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Ecological and Oceanographic Criteria for Alternate Ballast Water Exchange Zones in the Pacific Region

Critères écologiques et océanographiques des zones alternatives pour l'échange des eaux de ballast dans la Région du Pacifique

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ABSTRACT

We present an overview of the ecological risk associated with draft zoning regulations for disposal of ballast water that has not been exchanged in mid-ocean before vessels arrive at ports in British Columbia. Using data on average seasonal currents off the BC coast, we analysed the possible transport of ballast water organisms into deep ocean habitats and away from key ecosystems and habitats (pilot MPAs, productive fishing grounds, spawning grounds, areas of high primary and secondary productivity, aquaculture operations, areas where ballast water is already being discharged or exchanged, and submarine and estuarine features promoting landward transport). To decrease the risk of possible harm to coastal ecosystems, an amendment of the draft Transport Canada "Annex II" alternate ballast water exchange zone (ABWEZ) is suggested, as given below. Our analysis of currents, bathymetry, and eddies provide rationale for these amendments. Consideration is required of special ABWEZs inshore of the 50 n mi/500 m depth boundary, should weather conditions or other factors require them. Previous assessments showed that an ABWEZ in Juan de Fuca Strait and entrance was associated with risk for non-indigenous species introduction. Further risk assessment is required to investigate the suitability of other special ABWEZs in Pacific region. We also discuss the problematic issue of coastal transport of ballast water organisms and suggest some possible steps to reduce dispersal from this vector into BC waters.

With the exception of Bowie Seamount (53° 19′; 135° 38′, 50 n mi (92.6 km) diameter exclusion) and western Queen Charlotte Sound (50 n mi headland (50° 46.5′; 128° 26.0′) to headland (51° 55.6′; 131° 0.0′)), our proposed alternate ballast water exchange zone includes any waters more than 50 nautical miles from the coast and west of the 500 m depth contour.

RÉSUMÉ

Nous présentons un survol du risque écologique relié au projet de règlement sur les zones de déversement des eaux de ballast qui n'ont pas été changées au milieu de l'océan avant que les navires entrent dans les ports de la Colombie-Britannique. En nous servant des données sur les courants saisonniers moyens au large de la province, nous avons analysé le transport éventuel des organismes présents dans les eaux de ballast vers les habitats océaniques profonds et loin d'écosystèmes et d'habitats clés (ZPM pilotes, pêcheries productives, frayères, aires de forte productivité primaire et secondaire, installations aquacoles, endroits actuels de déversement ou de changement des eaux de ballast et caractéristiques sous-marines et estuariennes favorisant le transport vers le littoral). Pour réduire le risque de dommage possible aux écosystèmes côtiers, nous proposons un amendement au projet d'annexe II de Transports Canada portant sur les zones alternatives pour l'échange des eaux de ballast (ZAEEB), énoncé ci-dessous, que nous justifions d'après notre analyse des courants, de la bathymétrie et des remous. Il faut considérer les ZAEEB spéciales situées en deçà de l'isobathe de 500 m et de 50 milles marins du littoral lorsque les conditions météorologiques ou d'autres facteurs l'exigent. Des évaluations antérieures ont révélé qu'une ZAEEB située à l'entrée et dans le détroit Juan de Fuca posait un risque d'introduction d'espèces exotiques. Une évaluation du risque plus détaillée est requise afin d'établir si les autres ZAEEB spéciales établies dans la région du Pacifique sont adéquates. Nous discutons aussi le problème du transport côtier des organismes présents dans les eaux de ballast et proposons des mesures pour réduire leur dispersion dans les eaux de la Colombie-Britannique.

À l'exception du mont sous-marin Bowie [53° 19′; 135° 38′, rayon d'exclusion de 50 milles marins (92,6 km] et du secteur ouest du détroit de la Reine-Charlotte [50 milles marins de cap (50° 46,5′; 128° 26,0′) à cap (51° 55,6′; 131° 0,0′)], une autre zone alternative pour l'échange des eaux de ballast que nous proposons inclut toutes les eaux gisant à plus de 50 milles marins du littoral et à l'ouest de l'isobathe de 500 m.

Introduction

In this paper we consider the ecological risk of releasing non-indigenous species (NIS) into Canada's west coast waters through coastal ballast water obtained elsewhere in the world that has not been exchanged in mid-ocean or treated to kill NIS in situ. In accordance with Transport Canada guidelines, vessels entering the Canadian Exclusive Economic Zone (EEZ, up to 200 nautical miles (370 km) offshore) from a trans-Pacific voyage should have performed mid-ocean exchange in locations where water depths are not less than 2000 m. According to a draft Transport Canada regulation ("Annex II") and the harbour procedural manuals of three ports in BC, if a ship has not performed mid-ocean ballast water exchange, the ship can be sent back to sea to de-ballast, subject to safety concerns. The location of such de-ballasting, hereafter called the alternative ballast water exchange zone or "alternate BWE zone" is of concern because of the risk of introducing harmful NIS to ecosystems within Canadian waters.

General Description of Risks

Few studies have focused on ballast water organisms in the Pacific region, therefore it is difficult to provide data on "problem species" that may have been introduced through this vector. A comprehensive review of the potential ecosystem changes caused by ballast water mediated NIS in other regions of the world is beyond the scope of this paper, but a general discussion and additional references may be found in Levings et al. (2002) and Ruiz and Carlton (2003). Some of the ecosystem changes associated with NIS that have been identified in coastal British Columbia and elsewhere are provided in Table 1. Potential problems range from changes in biodiversity to introduction of parasites that may be harmful to cultured species.

The wide variety of marine ecosystem types found in the Pacific Region may render this area more vulnerable to NIS relative to other Canadian coasts. Although many ships arriving in BC have conducted mid-ocean exchange (MOE) outside the EEZ (see below) this procedure is not entirely efficient (Locke et al. 1991; Levings et al. 2004). As a result, some remnant NIS are probably routinely released by de-ballasting within BC coastal waters, both offshore and in harbours. Levings et al. (2002) noted that the Strait of Georgia has more recorded incidents of NIS relative to other high latitude temperate water bodies, possibly owing to the estuarine characteristics of the Strait. The wide range of temperature, salinity, and substrate conditions in the Strait allow ample opportunity for the colonization of organisms from a wide variety of coasts around the world. In addition, the large volumes of ballast water disposed of by ships using the Port of Vancouver and other harbours in the Strait may be an important factor.

For the purposes of this paper we define an area of low risk as an area where a non-indigenous coastal organism discharged from a ballast water tank has a low probability of surviving because it has been discharged into or transported to oceanic areas of adverse physical conditions, primarily water depth, salinity, and temperature (Levings et al. 2004; Wonham et al. 2001). In some cases biological factors can affect survival but in general these are poorly understood. Conversely an area of high risk would be an area where physical conditions are similar to the harbour or port where the organism was taken into the ballast water tanks.

Identification of Risk to Resources and Ecosystems from Currently Identified Alternate BWE Zones

Current procedures described by port authorities: It is difficult to specify the location of the currently identified alternate BWE zones on the west coast of Canada. There are at least 20 ports in BC that handle deep sea shipping, but only four or five have specific protocols for harbour management. Of these few ports, we could identify three that specifically mention alternate BWE zones.

Until recently, the alternate BWE zone described by the Vancouver Port Authority (VPA), which regulates most of the shipping on the west coast, was described as "in the outgoing current of the north side of the Strait of Juan de Fuca, west of Race Rocks". An amendment to the VPA website dated April 30, 2004 now specifies "Denial of permission to discharge ballast water that does not meet these requirements may result in the vessel being ordered to depart the POV (Port of Vancouver) in order to carry out a ballast water exchange to the satisfaction of the VPA" (http://www.portvancouver.com/the_port/harbour_operations.html). This is essentially the same regulation included in the Fraser River Port Authority (FRPA) operational document (http://www.frpa.com/pdf/PPs_July04.pdf). The Juan de Fuca Strait site is also specifically listed in the Nanaimo Port Authority (NPA) Regulations (http://www.npa.ca/en/corpinfo.htm). The operational procedures of the Prince Rupert Port Authority, one of the other major ports in the Region, do not mention alternate BWE zones (http://www.rupertport.com/home.htm).

Larson et al. (2003) and Levings (1999) discussed the risks associated with the Juan de Fuca alternate BWE zone. The oceanographic models used in the former analysis clearly showed that any site within this zone was associated with a risk for NIS introduction, especially owing to estuarine transport of deeper water into inshore areas with reduced circulation such as the Strait of Georgia. In addition, the close proximity of this zone to a pilot Marine Protected Area (Race Rocks; Wright and Pringle 2001) has raised concerns for a number of years (Levings 1999).

Alternate BWE zones proposed in draft Annex II of Transport Canada regulations: On June 10 2004, Habitat and Enhancement Branch, Pacific Region requested a review of the following draft Annex II, which was developed by representatives of the BC Chamber of Shipping and the Port of Vancouver.

A vessel that has been unable to carry out ballast water exchange due to weather or other reasonable circumstance may on notification of Transport Canada, through the Canadian Coast Guard MCTS referenced in section 3 of this annex, exchange ballast in waters under Canadian jurisdiction provided the exchange is carried in waters of at least 200 m depth and at least 50 nautical miles from the nearest land (Fig 1, 2).

Initial comments on this Annex were provided by one of us (MF) with the caveat that a peer reviewed response would be provided during a subsequent national review meeting.

This draft Annex appears to be the latest official position on the topic and incorporates the thoughts of the maritime industry on the Pacific coast. The distance and depth criteria described in the proposed Transport Canada alternate BWE zones (hereafter "draft Annex II zones") are therefore the main focus of our review.

Within Canada's Pacific EEZ (Table 2) there are a number of key ecosystems or habitats (KEHs) that could be harmed by NIS if coastal ballast water organisms are not dispersed by currents into mid-ocean and out of areas where they could colonize or influence coastal habitats and ecosystems. In most instances, our list of KEHs has common features with the "Ecologically and Biologically Sensitive Areas" being developed by others for a DFO framework for ocean management in the Pacific Region.

Table 2 lists the provisional criteria for identifying KEHs and other locations at risk from ballast water dispersal in the draft Annex II zone. Additional comments are provided below.

Seamounts: The Bowie Seamount Area is located between180 -230 km off the west coast of the Queen Charlotte Islands (Fig 3, Appendix Fig 1). Bowie Seamount proper rises from 3100 m depth to within 25 m of the surface while Davidson and Hodgkins Seamount rise to within 1146 and 596 m respectively. This unique and highly productive region is proposed as a pilot Marine Protected Area (Canessa et al. 2003). Establishment of NIS at the seamount would change the natural biodiversity and thereby contradict one key purpose of MPAs. Cobb Seamount, located further south and just outside the EEZ (Fig 3), also rises to within 25 m of the surface and is recognized as a high production habitat (Dower and Perry, 2001).

Highly productive fishing grounds: Productive bottom trawling and mid-water trawling areas are localized on specific grounds off the BC coast including the west coast of Vancouver Island, Queen Charlotte Sound, Hecate Strait, and Dixon Entrance (Figs 4, 5). Fish production could be negatively impacted if NIS were to establish in these areas and interfere with production by endemic fish food species.

Spawning areas: There are 48 species of marine fish and 61 species of marine invertebrates that are considered "significant" by DFO Pacific stock assessors. To map the specific spawning regions of all 109 species is beyond the scope of this paper. Some of the fishing grounds shown in Figs 4 and 5 are locations where spawning populations are frequently targeted by fishers. Since many marine fish and invertebrates have pelagic larvae that are subject to currents, the incubation areas are likely not the same as spawning areas. An example might be Pacific halibut (*Hippoglossus stenolepis*) (Fig 6), a species whose pelagic eggs and larvae are thought to drift with currents away from spawning grounds (St. Pierre 1984). However it should be noted that some important groundfish species such as the Pacific cod (*Gadus macrocephalus*) have demersal eggs (Thomson 1963) that sink to the bottom and hence bottom habitats might be considered "critical" for this species.

High primary and secondary production areas: Inshore intertidal and estuarine areas in BC are well documented as important rearing areas for juvenile fish and invertebrates (e.g. Levings et al. 1983). The intertidal zone on the west coast of Vancouver Island and the Queen Charlotte Islands and the eastern shore of Queen Charlotte Sound are also recognized as key areas for biodiversity (Jamieson et al. 2001; CERF 2000; Sloan et al. 2001). Several offshore areas on the continental shelf off the BC coast are characterized by high production at both the primary and secondary trophic levels (Fig 3). However, it should be noted that these areas cannot be considered to have discrete boundaries because the location of plankton in time and space is subject to shifts in water masses, upwelling, currents and other dynamic processes. Generally, areas of high production occur on the continental shelf and slope and are often over trenches where deep ocean water upwells, thereby creating favourable nutrient conditions for primary productivity.

Aquaculture: There are >100 marine plant, shellfish, and finfish aquaculture operations on the west coast of Vancouver Island. (MAFF 2004; http://www.agf.gov.bc.ca/fisheries/index.htm .) The shellfish and finfish operations are clearly at risk from harmful algal species that might be introduced from ballast water (Hallegraaf 2003). Potential NIS predators such as the Green crab (*Carcinus maenas*) have already been reported in Barkley Sound. While ballast water has not been shown to be a direct vector for this species' transport into BC waters, this medium has definite potential for spreading the species (Jamieson et al. 2002). Green crab have been reported from five estuaries in Oregon and two in Washington. Their year class strength and colonization patterns appear to be influenced by interannual variation in coastal currents (Yamada et al. 2001).

Cumulative effects: Based on vessel traffic patterns at specific areas along the coast, it is clear that the entrances to the Strait of Juan de Fuca and Dixon Entrance are regions where large quantities of exchanged ballast water containing oceanic organisms and remnant coastal NIS are discharged as vessels approach the coast (Fig 7). It would be prudent to avoid de-ballasting of non-exchanged water in these locations to prevent loading of the area by NIS species.

Other areas that should be avoided owing to concerns of cumulative effects include high traffic oceanic sectors where numerous vessels conduct MOE. Based on a relatively small subsample of data from ships using VPA in 1999, there was considerable MOE occurring between 100 and 500 km from the EEZ boundary (Fig 8). Since the promulgation of the Transport Canada guidelines in 2001, which excluded MOE within the EEZ, there may have been increased MOE in the area to the west of the boundary. However there are no syntheses of recent data to investigate patterns.

Identification of Additional Alternate BWE Zones with Lower Risk, Including Port-specific Strategies

Analysis of currents in the draft Annex II zone as a mechanism to transport ballast water organisms away from KEHs: Figures 1 and 2 show predicted summer subtidal currents at 30 m depth along the north and south coasts of BC. Summer currents in the draft Annex II zone therefore generally flow northwest from the north end of Vancouver Island. South of this point, the currents flow southeast. Current speeds within or westward of the draft Annex II zone are at least 0.1 m s^{-1} and are generally higher. These current fields were produced by a simulation carried out at the Institute of Ocean Sciences using ELCIRC, the finite volume model developed for Columbia River and plume studies (Zhang et al. 2004). The simulation was initialized using average summer temperature and salinity fields, and was forced with tides, average summer winds, and nudging back to the initial conditions. Though not yet validated against historical observations, these model currents have, at least qualitatively, captured most of the known circulation features off both the north and south coasts of BC. A similar run with average winter conditions produced directional patterns that tended more towards the northwest (the prevailing wind direction) and velocities that were slightly greater than those predicted by the summer simulation. In both cases it should be noted that these simulations produced average seasonal conditions. Episodic events such as storms or unusually high river runoff could generate substantially different flow patterns. We have assumed that unexchanged ballast water originates in coastal regions with relatively low salinity and the discharged water remains near the surface. Therefore simulations at 30 m depth are valid. However, vertical migration of many ballast water organisms (e.g. copepods and crab larvae) removes them from surface flow and can introduce them into estuarine countercurrents that travel landward (Larson et al. 2003; and see below).

Consideration of eddies, submarine canyons, bathymetry, and Bowie Seamount as features requiring modification of draft Annex II: If the current patterns were in fact consistently tending away from the coastline as described above, released ballast water organisms would therefore be expected to travel away from shallow water at speeds of at least 8.6 km per day. Although there is very high temporal variation in the survivorship of larval and encysted organisms, invertebrate larvae would not survive and affect KEHs if they were moved into deeper water well off the continental shelf. For invertebrate species with long-duration larvae, Fofonoff et al. (2003) gave an estimate of mean larval duration of 2 weeks. As a regional example, Varnish clam larvae, with a planktonic phase lasting 3-8 weeks (Dudas et al. 2003) would be transported into deep water 180-481 km to the northwest, into the Gulf of Alaska, or southeast, into the California Current regime. However there are several complicating factors that in our opinion require modification to the draft Annex II zone and these are described below.

On the west side of Queen Charlotte Sound, the boundary should be 50 n mi from a line joining Cape St. James and Cape Scott to prevent risk to the KEHs in Queen Charlotte Sound and on the Queen Charlotte Islands. Our summer model simulation showed a clockwise eddy over the westward portion of the shelf in this region (Fig 9), a feature consistent with current meter observations described by Crawford et al. (1995). In addition, intense and variable flows, and eddies (Thomson and Wilson, 1987; Di Lorenzo et al, 2005) are forecast in both summer and winter near Cape St. James (Fig 9 and 10). Ballast water organisms released inshore of the 200 m depth contour (Fig 1) extending into the Sound could be transported towards critical areas (e.g. halibut spawning grounds) off Cape St. James and into Hecate Strait. Secondly, there are three submarine canyons on the west side of the Sound that bring deep water from off the shelf towards the land, in an estuarine-like process. Larson et al. (2003) showed that this process can transport vertically migrating ballast water organisms landward where there is enhanced risk of NIS establishment.

Off the southwest end of Vancouver Island, the 50 n mi distance criteria places the boundary in deeper water (> 200 m) where the prevailing currents should help direct transport to the west and avoid submarine canyons. This should help move ballast water organisms away from the Juan de Fuca Eddy in summer (Fig 11) and place them in the strong northeast flow in winter (Fig 12). In fact off all of western Vancouver Island, the 50 n mi exclusion zone boundary (Fig 2) is westward of both the 200 m and 500 m depth contours. So in this region our suggested amendment poses no change to the Annex II proposal. Both proposals would therefore reduce the risk of releasing ballast water NIS organisms into the KEHs in this region. Risk owing to possible cumulative effects might also be reduced as the entrance to Juan de Fuca Strait is heavily used by shipping and it is likely large amounts of exchanged ballast water with remnant NIS are discharged in the area.

Initially, depending on specific de-ballasting locations, NIS released into the Juan de Fuca Eddy might encounter shallow water off the Washington coast. However, these American waters are excluded from the mandatory ballast water exchange protocols of the VPA and other BC harbours (see below). It is possible then that the organisms might eventually be transported to Canadian waters by vessels exchanging ballast in US waters. Larson et al. (2003) concluded that landward transport of vertically-migrating ballast water organisms in the Juan de Fuca canyon could be a mechanism transporting NIS into the Strait of Georgia and Puget Sound.

As an added safety factor to help protect KEHs on the continental shelf, we suggest that the 500 m contour be used as a boundary along the entire BC coast, in association with the 50 n mi offshore line. Steeper slopes on the outer continental shelf, where depth decreases hundreds of metres over a few kilometres, have been recognized as topographic features which can "guide" currents parallel to the shelf and hence direct ballast water organisms away from KEHs in shallow water (Barth et al. 2003). However, as seen in Figure 1, even when the 500 m depth contour is combined with the 50 n mi constraint to define a boundary in Queen Charlotte Sound, there is a reasonable expectation that the prevailing currents could transport NIS in de-ballasted water landward. We therefore recommend that in this region, a pseudo-shoreline be drawn from Cape Scott (50° 46.5′; 128° 26.0′) to Cape St. James (51° 55.6′; 131° 0.0′) and the 50 n mi boundary be taken seaward from that line. Doing so actually removes the need for the additional 500 m depth constraint as now, all along the BC coast, this depth contour is closer than 50 n mi from the shore or pseudo-shore.

Because of the ecological importance of Bowie Seamount (Table 2), we recommend that a 50 n mi diameter exclusion zone be placed around the shallowest part of this feature (Fig 3). The Seamount is outside the boundaries of the model used for current prediction, and there are no current measurements available for this region, either directly from current meters or indirectly via drifters. The prevailing current direction in the top mixed layer around Bowie is probably towards the northwest as part of the Gulf of Alaska gyre, although it is possible that there is a semi-permanent/retentive clockwise eddy around the seamount owing to tidal rectification. Studies around Cobb Seamount several years ago suggested the existence of a semi-permanent eddy, and a similar feature is expected to occur at Bowie Seamount. The Haida Eddies that form off Cape St. James and drift into the Gulf of Alaska each winter have been observed passing over Bowie. It may be possible to manage the exclusion zone around Bowie in real time. The University of Colorado web site: http://e450.colorado.edu/realtime/gsfc_global-real-time_ssh/ shows global satellite altimetry, and the NE Pacific can be magnified to reveal Haida Eddies when they occur.

With the exception of Bowie Seamount (50 n mi diameter exclusion) and western Queen Charlotte Sound (50 n mi headland to headland), our proposed alternate BWE zone therefore includes any waters beyond 50 nautical miles from the coast and west of the 500 m depth contour.

Special ABWEZs Inshore of the 50 n mi/500 m Depth Boundary

Consideration is required of special ABWEZs inshore of the 50 n mi/500 m depth boundary, should weather conditions or other factors require them. Previous assessments using oceanographic models (Larson et al 2003) showed that an

ABWEZ in Juan de Fuca Strait and entrance was associated with risk for non-indigenous species introduction. Further risk assessment is required to investigate the suitability of other special ABWEZs in Pacific region. This will require additional information from the shipping industry so that appropriate locations can be investigated.

Coastal Traffic Issues

Adjacent US waters: Beeton et al. (1998) recommended locations west of the California current (Appendix Fig 1) as an alternate BWE zone for ports in Washington and Oregon. This recommendation was supported by the model simulations by Larson et al. (2003) who, due to the extent of their model domain were only able to evaluate an inshore version of these sites (water of approx. 200 m depth). The analyses indicated that, under normal conditions, organisms moved southward (summer) or northward (winter) in the Shelf Break and Davidson Currents, respectively. Under strong eastward or northward winds they were transported to the Washington or Vancouver Island shorelines, imposing some risk to the latter ecosystems.

More recently, Barth et al. (2003) produced a report to inform ballast water management policy by reviewing significant features of the nearshore water movement in the waters off Washington, Oregon, and California. Though their conclusions were not based on research specific to ballast exchange, their recommendations were made by physical oceanography experts with many years of research on coastal currents along the West Coast of North America. They noted that though general current trends should be carefully considered when determining “if, when, and where” coastal ballast exchange should take place, strong storms and other events could dramatically change these general trends for a short period of time. They also noted that although many of these events/changes can be detected, it is unlikely (although not impossible) that real-time data could be used to determine when and where to exchange coastal ballast water.

A summary of their recommendations and comments on their application to the BC coast are as follows:

i) Six retention zones including the Juan de Fuca Eddy (48°30′N to 47°40′N) were identified as having the capacity to retain organisms. Due to their retentive abilities, these areas should be considered as possible exclusion zones for ballast water exchange (from the shoreline to 50 nautical miles offshore). This conclusion provides support for our recommendation concerning not only the Juan de Fuca eddy but the headland to headland approach for avoiding retentive eddies in Queen Charlotte Sound and the 50 nautical mile zone off the southwest Queen Charlotte Islands where Haida Eddies are generally formed in winter.

ii) Barth et al. (2003) concluded large river or estuarine plumes (e.g. Columbia

River) have the capacity to pull water into the estuary within a few tens of kilometers of the mouth of each estuary on each tidal cycle. Therefore areas just outside estuaries (up to a 15 nautical mile radius) were recommended as possible exclusion zones for ballast water exchange. Although there are no large rivers discharging directly onto the outer coast of BC, estuarine flows arising from the Fraser and Skeena Rivers and numerous smaller rivers emptying into inland seas like the Strait of Georgia and Hecate Strait do exist in Juan de Fuca Strait, Queen Charlotte Strait, Queen Charlotte Sound and Dixon Entrance. However our 50 nautical mile zone should pre-empt the possibility that either flood tide currents or bottom estuarine flows could transport NIS shoreward in the vicinity of these sites.

iii) Along all other areas of the Washington and Oregon coast, Barth et al. (2003) concluded any ballast water discharged outside of the 1000 m isobath has a relatively low probability of reaching the shoreline due to the prevailing currents and the bottom topography (the 1000 m isobath is located along a steep slope). As a general trend in these locations, if the ballast water is discharged closer to the shoreline (moving off the steep slope and onto the continental shelf inside the 200 m isobath), the probability of the organisms reaching the shoreline will increase. Off the BC coast the steep slope usually begins at the 500 m contour and the 1000 m isopleth is only a few kilometres seaward, adding support to our suggestion of the 500 m isobath as a boundary.

iv) Barth et al. (2003) also recommended that seasonal fluctuations should also be considered when determining “when and where” to exchange ballast water. In the spring and summer, prevailing winds mean that currents from Vancouver Island to Point Conception tend to be offshore and southward. In the late fall and winter, the winds reverse and currents in this region tend to be onshore and northward. However disruptions in these regular trends should be taken into consideration. We also considered seasonal differences in forecasted flows, both off Vancouver Island and further north along the BC coast, and with exception of features like the Juan de Fuca and Haida Eddies, generally found these same seasonal patterns.

Because of the complexity of the circulation off southeast Alaska, and elsewhere in Gulf of Alaska, Beeton et al. (1998) recommended that ballast water should be exchanged no closer than 200 km offshore. A particular concern for ecosystems in coastal southeast Alaska might be the existence of the anticyclonic Sitka Eddy which forms north of Baranof Island, has a diameter of 200-300 km and generally moves southwestward (Tabata 1982). If ballast water organisms were released 50 n mi offshore of the northern end of the Queen Charlotte Islands when this eddy was present, it is possible they could be caught and transported by this eddy. This may be another instance where real-time management of ballast water disposal might be desirable.

Exemptions to MOE for traffic arriving from ports north of Cape Blanco: Many vessels arriving in BC ports originate from the west coast of North America (Mexico, California, Oregon, Washington, and Alaska). Some of these vessels are arriving from Puget Sound, WA, and others come from additional West Coast areas (e.g. between January 1 and March 31, 2004 118 vessels departed a California port for a Canadian west coast port; Summary of April 28, 2004 Workshop in Oakland, CA). There is also substantial traffic along the BC coast; for example, between 297 to 333 bulk cargo carriers passed Comox annually in each of 1999, 2000, and 2001 (Haggarty et al. 2003).

According to the proposed Annex II document and harbour procedure manuals for the VPA, NPA and FRPA, an alternate BWE zone would not be required for some of these vessels since they originate in coastal ports within BC, Alaska, north of Cape Blanco in southern Oregon (or Cape Mendocino for NPA). Based on the views of some oceanographers (e.g. Lluch-Belda et al. 2003) that the waters from northern California to Alaska represent a homogenous ecological unit, these vessels are exempt from mandatory ballast water exchange. However this conclusion is not shared by all scientists (e.g. Watson et al. 2003). We are not sure if vessels bound for US ports are subject to such exemptions and hence are not required to follow alternate BWE procedures.

If unexchanged ballast water from certain coastal ports within the exemption zone is being discharged in the interconnecting waterways of Strait of Georgia, Puget Sound, and Juan de Fuca Strait it is likely that ecosystems are at risk from NIS. We have provided a brief rationale below for this conclusion.

Levings (1999), Gramling (2000), Cordell et al. (2003) and Levings et al. (2004) concluded that there is a significant risk of introducing a variety of NIS into BC and Puget Sound from excluded coastwise vessel traffic. In addition, there was consensus during two workshops in Oakland, CA (January 6-7 2003 and April 28 2004; summaries available from CDL) that coastwise and estuary-to-estuary transport of ballast water organisms along the west coast of North America was problematic. The risk may be particularly high when vessels have taken on ballast at west coast estuaries north of Cape Blanco where NIS have been reported (e.g. Green crab: Grays Harbour, Coos Bay, Newport (Yamada et al. 2001); New Zealand mud snail (*Potamopyrgus antipodarum*): Astoria (Hanson and Sytsma 2001)). There are two main reasons for this concern. 1) A number of invertebrate taxa exhibit direct development, without planktonic larvae that can be transported by currents out of estuaries. The populations of species with direct development may be restricted to particular bays or estuaries. For example, amphipods undergo direct development and can readily be transported in ballast water (Chapman 1988). Other taxa with direct development that are potential NIS include cumaceans and tanaids (Waage-Nielsen et al. 2003), isopods (O'Clair and O'Clair 1998), Foraminifera (Sloan and McGann 2000) and a variety of other groups including nematodes and oligochaetes. Dinoflagellates and phytoplankton that form cysts and macroalgae that reproduce via fragments are also sources of concern (Murray et al. 2004), as are seeds from vascular plants. Although some of the above crustacean taxa are usually present in small numbers in coastal ballast water (Levings et al. 2004; Locke et al. 1991), this finding may result from sampling bias. Many organisms with direct development are associated with sediment, which is normally taken in with ballast water in shallow harbours but often not sampled from tanks with the pumps and nets typically used in surveys. 2) The transit time from key ports north of Cape Blanco to BC water is short, likely less than 3 days, which is much faster than might be expected if larvae or other propagules travel only with currents. Larval survival is therefore enhanced with transport by ballast water. Fish have also been recorded in ballast water (e.g. Eurasian ruffe, *Gymnocephalus cernuus*, (ruffe); Pratt et al. 1992), and individuals transported by ballast water over short time periods could also remain viable.

Port-specific Issues

During one of the breakout sessions at the January 2003 ballast water workshop in Oakland, CA, it was suggested that estuaries on the west coast of North America receive a Red, Blue, or Green status based on their NIS communities. Although this methodology would be subjective without a scientifically robust and universally acceptable risk protocol, this concept may be applicable to other ports around the world. A "Red" port would be a harbour that is known to have organisms that are a known ecological threat to endemic organisms or aquaculture species. The "Blue" designation would indicate a possible threat and a "Green" port would be an area free of dangerous NIS. This scheme would obviously require major research and survey programs, as well as significant international cooperation. However, a similar scheme has been developed for NIS-borne disease organisms that might provide a template (AAPQIS 2004).

In our context, if ballast water originated at a "Red" port, then the vessel should be required to exchange this water in a very low risk area prior to entering a Canadian port. It is also possible that emerging ballast water treatment technology (Sutherland et al. 2003) might be employed to decrease the probability of NIS transport.

Uncertainties and Recommendations for Research

Consideration is required of special alternate BWE zones inshore of the 50 n mi/500 m depth boundary, should weather conditions or other factors require them. Larson et al. (2003) and Levings (1999) discussed the risks associated with a special alternate BWE zone in Juan de Fuca Strait and entrance. The oceanographic models used in the former analysis clearly showed that any site within this zone was associated with a risk for NIS introduction. Further risk assessment is required to investigate the suitability of other special alternate BWE zones in Pacific region.

Improvements of methods used for surveying NIS on ships that have not performed MOE are needed to determine the relative risk from NIS in water compared to sediment as well as various types of ballast tanks. Improved survey methods and better assessment of risk would help managers decided if a ship should be sent to an alternate BWE zone.

One of the difficulties in identifying KEHs where NIS pose a risk in our Region is the lack of data on the viability of discharged ballast water organisms in BC coastal waters. There are particular concerns about fish, invertebrates with direct development, algal cysts and fragments, and vascular plant seeds. Propagules from NIS are probably viable immediately after discharge. The survivorship of eggs, egg-carrying organisms and larvae is difficult to predict because there are no local data on this topic. Another problem is our lack of data on the differential susceptibility of various habitats to NIS invasions. Estuaries such as the Strait of Georgia are likely more at risk because of the variety of temperature and salinities regimes found there. However, other habitats can also be affected. For example subtidal benthic habitats in Puget Sound, where temperature and salinity changes are moderate, have been invaded by the encrusting tunicate *Didemnum cf lahillei* (Anon, 2005).

New ecological surveys of ports north of Cape Blanco are required to update databases and evaluate the risk posed by NIS in particular harbours (e.g. Coos Bay, Carlton et al. 1993). An international “Standing Committee” to inform industry and managers in Canada and USA of these data should be considered. Syntheses of ballast water records for vessels arriving into Pacific Region from trans-Pacific voyages are required to confirm that all MOE is occurring outside the EEZ. An analysis of the locations for MOE adjacent to the boundary is required to assess risk of cumulative effects from ballast water organisms released in this oceanic region.

Conclusions and Recommendations

To decrease the risk of possible harm to coastal ecosystems in Pacific Region, an amendment of the draft Annex II zone is suggested, as given below. Our analysis of currents, bathymetry, and eddies provide rationale for these amendments.

With the exception of Bowie Seamount (50 n mi diameter exclusion) and western Queen Charlotte Sound (50 n mi headland to headland), our proposed alternate ballast water exchange zone includes any waters more than 50 nautical miles from the coast and west of the 500 m depth contour.

Consideration is required of special ABWEZs inshore of the 50 n mi/500 m depth boundary, should weather conditions or other factors require them. Previous assessments showed that an ABWEZ in Juan de Fuca Strait and entrance was associated with risk for non-indigenous species introduction. Further risk assessment is required to investigate the suitability of other special ABWEZs in Pacific region.

Unexchanged ballast water from certain coastal ports north of Cape Blanco, Oregon, discharged in the interconnecting waterways of Strait of Georgia, Puget Sound, and Juan de Fuca Strait poses a risk to these ecosystems. Exemptions from mandatory ballast water exchange for water from these ports should be reviewed.

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Appendix I

List of references identifying areas of high primary or secondary productivity off the British Columbia coast. Numbers relate to those in KEH areas in (Figure 3).

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Table 1. List of selected non-indigenous species, related problems, and potential effects on coastal ecosystems in BC and elsewhere.

Species or Taxa	**Potential Effect**	**Comments and Reference**
Atlantic cordgrass (*Spartina alterniflora*)	Colonization of mudflats and changes in habitats for oyster culture	Major problem on the outer coast of Washington; other species of Spartina have colonized Fraser River estuary mudflats (DFO, unpublished)
Green crab (*Carcinus maenas*)	Potential predator on intertidal bivalves	Recorded from west coast of Vancouver Island (e.g. Barkley Sound) but as far as known has not colonized (Jameison et al. 2002)
Varnish clam (*Nutallia obscurata*)	Possible competitor with native intertidal bivalves	Now commercially harvested in BC (Gillespie et al. 2001)
Tropical green seaweed *Caulerpa taxifolia*	Nuisance species and may compete with endemic algae	Colonized California intertidal zone (Williams et al. 2002) but temperature may be a barrier for BC
Dinoflagellates associated with harmful algal blooms	Some species can cause human health effects in seafood	None identified in limited survey of BC ballast water (Waters et al. 2002) but a serious international problem (Hallegraeff 2003)
Change in biodiversity and possible "invasion meltdown"	Of concern for Marine Protected Areas (e.g. Bowie Seamount) and National Marine Conservation Areas (e.g. Haida Gwaii)	Canessa et al. 2003, Sloan in press, Levings et al. 2004, Ricciardi 2001
Ctenophore *Mnemiopsis leidyi* in the Black Sea	Changes in energy flow in the pelagic zone on continental shelf	Bilio and Niermann 2004
Bivalve *Theora lubrica* in New Zealand	Changes in dominant species in benthic organisms used as fish food	Morley and Hayward 1999
Sabellid polychaete in abalone	Parasite on cultured species	Bower 2000
Harpacticoid copepods in estuaries	Possible changes in food supply for juvenile salmon	Bollens et al. 2003

Table 2. Criteria and risk factors for seven types of locations on the BC coast that may be within the draft Annex II zone. KEH (Key Ecosystem and Habitat).

Ecological function of feature to consider when determining risk of a location from ballast water exchange	**Comments, Figure in present document, and References**	**Risk relative to draft Annex II zone**
Pilot MPA (KEHs) (Biodiversity, endemic species)	Relevant areas: Race Rocks, Bowie Seamount (Wright and Pringle 2001; Canessa et al. 2003) (Fig 3).	Low risk for Race Rocks; high risk for Bowie
Important fishing grounds (which are often also major spawning grounds) (KEHs)	Pers comm., Dr Alan Sinclair, Pacific Biological Station (Fig 4,5)	High risk for grounds influenced by Juan de Fuca and Haida Eddies (Fig 9,11)
Fish spawning grounds (KEHs)	Examples: halibut off Cape St James (St. Pierre 1984); Pacific cod on Amphitrite Bank, southwest coast Vancouver Island (Sinclair et al. 2001) (Fig 4,6)	High risk for grounds influenced by Juan de Fuca and Haida Eddies (Fig 9,11)
Shorelines and estuaries (multiple KEHs)	Levings et al. 2002, Jamieson et al. 2001, Sloan et al. 2001, CERF, 1999	Low risk except areas influenced by Juan de Fuca and Haida eddies (Fig 9,11)
Area of high primary or secondary productivity (pelagic or benthic) (KEHs)	See Appendix list of references (Fig 3)	High risk for grounds influenced by Juan de Fuca and Haida Eddies (Fig 9,11)
Areas where significant amounts of ballast water are being discharged or exchanged	Present document (Fig 7,8); Levings et al. 2004	Risk for areas > 50 n mi offshore unclear but higher off entrance to Strait of Juan de Fuca
Marine plant, shellfish, and finfish aquaculture	Present document; BC gov't website	High risk for coastal sectors influenced by Juan de Fuca and Haida Eddies; moderate risk for other areas (Fig 9,11)
Submarine features promoting landward transport in estuarine and estuarine-like processes	Present document; Larson et al. 2003	High risk off entrance Juan de Fuca Strait (Larson et al. 2003) and west Queen Charlotte Sound (present document)

List of Figures

Figure 9. Darker colour denotes the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average summer model currents at 30 m are also shown.

Figure 10. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average winter model currents at 30 m are also shown.

Figure 11. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average summer model currents at 30 m are also shown.

Figure 12. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average winter model currents at 30 m are also shown.

Appendix Figure 1. Location of places and oceanographic features named in the text.

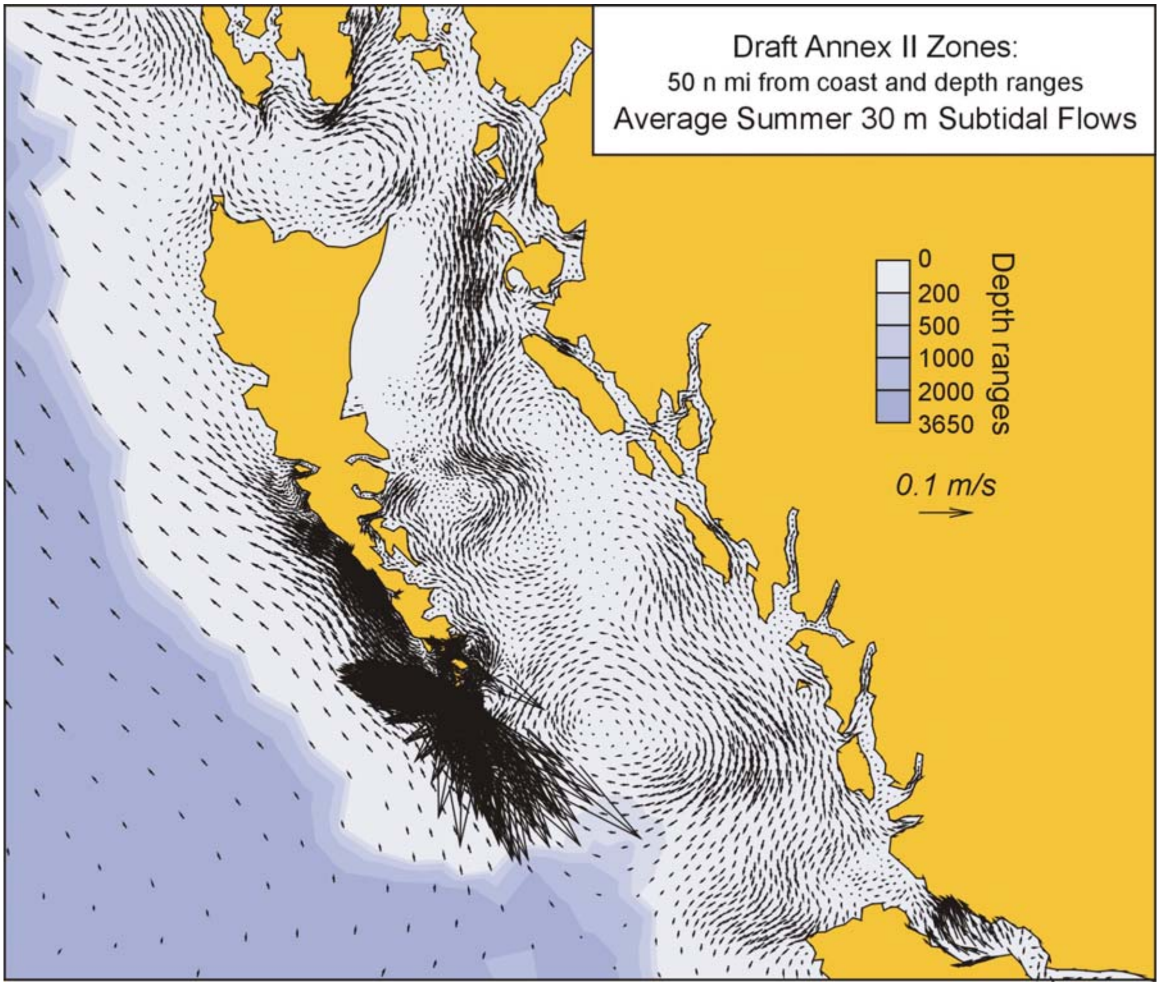

Figure 1. Average summer subtidal currents (from model and data) and zones arising when the 50 n mi constraint is combined with depth limitations. The lightest colour denotes the Annex II exclusion zone comprising regions that are either less than 50 n mi from shore or less than 200 m depth. The next lightest colour shows how much larger this Annex II zone becomes when 200 m is replaced by 500 m, and so on.

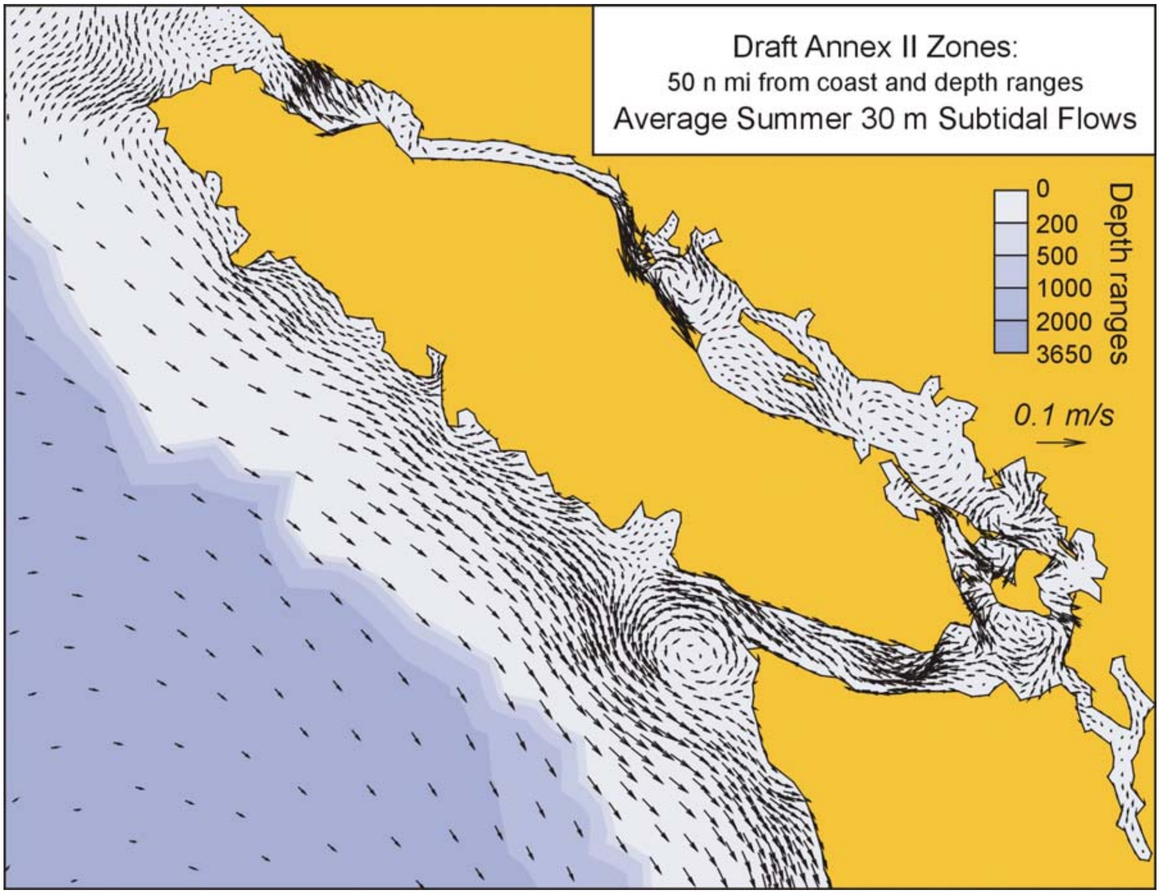

Figure 2. Average summer subtidal currents (from model and data) and zones arising when the 50 n mi constraint is combined with depth limitations. The lightest colour of blue denotes the Annex II exclusion zone comprising regions that are either less than 50 n mi from shore or less than 200 m depth. The next lightest colour shows how much larger this Annex II zone becomes when 200 m is replaced by 500 m, and so on.

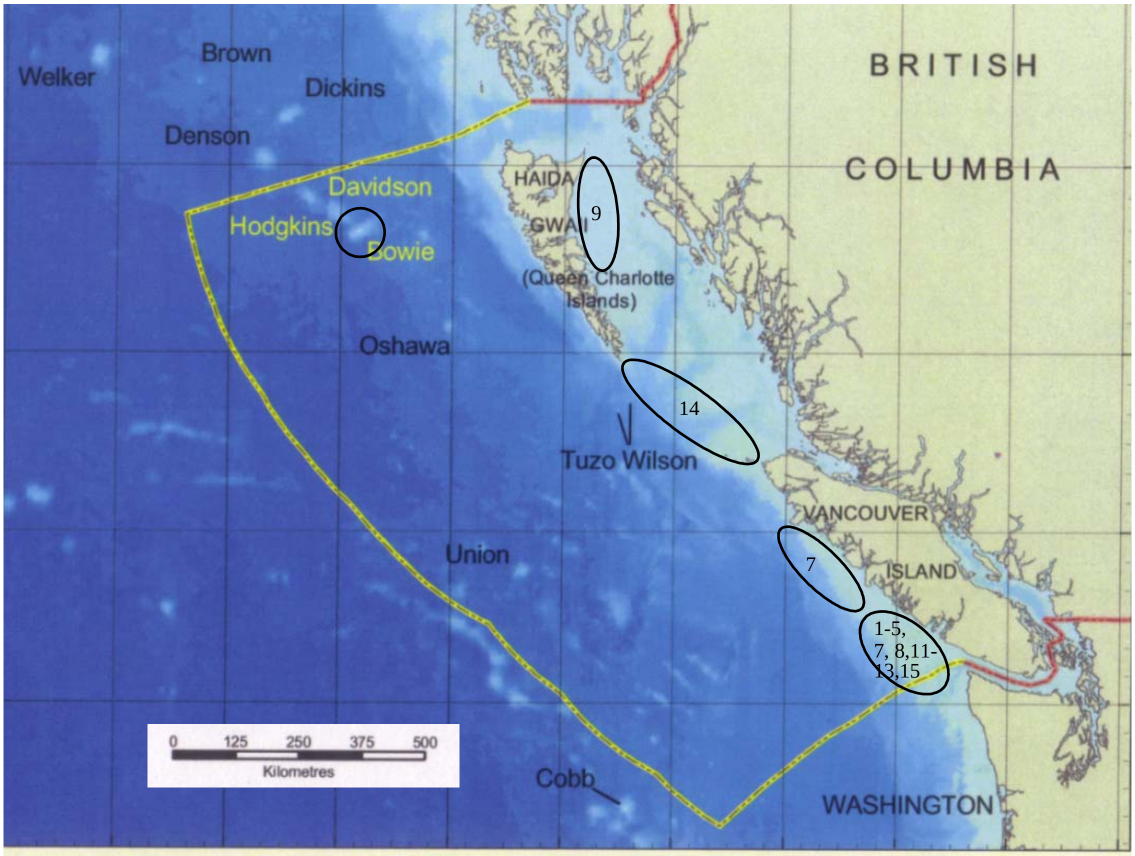

Figure 3. Map of the BC coast showing the EEZ boundary, Bowie and other Seamounts, and areas of high primary and secondary productivity. Ellipses denote regions of high productivity and the enclosed numbers refer to papers listed in Appendix I.

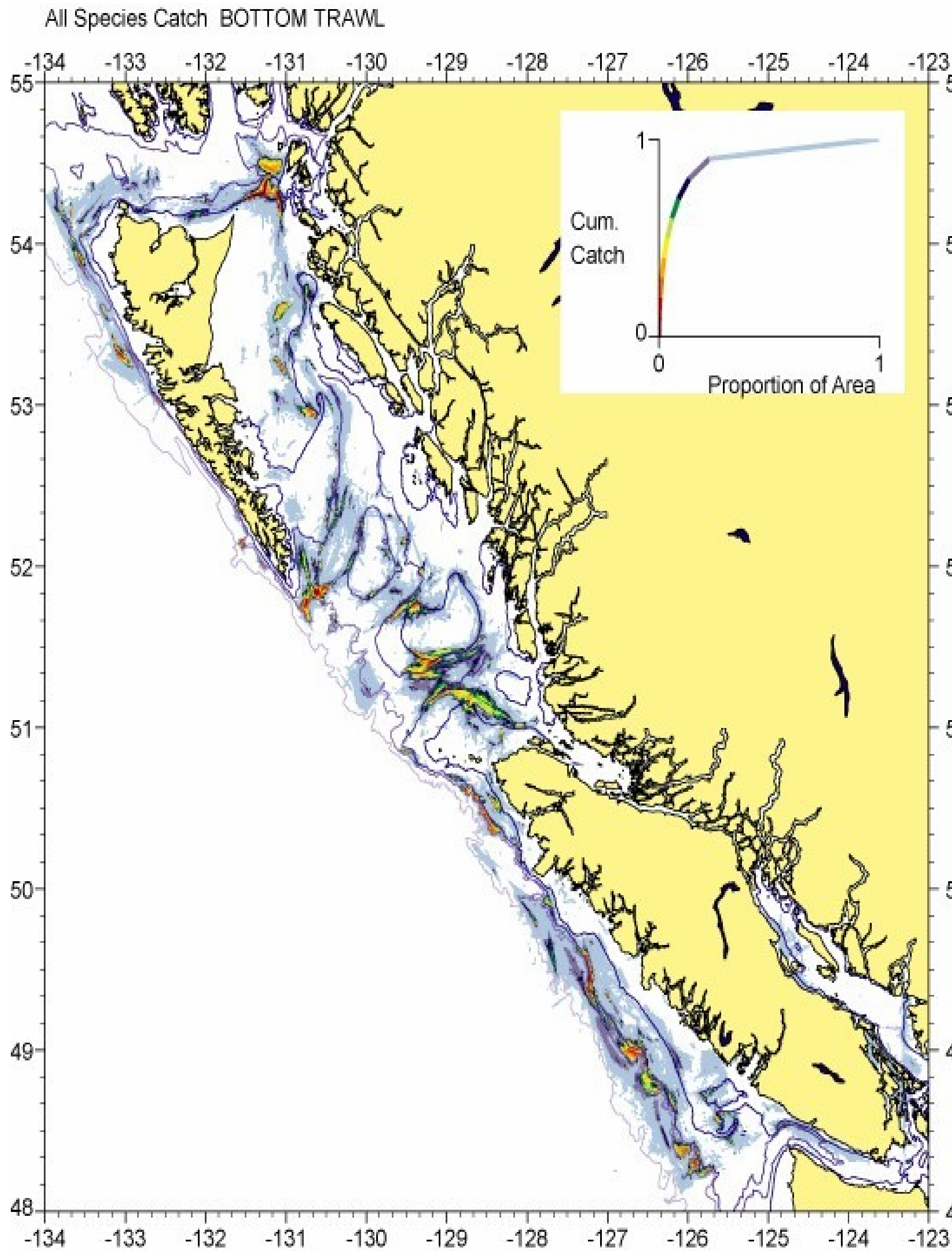

Figure 4. Highly productive trawling grounds for groundfish off the coast of BC. Inset shows a colour code for cumulative catch for proportion of specific area fished. Depth contours are 100m, 200m, 500m and 1500m. Courtesy of Dr Al Sinclair, Pacific Biological Station, Nanaimo.

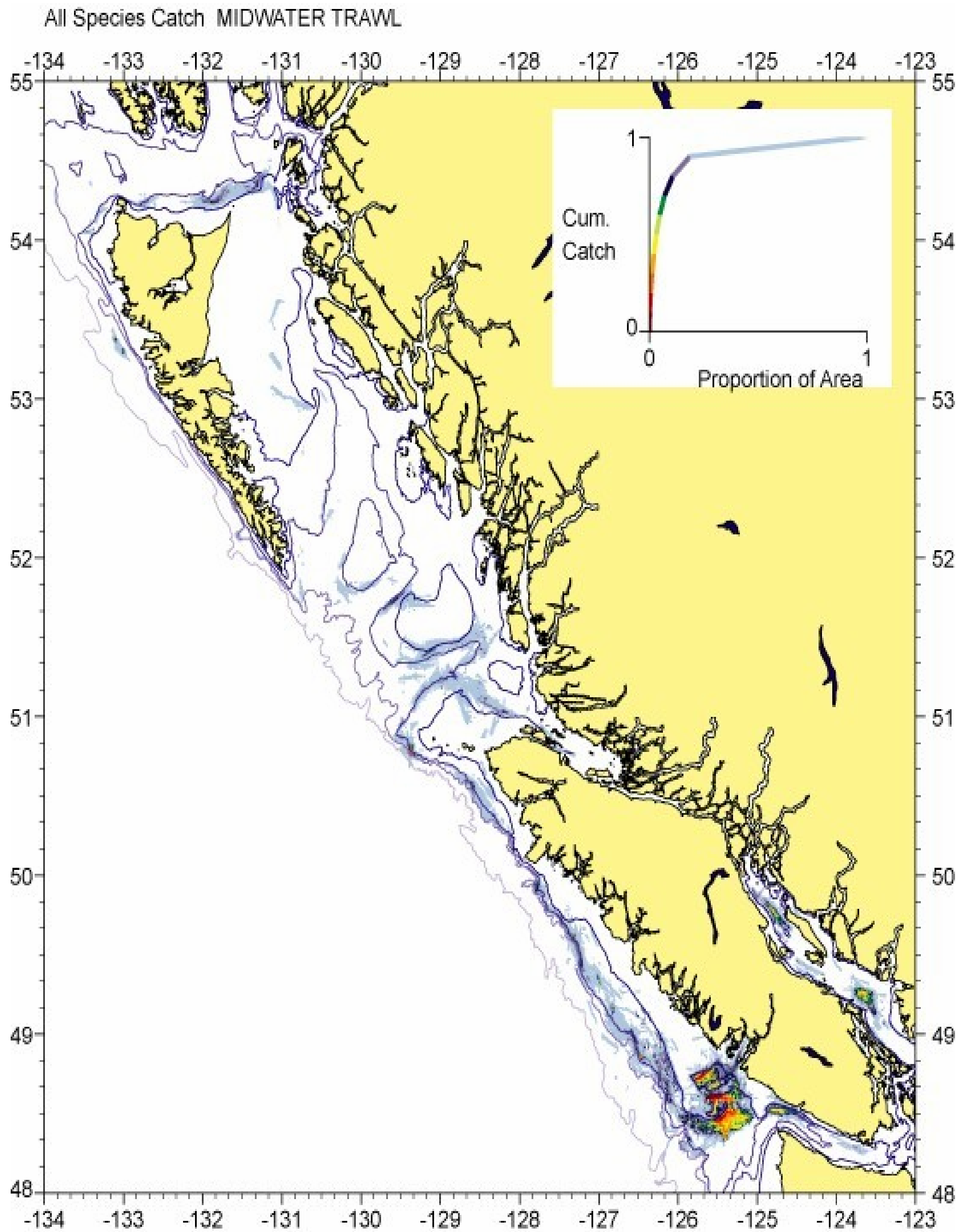

Figure 5. Highly productive areas for mid-water trawling off the coast of BC. Inset shows a colour code for cumulative catch for proportion of specific area fished. Depth contours are 100m, 200m, 500m and 1500m. Courtesy of Dr Al Sinclair, Pacific Biological Station, Nanaimo.

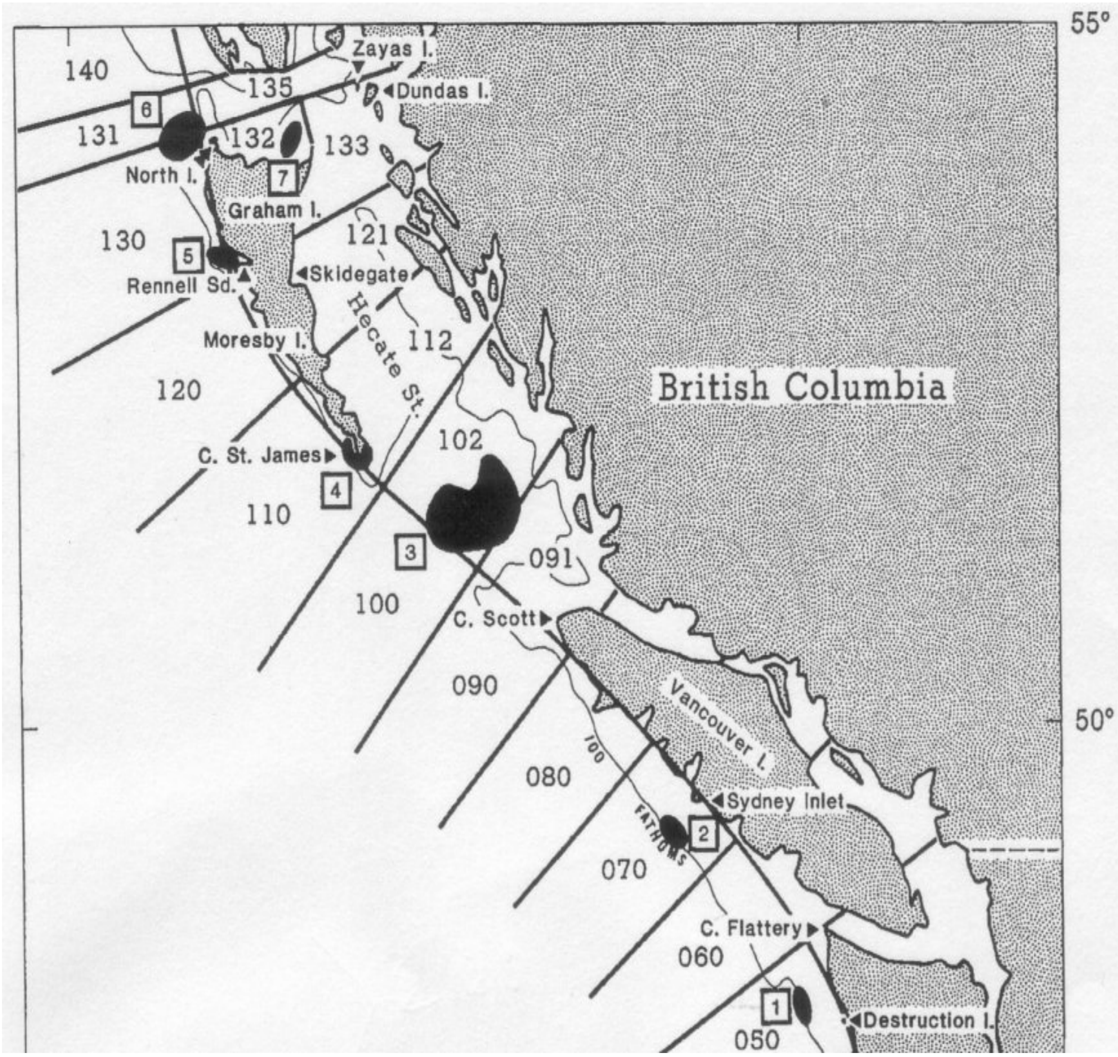

Figure 6. Halibut fishing and spawning grounds off the BC coast. Cape St James and Rennel Sound are known spawning grounds (from St Pierre 1984).

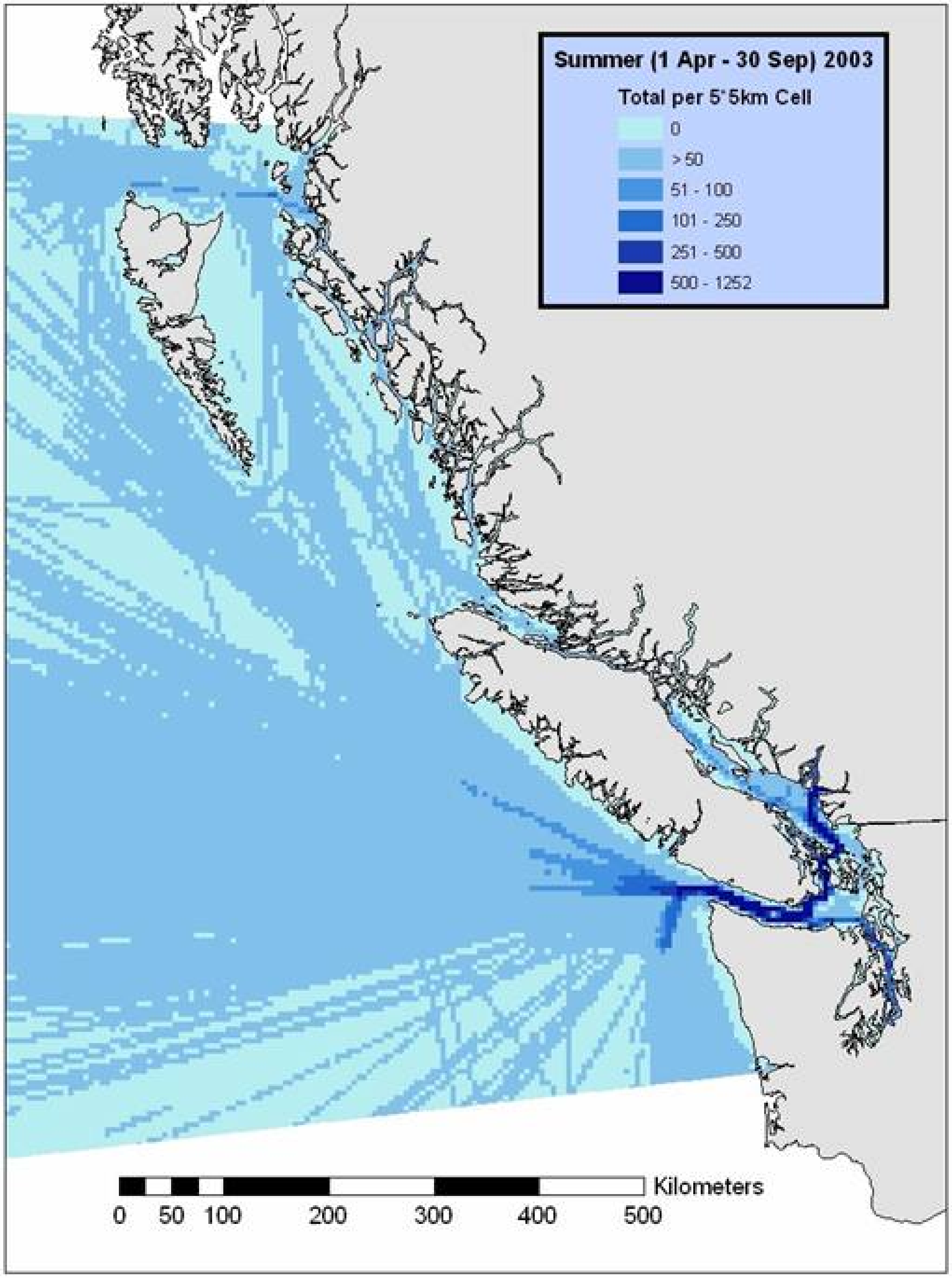

Figure 7. Vessel traffic in summer 2003 off the coast of BC based on data from the Canadian Coast Guard Marine Communication and Traffic System. Colour code in upper right shows density of vessels in 5 x 5 km grids. Data courtesy of Dr. Patrick O'Hara, IOS.

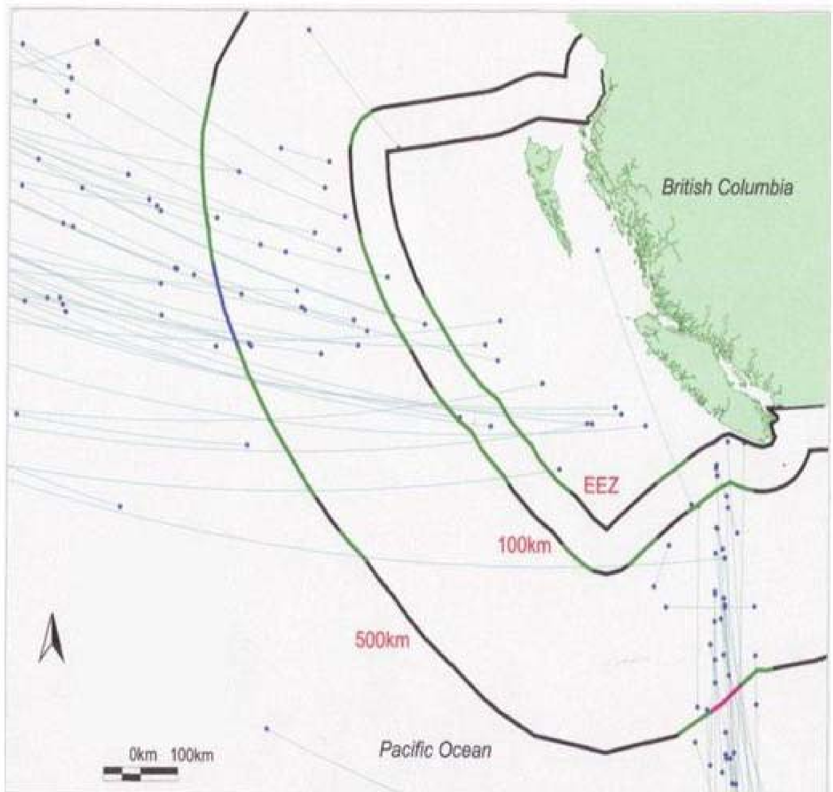

Figure 8. Map of the BC coast showing locations where ships travelling eastbound or northbound to Vancouver exchanged ballast water, based on a subsample of approximately 300 interviews in 1999. Boundaries shown are the EEZ and 100 and 500 km out from the EEZ boundary. Ballast water transects are shown, where the circles indicate locations where ballast water pumps were turned off or on (see Levings et al. 2004).

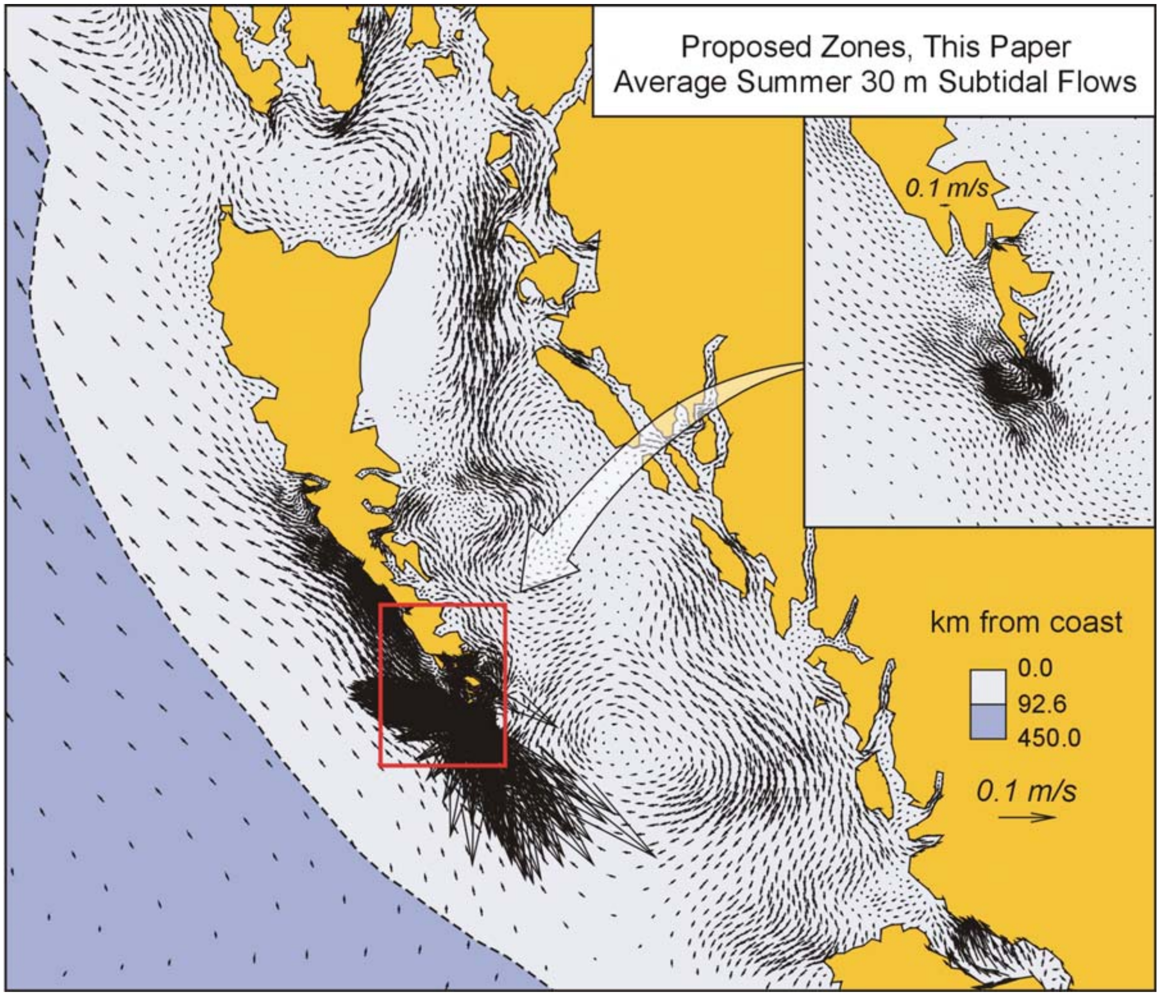

Figure 9. Darker colour denotes the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average summer model currents at 30 m are also shown.

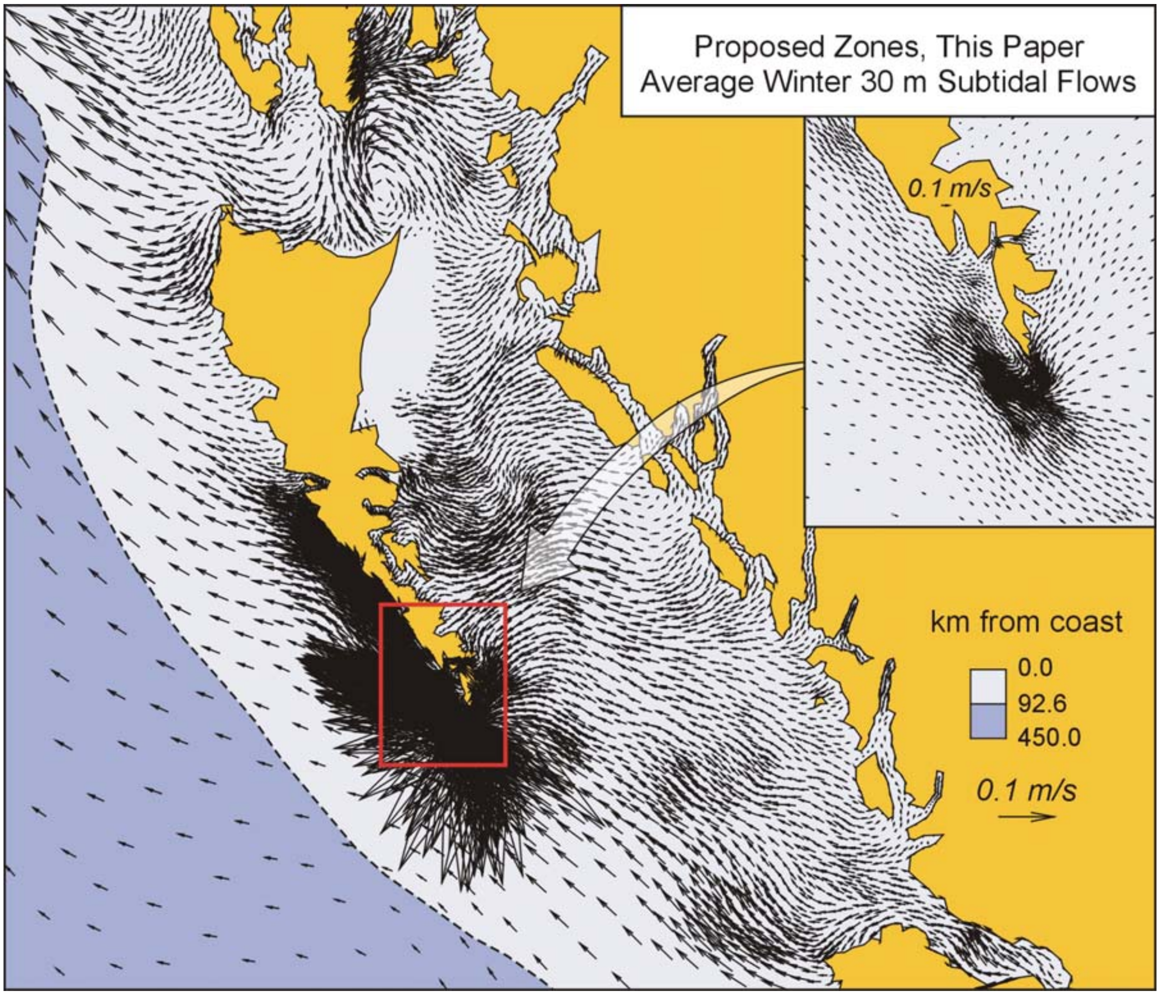

Figure 10. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average winter model currents at 30 m are also shown.

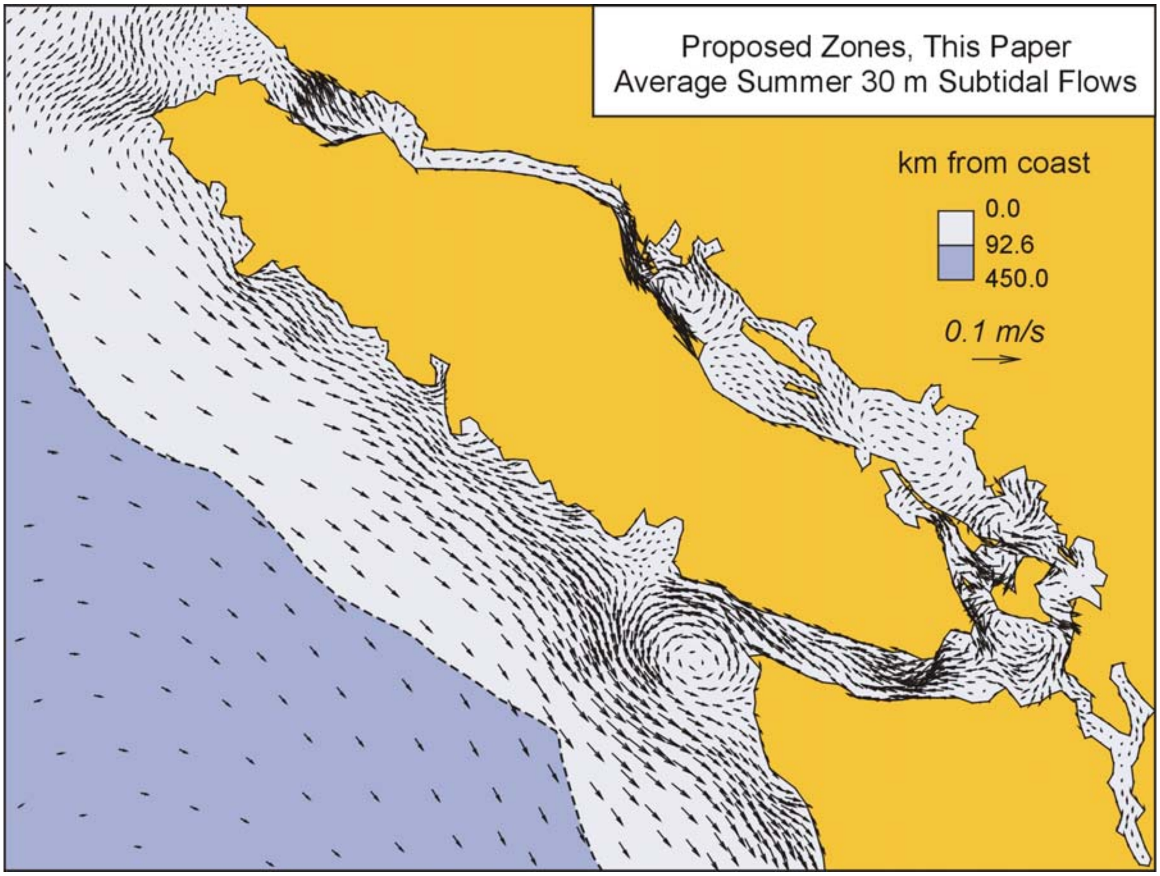

Figure 11. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average summer model currents at 30 m are also shown.

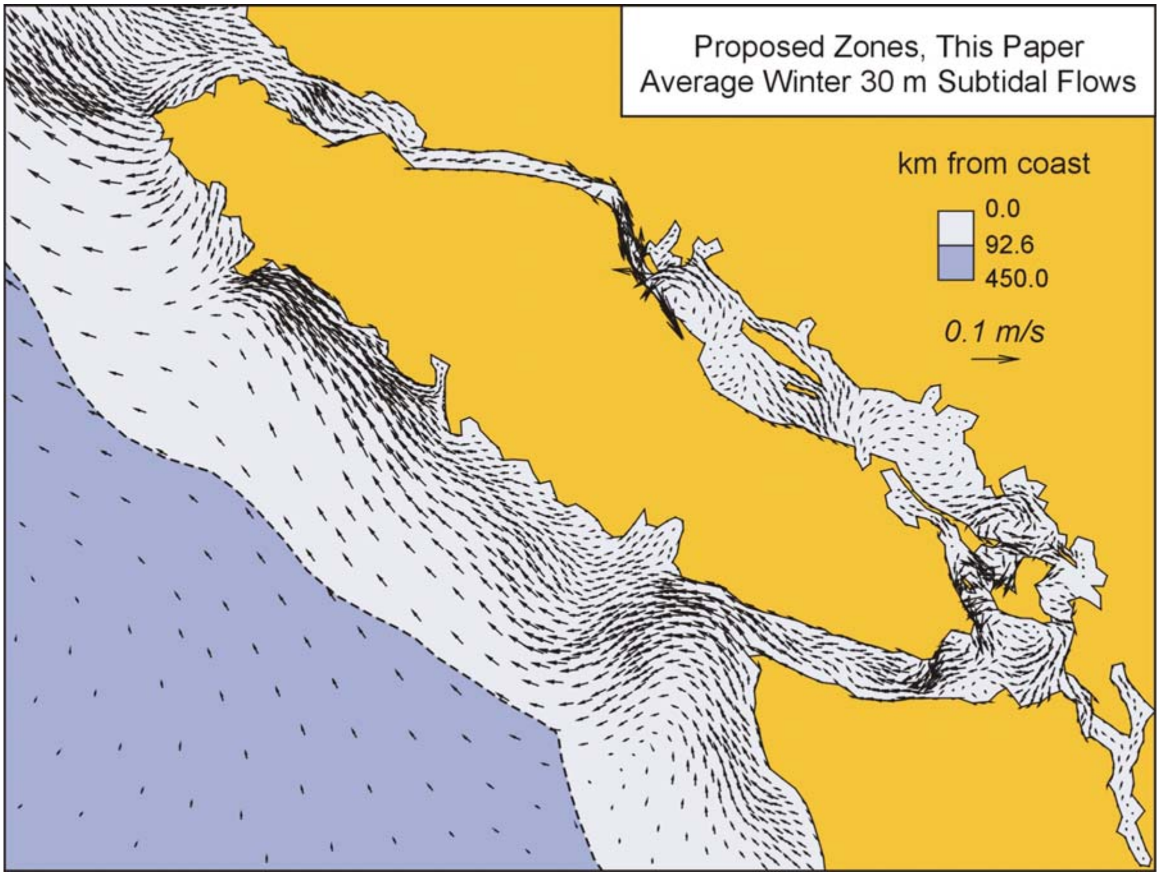

Figure 12. Darker colour indicates the alternate BWE zone (with a dashed line marking the boundary) proposed in this paper. Average winter model currents at 30 m are also shown**.**

Appendix Figure 1. Location of places and oceanographic features named in the text.