals at 0, 25, 30 and 60 days. Clean > contaminated took up Cd and Pb (during the first 15 days..then no change between 25 and 60 days) to levels (2.97 ug/g) Cd similar to oysters native (3.54 ug/g dry) to the contaminated site. Cu and Zn were accumulated to lower levels than in native sp. Subsequent elimination experiment by re-introducing oysters to the uncontaminated area showed reduction in Cd and Pb back to original uncontaminated levels but not in Cu and Zn after 30 days. A second experiment found that oysters exposed for 60 d in the contaminated site transferred back to the uncontaminated site underwent reduction in Cu and Pb but not in Cd (2.03 > 2.14 ug/g) and Zn. Ambient levels of Cd in seawater were low but not specified. Different degrees of trace metal fixation eg metallothionein binding were thought to account for these differences. e.g. slow turnover of Cu and Zn. *Of limited use as SW ambient concentrations not reported nor are pertinent WQ data . However the discussion of uptake/depuration rates differing in the same species acclimatized to different environments is useful. Implication is that MT generated after long-term exposure has influence on depuration rates is consistent with the literature. Equilibration time for Cu and Zn may be as long as 8 mo and 5 mo respectively. No estimate given for Cd. Reference is made to literature indicating examples of long (~1yr) vs short ~2 wks required for transplanted bivalves Macoma balthica and Mytilus edulis respectively to reach levels (Cu/Zn) similar to those of resident species that have been long-term acclimatized. This is consistent with the literature indicating large interspecies differences in metals uptake.*

Wang, W-X., Fisher, N.S. and Luoma, S.N. 1996. Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*. Mar. Ecol. Prog. Ser. 240: 91-113.
Discuss the roles of particulate and aqueous phases in metals availability i.e. that taken up from the dissolved phase vs. ingestion of particulate matter containing metals. The influence of tide on particle composition was investigated. Radiotracers were used to determine proportion of metal associated with seston and degree of depuration. Cd was unique among 6 metals radiosotopes in that it was more efficiently assimilated when less chlorophyll A was present in the seston. Assimilation efficiences were calculated. Influx rates of metals increased as the salinity dropped from 34 to 20 ppt. For Cd this was in the range of 1.7x however between 15-20 ppt there was little change in uptake. Efflux

rates were studied and were similar whether food or dissolved phase was the source of exposure. Depuration of Cd was described as 1 compartmental (perhaps bound to metallothionein) and very slow. Excretion via defecation was very low. The biological half life was given as 67.4 days. Most of the Cd was associated with digestive glands and soft tissue. Cd was unique in that very little was taken up by the shell. The proportion of total body burden predicted from laboratory experiments to come from the dissolved phase ranged from 51-76% and was remarkably consistent with data from San Francisco Bay and Long Island Sound. Under most conditions >50% of Cd in mussels comes from the dissolved phase. Total suspended solids (TSS) had essentially no effect on predicted bioaccumulation factor for Cd however variation in Kd (partition coefficient of suspended particles) can have major effects, e.g. a 10 fold increase in Kd would result in a 145% increase in Bioconcentration Factor for Cd. Assimilation rates of Cd from different types of algal food were 11 and 34% Salinity influence on uptake is discussed in relation to changes in metals speciation and increased bioavailability at lower salinity. Reference is made to literature indicating an increase in Cd uptake by mussels related by decreased osmolarity. Table 9 provides literature values of biological half lives reported from both laboratory and field studies. Range 16-1155 days for Cd. Application of the kinetic model developed in this paper to field survey data of Cossa (1988) predicted 45% of Cd in mussels was obtained from food and 55% via uptake from water.

If these relationships are similar in oysters, they may prove valuable in comparisons of various BC sites and culture methods.

Appendices

Appendix 1

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 1(a-h) for details.

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

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

Figure 1c. Comparison of cadmium residues (ug Cd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Barkley Sound.

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

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

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

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

Figure 1h. Comparison of cadmium residues (ug Cd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Ladysmith Harbor.

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 1(a-h)

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.

Appendix 2

Current oyster culture techniques from B.C. Shellfish Growers Association Web Site. (http://www.island.net/~bcsga/bcsgirs/oysters/oyster.htm)

Appendix 3

DFO/BC Fisheries oyster sampling proposal with outline of longer term experimentation. GMK July 11/2000.

After plotting all available Cd/oyster historical data on charts, it is starting to look like something in the culture technique may be responsible for the apparently elevated levels. This is in addition to the occurrence of geographic areas that have historically had elevated Cd levels in beach oysters. Given the current concern and search for a potential solution, we have come up with two proposals; both requiring coordinated participation from growers.

1a) **Short Term**. Locate 3 leases in the upper Strait of Georgia, one in the mid Strait e.g Denman Island and one on the West Coast e.g. Barkley Sound where there are "wild" oysters along with cultured oysters that are undergoing "beach hardening". Assuming that age cannot be easily determined, collect 10 of each of similar size and analyze for Cd. History of the beach-hardened oysters should be known.

b) To get an idea of relationship of size to Cd residues, collect 20 "wild" oysters of a wide size range from a beach location such as Lasqueti, which has historically elevated Cd levels.

c) Obtain samples of representative materials used in culture operations e.g. "oyster blue", plastic trays, pipes, etc. for testing for potential leaching of Cd. Cadmium sulfide has been used as a component of pigments in plastics and as Cadmium/Barium carboxylates as UV stabilizers in PVC.

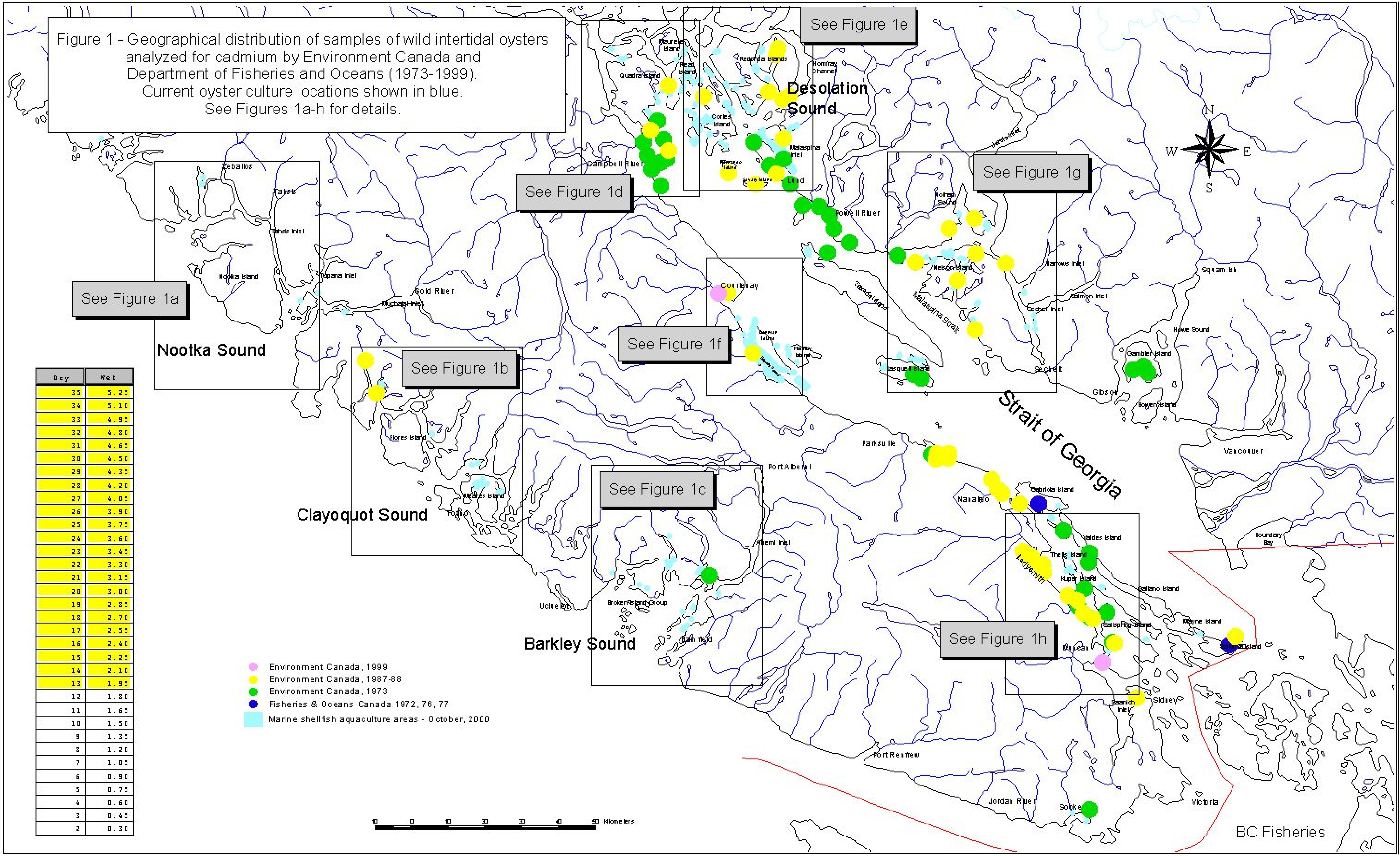
2**) Long Term.** Distribute spat from a known stock (hatchery) to representative locations for suspension culture. After 1 year, sample for Cd. This should integrate information on local conditions e.g. geography, salinity, temperature, productivity, that may lead to enhanced Cd uptake under suspension culture. If necessary, samples could be taken again at the end of the suspension phase (2 years).

Proposed sharing of responsibility:

1) Growers/BC Fisheries determine which sites meet the above criteria, work out access logistics including boats, DFO (GK) will assist in collection, will arrange analytical chemistry, data analysis and report preparation. Recommendations and mitigation strategies, if possible, will be identified. Collection phase of 1a & b should be completed as soon as possible to avoid the added complication of spawning.

1c) Growers/BC FIsheries to provide representative samples of equipment used. DFO will arrange Cd analysis and prepare report.

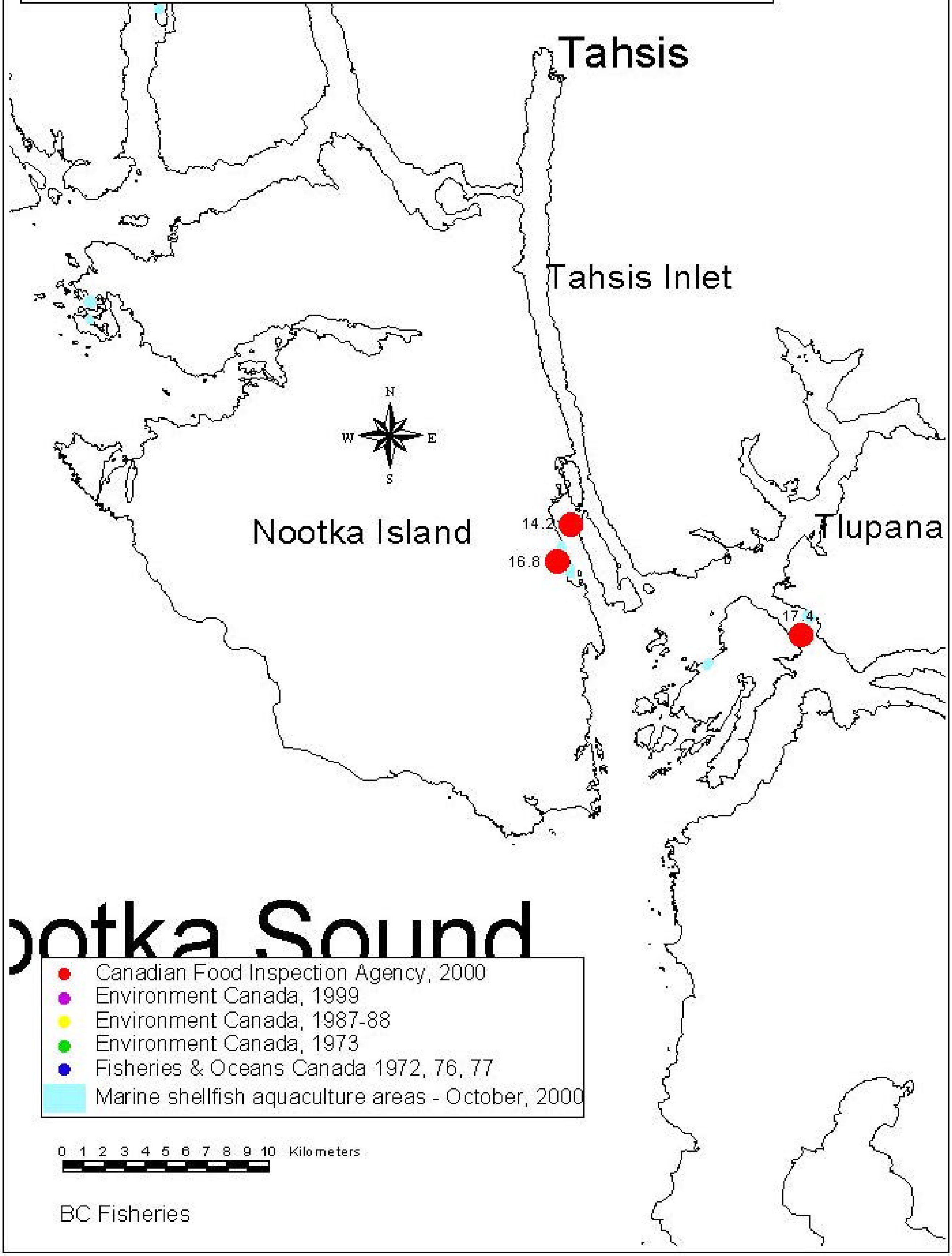
2) In consultation with DFO on appropriate sites and to ensure comparable rearing techniques, Growers/BC Fisheries distribute spat this season and provide samples for Cd analysis next summer. DFO will be responsible for analytical work, interpretation and reporting as above.



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 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



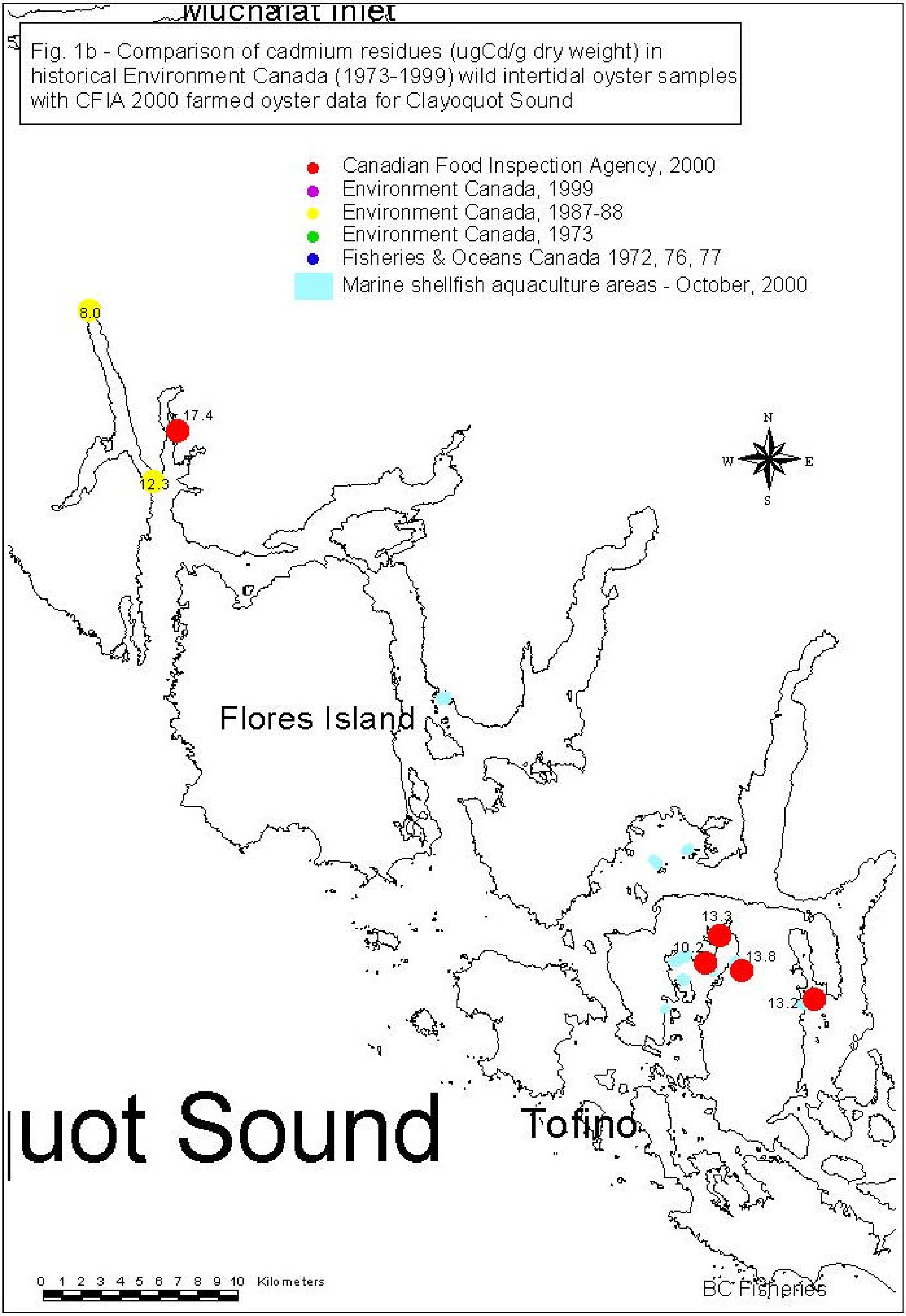


Fig. 1b - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Clayoquot Sound

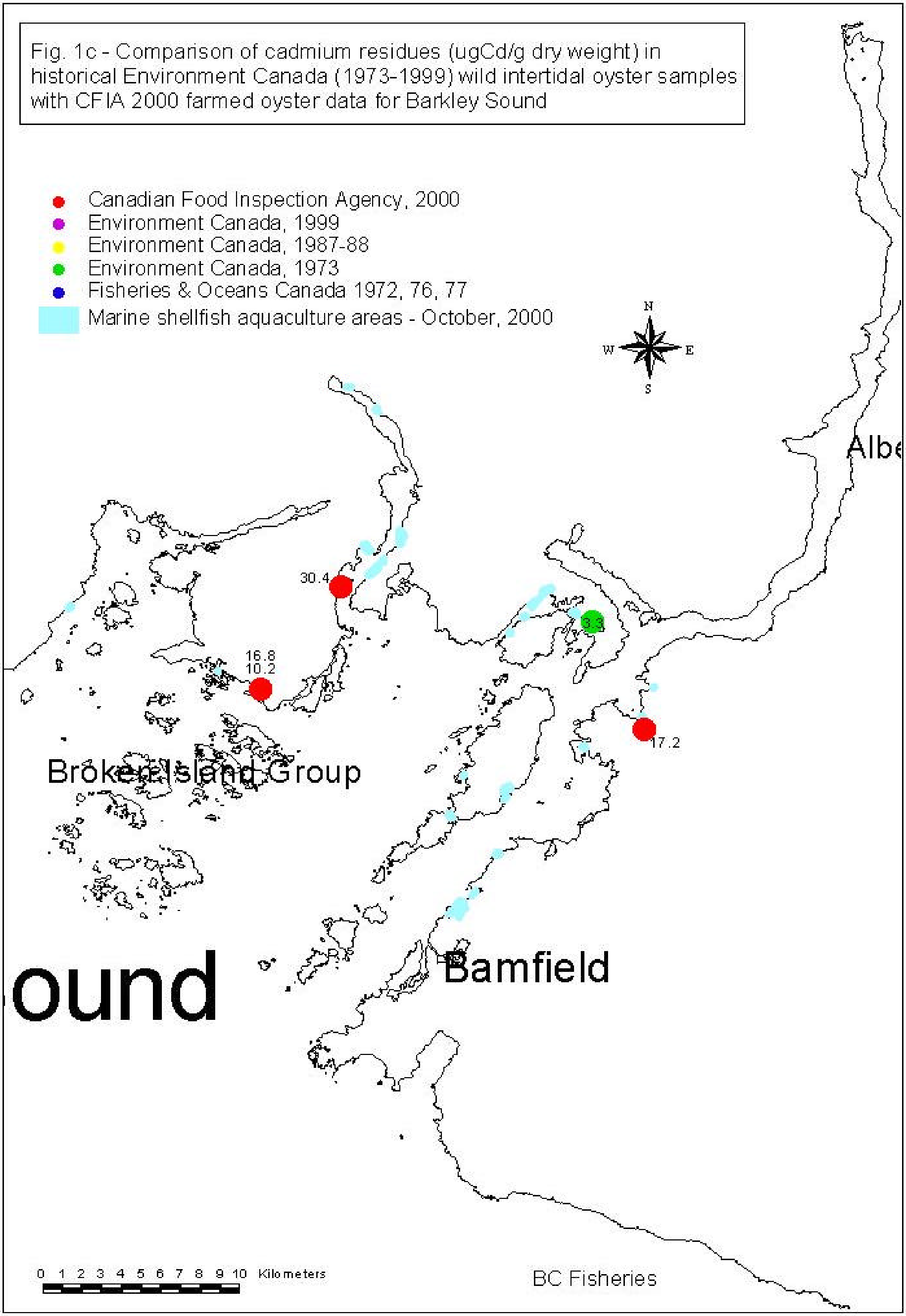


Fig. 1c - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Barkley Sound
Canadian Food Inspection Agency, 2000
Environment Canada, 1999
Environment Canada, 1987-88
Environment Canada, 1973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

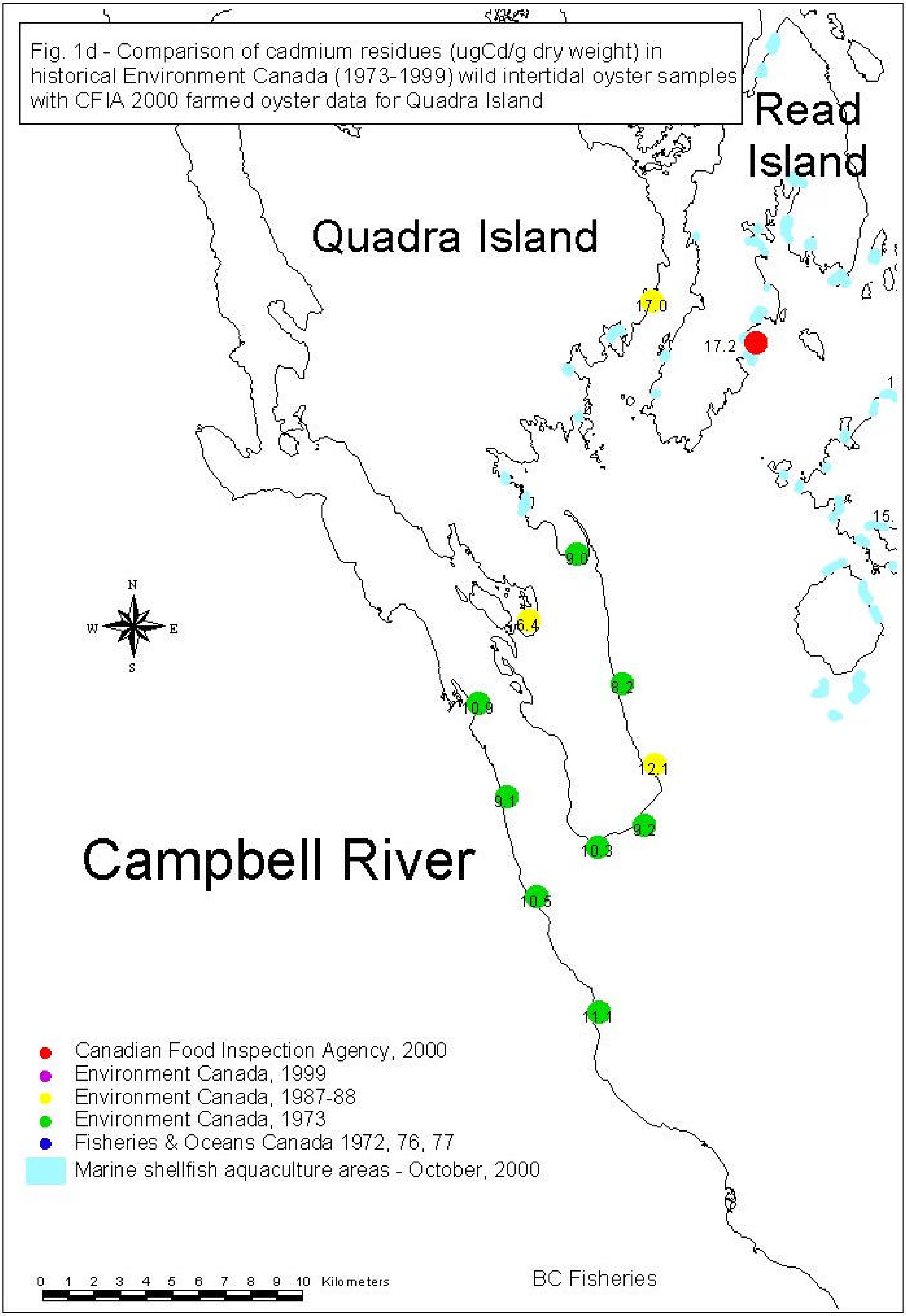


Fig. 1d - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Quadra Island

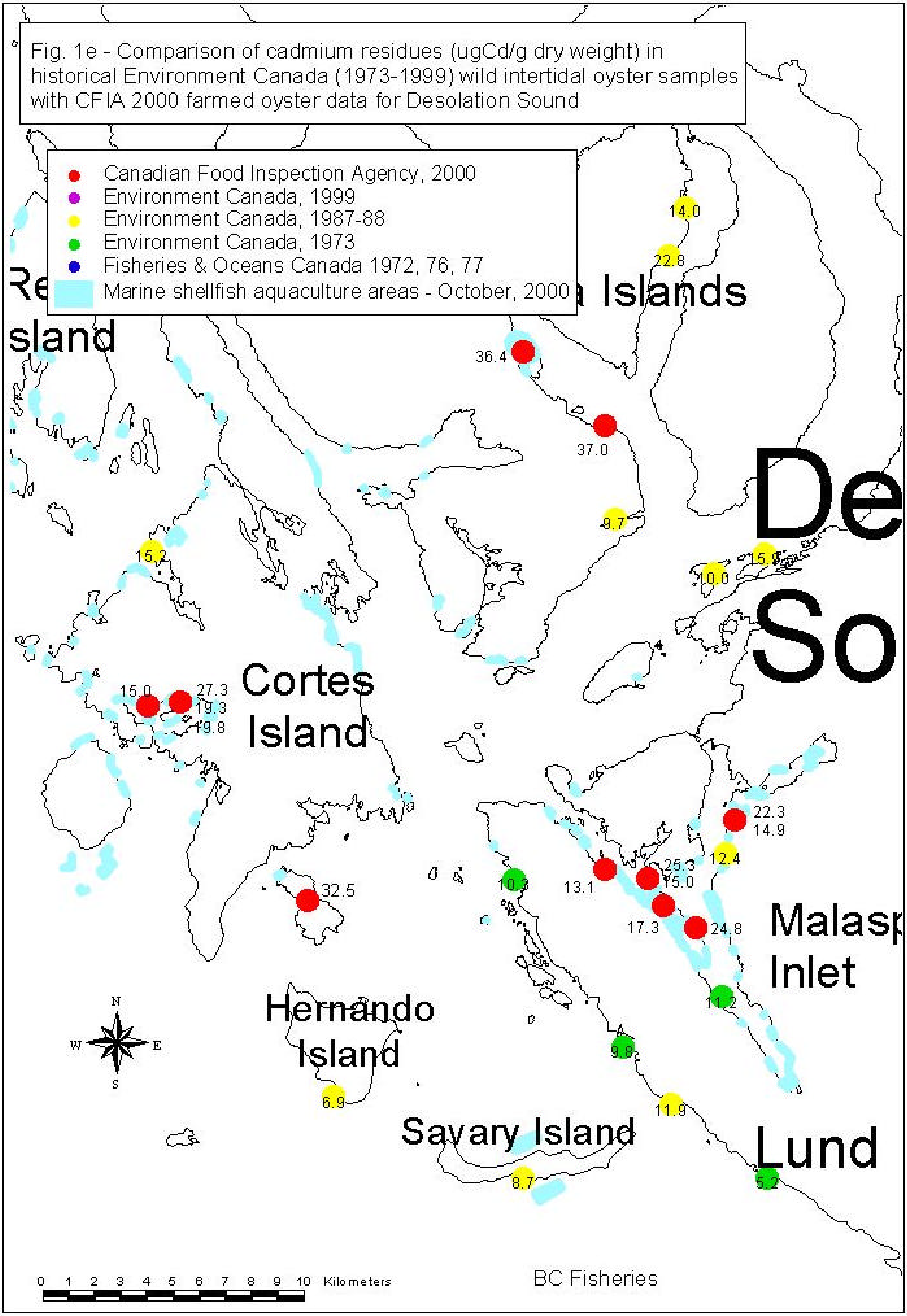


Fig. 1e - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Desolation Sound

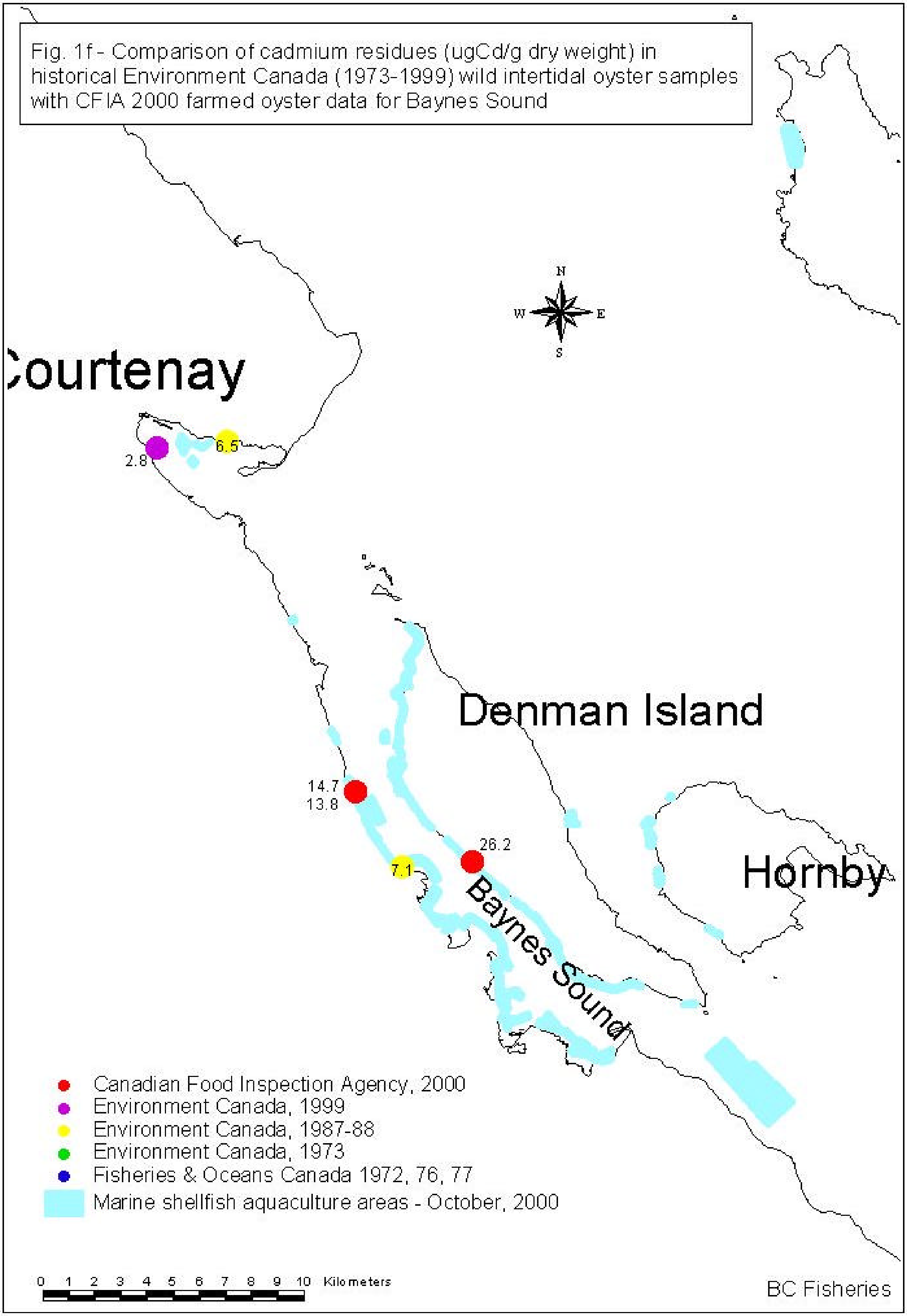
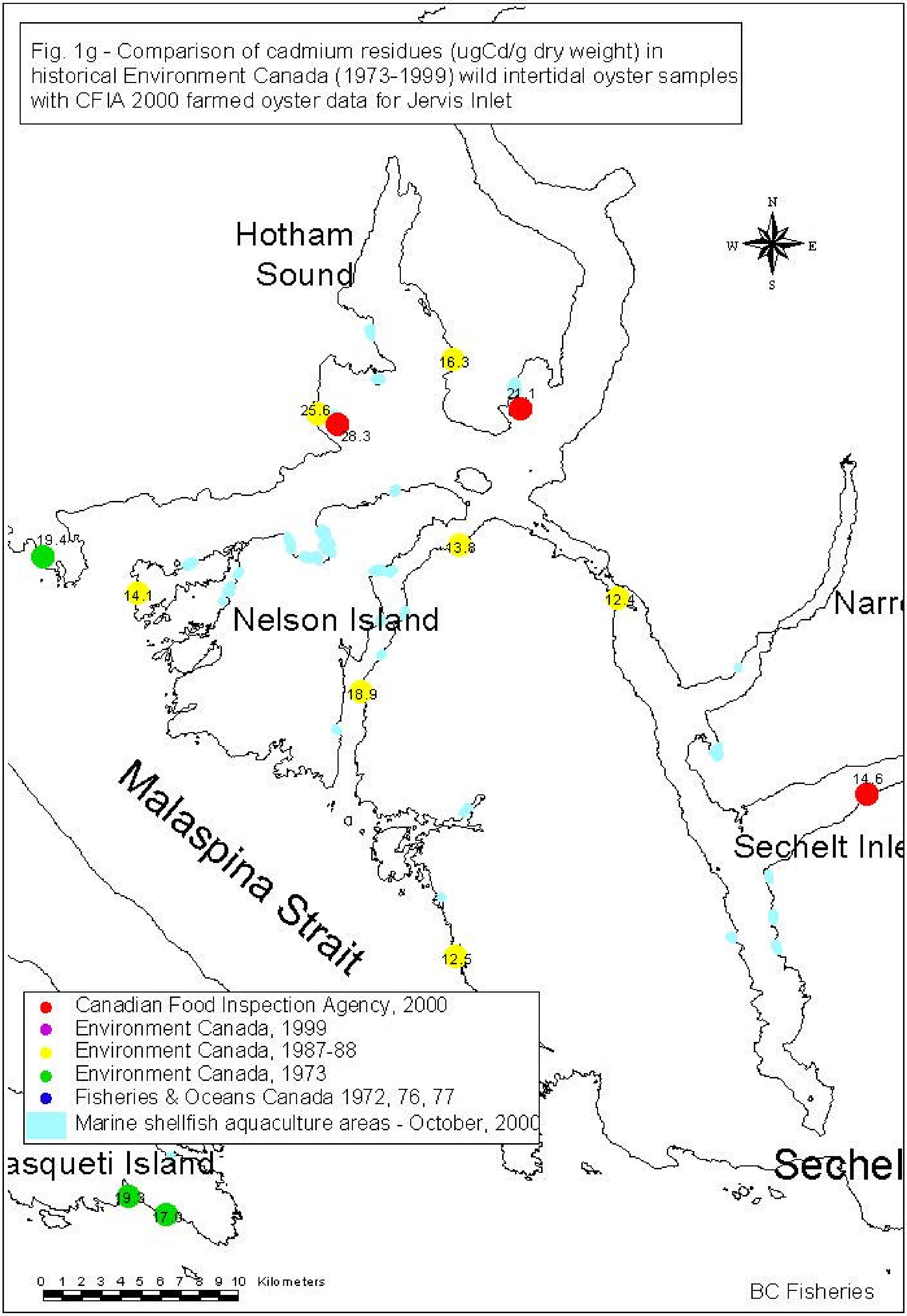


Fig. 1f - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for Baynes Sound
N
W
E
S
Courtenay
2.8
6.5
Denman Island
14.7
13.8
26.2
7.1
Baynes Sound
Hornby
Canadian Food Inspection Agency, 2000
Environment Canada, 1999
Environment Canada, 1987-88
Environment Canada, 1973
Fisheries & Oceans Canada 1972, 76, 77
Marine shellfish aquaculture areas - October, 2000
0 1 2 3 4 5 6 7 8 9 10 Kilometers
BC Fisheries

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



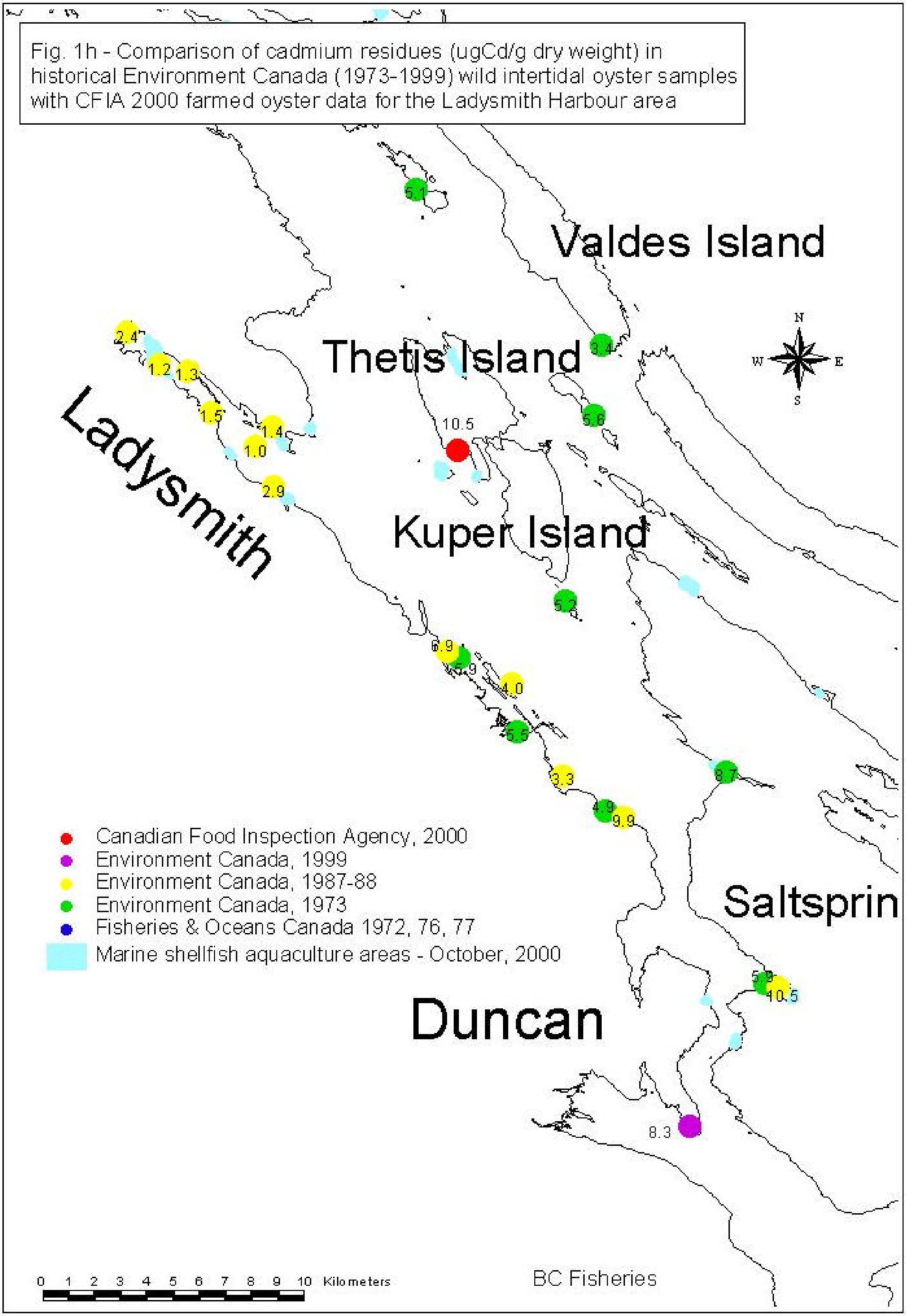
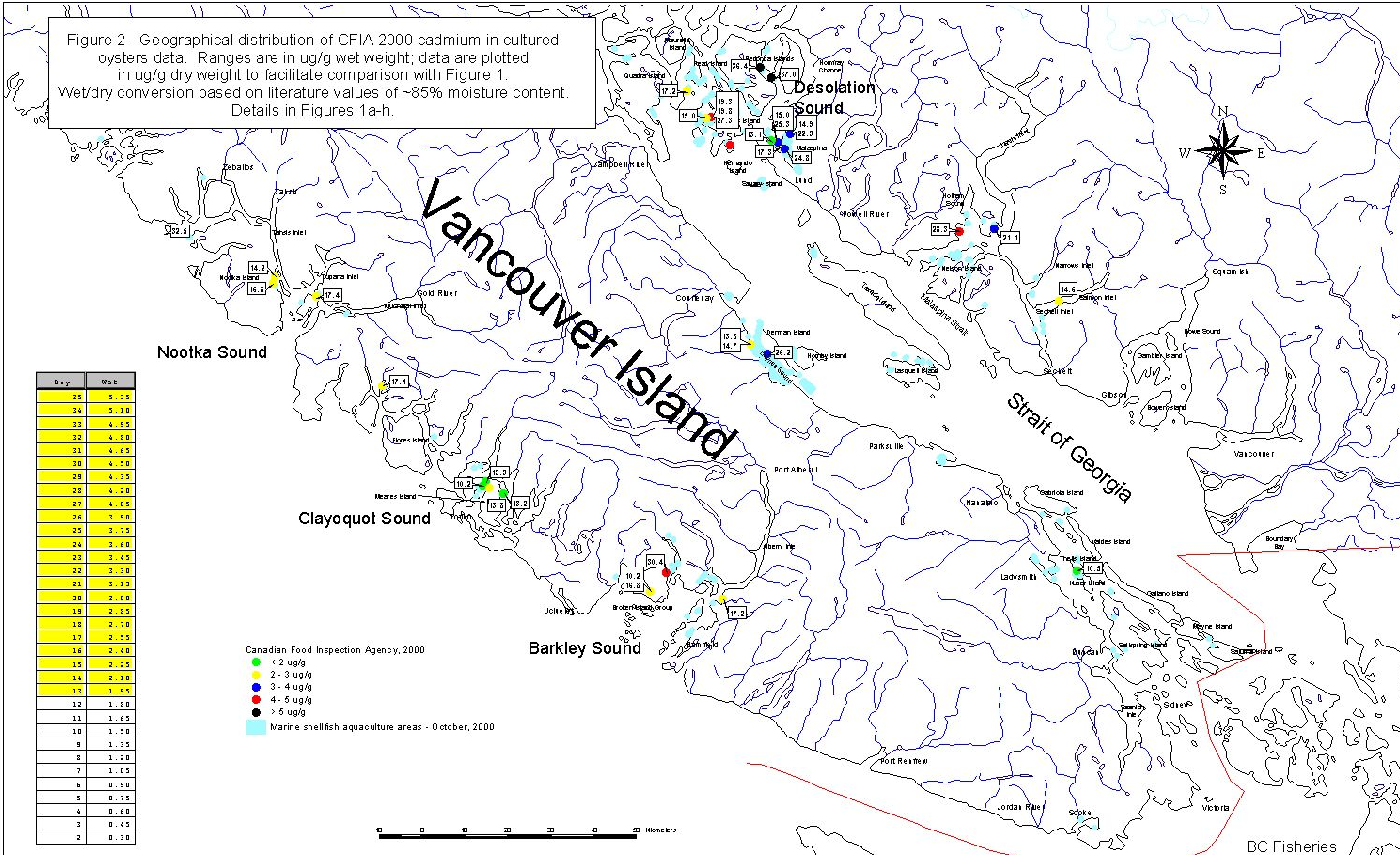


Fig. 1h - Comparison of cadmium residues (ugCd/g dry weight) in historical Environment Canada (1973-1999) wild intertidal oyster samples with CFIA 2000 farmed oyster data for the Ladysmith Harbour area
Valdes Island
Thetis Island
Kuper Island
Ladysmith
Saltsprin
Duncan
N
W
E
S
5.1
3.4
5.6
10.5
2.4
1.2
1.3
1.5
1.4
1.0
2.9
5.2
6.9
5.9
4.0
5.5
3.3
4.9
9.9
8.7
5.9
10.5
8.3
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
0 1 2 3 4 5 6 7 8 9 10 Kilometers
BC Fisheries

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

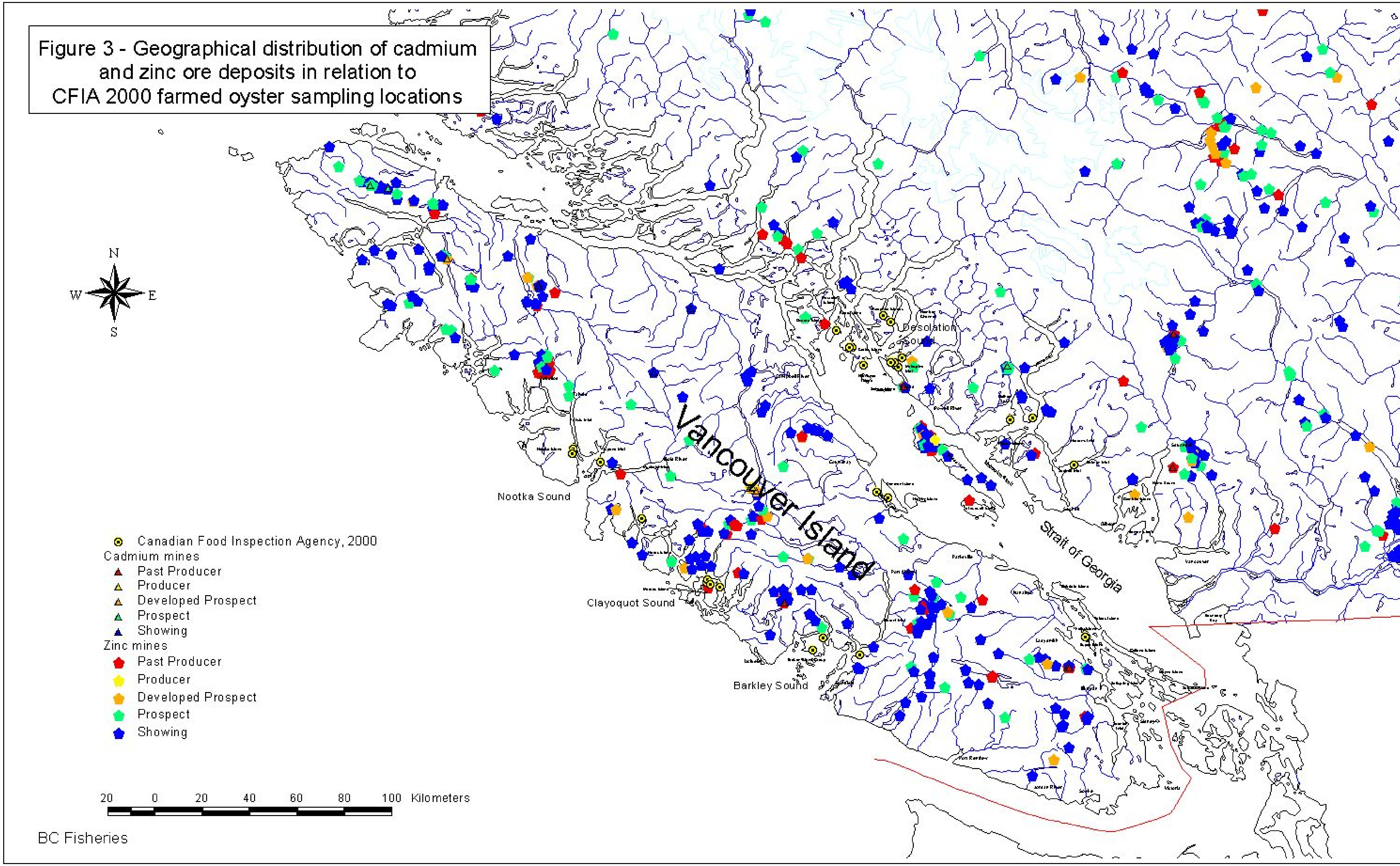


Figure 3 - Geographical distribution of cadmium and zinc ore deposits in relation to CFIA 2000 farmed oyster sampling locations
N
W
E
S
Desolation Sound
Vancouver Island
Nootka Sound
Strait of Georgia
Clayoquot Sound
Barkley Sound
Canadian Food Inspection Agency, 2000
Cadmium mines
Past Producer
Producer
Developed Prospect
Prospect
Showing
Zinc mines
Past Producer
Producer
Developed Prospect
Prospect
Showing
20 0 20 40 60 80 100 Kilometers
BC Fisheries

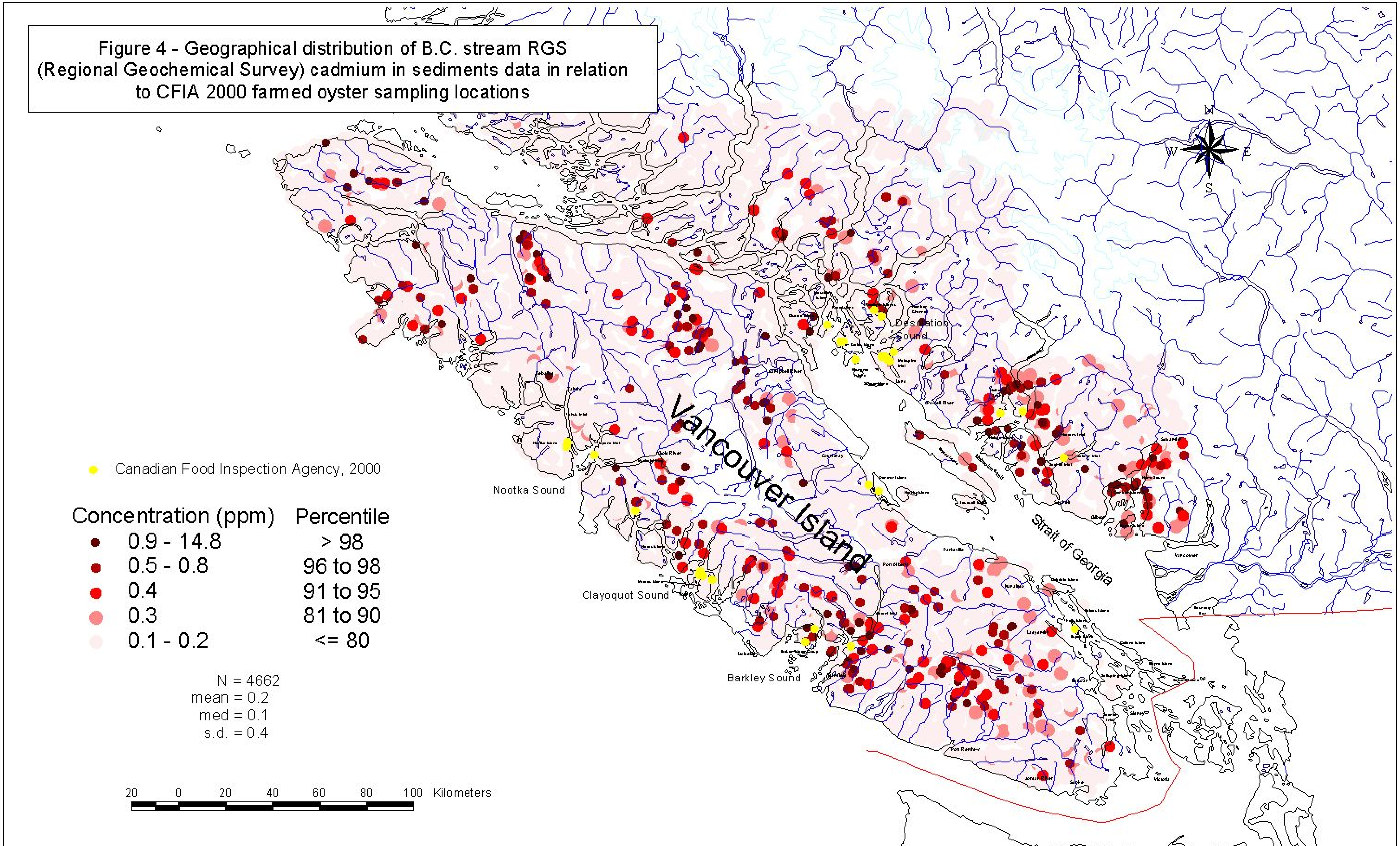


Figure 4 - Geographical distribution of B.C. stream RGS (Regional Geochemical Survey) cadmium in sediments data in relation to CFIA 2000 farmed oyster sampling locations