Ecosystem Overview:
Pacific North Coast Integrated Management Area (PNCIMA)

B.G. Lucas, S. Verrin, and R. Brown (Editors)

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2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

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ABSTRACT

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

This report provides an overview of physical and biological ecosystems in the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is one of several Large Ocean Management Areas created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada. PNCIMA includes the Pacific coast of British Columbia from the Canada-Alaska border in the north to Brooks Peninsula on NW Vancouver Island and Quadra Island and Bute Inlet in the south; from the outer limit of the continental slope in the west to the coastal watersheds in the east.

PNCIMA is characterized by steep and rugged coastal mountains, abundant offshore islands, a coastline dominated by rocky shores with few sand and gravel beaches, valleys and fjords that extend to the ocean floor, and a glacially scoured continental shelf with cross cutting troughs. The Pacific Ocean moderates the climate, resulting in warm wet winters and cool summers. PNCIMA is located in a transition zone between two areas, one dominated by Alaska Coastal Current downwelling (north), and the other by California Current upwelling (south). PNCIMA's semi-enclosed basin, varied bottom topography, and freshwater input set it apart from other areas of the North American west coast. The troughs and steep edges influence, and likely enhance, plankton and fish production. Strong tidal mixing in the narrow passes and channels enhances productivity around the periphery.

The overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components in the food web, as long as other species occur within the same functional group. However, trophic pathways to individual species may be more constrained; it is unknown which species may be critically sensitive to the reduction or elimination of other species. Existing data suggests that the trophic structure is largely controlled by "bottom-up" forcing.

The ecosystem receives a large biomass of migratory species: stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that enter PNCIMA when conditions are unusually warm. Migrants provide an input of energy and food, but also can export energy from the system, as in Pacific salmon's transfer of energy and nutrients from marine to terrestrial coastal ecosystems.

Habitat use for many large and/or commercial marine species found within PNCIMA is summarized, including significant nearshore and biologically productive pelagic habitats. Eleven appendices detail our current state of knowledge for the geology, meteorology and climate, physical and chemical oceanography, plankton, marine plants, invertebrates, groundfish, pelagic fishes, Pacific salmon, marine mammals and turtles, and sea birds in PNCIMA.

RÉSUMÉ

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

Le présent rapport donne un aperçu des écosystèmes biologiques et physiques de la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP). La ZGICNP est une zone étendue de gestion océanique parmi plusieurs créées afin que le ministère des Pêches et des Océans (MPO) puisse assurer la gestion écosystémique des activités humaines dans les zones marines. La ZGICNP est délimitée au nord par la frontière entre la Colombie-Britannique et l'Alaska, au sud par la péninsule Brooks (Nord-Ouest de l'île de Vancouver), l'île Quadra et l'inlet Bute, à l'ouest par la limite extérieure du talus continental et à l'est par les bassins hydrographiques côtiers.

La ZGICNP est caractérisée par des montagnes côtières abruptes et escarpées, un grand nombre d'îles extracôtières, une ligne de côte dominée par des rivages rocheux et quelques plages de sable et de gravier, des vallées et des fjords qui se prolongent sur le fond océanique, et une plate-forme continentale affouillée par les glaciers et présentant des dépressions transversales. L'océan Pacifique a un effet modérateur sur le climat et est responsable, de ce fait, des hivers chauds et humides et des étés frais de la côte Ouest. La ZGICNP est située dans une zone de transition entre une zone caractérisée principalement par la plongée du courant côtier de l'Alaska (au nord) et une zone caractérisée par la remontée du courant de Californie (au sud). La ZGICNP se distingue des autres zones de la côte ouest de l'Amérique du Nord par son bassin partiellement fermé, son fond à topographie variée et son apport en eau douce. Ses dépressions et ses bordures abruptes améliorent probablement la production de poissons et de plancton. Un mélange tidal important dans les passages et chenaux étroits entraîne une hausse de la productivité en périphérie.

La structure trophique globale de la région de la ZGICNP semble être relativement stable en cas de réduction ou d'élimination de composantes individuelles du réseau trophique, en autant que le ou les groupes fonctionnels touchés soient constitués d'autres espèces. Cependant, les voies trophiques menant à des espèces individuelles sont peut-être plus restreintes; les espèces qui pourraient être très vulnérables à la réduction ou à l'élimination d'autres espèces sont inconnues. Les données existantes suggèrent que la structure trophique est largement régulée par un mécanisme de forçage ascendant.

L'écosystème accueille une biomasse élevée d'espèces migratrices : il constitue la destination de certaines espèces, telles des baleines; il sert d'escale, notamment pour le saumon du Pacifique et des oiseaux marins migrateurs; il sert d'habitat pour des espèces, telles le zooplancton et des poissons pélagiques, qui y migrent lorsque les conditions sont plus chaudes que la normale. Les migrateurs importent et exportent de l'énergie et des ressources alimentaires de l'écosystème, comme dans le cas du saumon du Pacifique qui transfert de l'énergie et des éléments nutritifs des écosystèmes marins aux écosystèmes côtiers terrestres.

Le présent document comprend un sommaire de l’utilisation des habitats de la ZGICNP par de nombreuses espèces marines commerciales ou de grande taille, notamment des habitats pélagiques importants à productivité biologique élevée et situés près des côtes. Onze annexes présentent en détail nos connaissances actuelles relatives à la géologie, à la météorologie et au climat, à l’océanographie chimique et physique, au plancton, aux plantes marines, aux invertébrés, au poisson de fond, aux poissons pélagiques, au saumon, aux mammifères marins, aux tortues et aux oiseaux marins dans la ZGICNP.

PREFACE

This Ecosystem Overview is one of a several reports on the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is a Large Ocean Management Area (LOMA) created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada (DFO). This Ecosystem Overview covers the ecosystem status and trends for geological, oceanographic and biological systems in the LOMA. Other reports may include marine use analyses, ecologically and biologically sensitive areas, ecologically sensitive species, depleted species, degraded areas, ecosystem assessments, conclusions and recommendations.

Parts of this volume were based on an earlier report (Johannessen *et al.* 2005), which was drafted to compile background information for regional management of the north coast of British Columbia for DFO, and later expanded to include the central coast management area.

INTRODUCTION

PROJECT DEFINITION

Context and purpose

Canada's *Oceans Act* states that "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment." Implementation of integrated management planning is central to the new governance and ecosystem based management approach of the Oceans Action Plan (OAP). The OAP identified five priority Large Ocean Management Areas (LOMAs) across Canada for coordination of Integrated Management (IM) efforts. The Pacific North Coast Integrated Management Area (PNCIMA) is one; the others are the Eastern Scotian Shelf, Beaufort Sea, Gulf of St. Lawrence, and Placentia Bay/Grand Banks. Ecosystem Overview and Assessment Reports (EOARs) are one of the tools being used to develop ecosystem objectives for these LOMAs. Other reports being developed under the OAP include a Marine Use Analysis and a Socio-Economic Overview and Assessment Report.

The purpose of the PNCIMA Ecosystem Overview is to provide an overview of our current state of knowledge of the ecosystem(s) in PNCIMA. This Ecosystem Overview provides a knowledge base upon which impact assessments can be completed and recommendations provided for integrated management and sustainable use of the area (DFO Oceans Directorate 2005). As an overview, it provides a summary of the most relevant information and directs readers to publications with more comprehensive information. It is a science-based technical document, intended for use in ecosystem planning, and in preparation of later volumes of the EOAR.

The PNCIMA Ecosystem Overview was guided by a series of common EOAR principles: ecosystem focus, brevity and highlights, state of knowledge, scale integration of nested systems, ecologically significant boundaries, collaborative and team project, flexibility to regional constraints, multiple volumes, information management, and plain language (DFO Oceans Directorate 2005). It was produced with the best available information and state of knowledge.

Boundaries of the study area

PNCIMA's boundaries were determined primarily on ecological characteristics, and encompass approximately 88,000 sq km. It extends from the outer limit of the foot of the continental slope in the west, to the coastal watersheds in the east. The Canada-US border for Alaska is the northern boundary. The Brooks Peninsula on NW Vancouver Island and Quadra Island are encompassed in the southern boundary.

Report structure

This Ecosystem Overview is comprised of two summary chapters and 11 appendices. The first chapter is a description of what we know about how the ecosystem functions, the linkages, and interactions. It integrates the information detailed in the appendices and highlights key information gaps. Chapter 1 was reviewed and refined at a workshop in March 2006 held at the Institute of Oceans Sciences, in Sidney, BC.

The second chapter summarizes what is known about the use of habitat in PNCIMA by marine organisms for important life history functions, such as feeding, breeding, and migrating. The habitat map folio illustrates geographical areas for specific species or groups where those areas are large enough to be visible on a LOMA scale.

The appendices are excellent primers on their topics. They each provide important background details to understanding how and why PNCIMA ecosystems are structured and function the way they do. They also provide references to current literature for in-depth information on pertinent subjects.

CHAPTER 1: ECOSYSTEM DESCRIPTION

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1.0 INTRODUCTION

This chapter integrates the information presented in the appendices, and provides the broad overview and synthesis of this material to understand "how the marine ecosystem(s) of the central and north BC coast (the Pacific North Coast Integrated Management Area; PNCIMA; Figure 1.0) works." It attempts to understand the structure and function of the system, and where there may be critical "control points" in space, time, or organisation (*e.g.,* trophic connections). An important additional objective is to identify critical unknowns and key information gaps to our understanding of how the ecosystem works.

This analysis includes nearshore and open water systems of the PNCIMA region. It does not include detailed consideration of inlet and fjord waters, largely because there are insufficient data from these areas. It also does not consider terrestrial systems nor detailed connections between terrestrial and marine environments.

We build our understanding of these marine ecosystems using four principal themes: (a) spatial patterns and processes; (b) food web interactions; (c) migratory species; and (d) temporal variability. We conclude with a summary and short discussion of key data gaps and uncertainties.

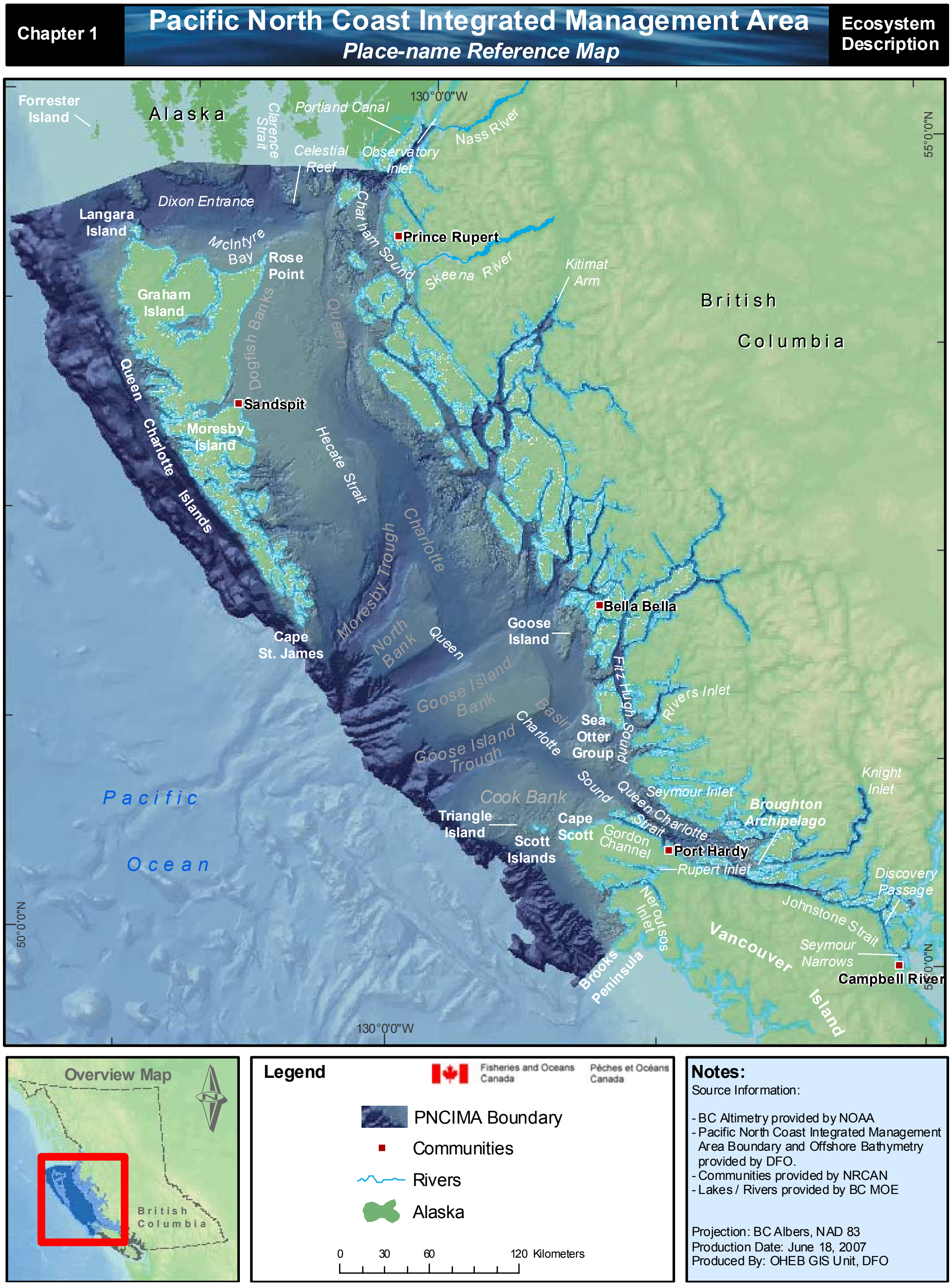


Figure 1.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 1.

1.1 GEOLOGICAL SETTING

The geology of the PNCIMA region steers and determines much of its physical and biological processes. The Pacific Coast today is the result of geological processes stretching back hundreds of millions of years. Over the largest time scale, the dominant process involved is plate tectonics, by which terranes from other parts of the world were accreted onto North America. Most of the bedrock of British Columbia was added to North America in this way. The slow but inexorable forces involved in this process also caused the tectonic uplift and buckling of the crust resulting in the mountain ranges of BC. Subsequent erosion of these mountains developed the sediment filled basins between these ranges.

The tectonic forces that have formed BC continue today and BC's offshore has a complex combination of plate boundaries including a subduction zone, spreading ridges, and transform faults. This results in a variety of earthquake environments that are capable of everything from frequent low magnitude earthquakes to giant megathrust earthquakes that can achieve magnitudes greater than 9 and have occurred roughly once every 300 years.

Over the last few million years, finer details have been chiselled into the tectonically developed bedrock features by the repeated advance and retreat of glaciers over the land. As subsequent glaciations largely erase the effects of the previous ones, most of the glacial features seen today are a result of the last glacial advance (between 10 and 30 thousand years ago). Many of the terrestrial glacial features have in turn been modified by fluvial erosion and deposition during postglacial time (the last 10,000 years), while the marine features have been subject to tides, currents, and littoral processes. Sedimentary input to the continental shelf has been very low since glacial retreat because the deep basins of the coastal fjords allow the settling of river-borne sediments. This results in a 'sediment starved' shelf where the older glacial deposits are constantly re-worked and produces a coastline dominated by rocky shores with few sand and gravel beaches.

The physical features of the coast also affect the freshwater input to the marine area. The PNCIMA area contains a variety of watershed forms resulting in different hydrologic profiles, though spring and summer meltwater runoff dominate the mainland watersheds which provide most of the freshwater input. This input and its timing are critical to phytoplankton blooms which form the base of the marine food chain. Global warming is already seen to be affecting the timing and volume of freshwater input in this area.

The PNCIMA area is also host to potentially significant petroleum-based resources. The Queen Charlotte Basin is one of four sedimentary basins found beneath Canada's Pacific continental shelf. Exploration from the 1960s to the 1980s suggests that this basin may hold significant reserves of oil and gas. Natural gas hydrates have also been found on southern portions of BC's continental slope. This potentially significant source of natural gas may also exist on the slope within the PNCIMA area. See Appendix A for more information on the geology of PNCIMA.

1.2 METEOROLOGY AND CLIMATE

British Colombia's coastal climate and weather conditions are a direct result of its position between the northeast Pacific Ocean and the Coast Mountains. Winds are dominated by the Aleutian Low Pressure system in winter and the North Pacific High in summer. This means that winter storms absorb great amounts of moisture as they track eastward toward the British Columbia coast. Much of this moisture falls as precipitation when it hits the Coast Mountains, making BC's coast the wettest place in Canada. The positions of the air pressure systems often cause winter storms to hit the central and north coast of BC more frequently than the southern coast. This results in the highest precipitation totals occurring within PNCIMA.

The ocean also moderates temperatures, with the winter storm winds transporting heat across the central Pacific and the milder northwest summer winds bringing relatively cooler air masses onto the coast. These air pressure systems and their winds also drive ocean circulation, which controls the source, and thus temperature, of water off the BC coast, which in turn affects coastal air temperatures.

Variations in climatic conditions strongly affect ecosystems. Most obvious is the seasonal variation that controls such things as the spring phytoplankton bloom, timing of peak stream flow, ocean wave intensity and ocean current strength and direction. However, the variation between years and decades for a given season is of great significance as these conditions can strongly affect the timing of ecosystem functions, which can be critical to the success of various biota. El Niño events, for example, transport warm waters and their biological communities northward to the BC coast, creating competition between indigenous and invasive organisms. There is an increasing focus in research on understanding how climate variability affects the ecosystem and whether that variability can be predicted.

PNCIMA is located in a transition zone between a northerly area dominated by the Alaska Current system and a southern area dominated by the California Current. The location of this transition zone varies depending on the relative dominance of these two systems. Shifts in this location are marked by periodic appearance of northern and southern species. See Appendix B for more information on the meteorology and climate of PNCIMA.

1.3 OCEANOGRAPHIC SETTING

PNCIMA forms the portion of BC coastal waters north of Campbell River and Brooks Peninsula and includes all salt and brackish waters in BC north of these two points as well as freshwater streams draining into these seas (Figure 1.0). In physical oceanographic terms, these waters form a transitional region north of the northern end of the California Current domain, and south of the southern end of the Alaska Current domain. Brooks Peninsula, on northwest Vancouver Island, is generally considered to be the dividing point between Alaska Coastal Current and California Current domains. Whereas the California Current is characterized by moderate to strong upwelling winds in summer, the Alaska Coastal Current is characterized by relaxation of winter downwelling in spring and summer rather than by upwelling winds. Where upwelling winds do occur in summer, generally in PNCIMA and SE Alaska, they are generally weak and persist only for a few months.

PNCIMA, in common with SE Alaska to the north, experiences extremely strong storms in autumn and winter with accompanying winds from the southeast and accumulations of metres of precipitation over autumn and winter (Figure 1.1). Coastal currents are forced by these winds to flow to the northwest alongshore, and can be considered the southern end of the Alaska Coastal Current. In parts of the three main basins on the shelf, Queen Charlotte Sound, Hecate Strait and Dixon Entrance, the currents are forced by the bathymetry to flow westward, or even upwind, but the overall surface flow is alongshore. The outer coast is wind and wave swept, and some inside regions, such as Dogfish Banks, experience sediment transport and shoreline erosion due to wind-forced waves. Inside channels and inlets are much more protected from waves and winds, and along many of these channels the trees extend right down to the high-tide line. Tidal currents range from the world’s strongest to almost nil, with varying impact on the biota.

Inflow of major rivers is mainly into Chatham Sound and Observatory Inlet in the north, and into Fitz Hugh Sound on the central coast. Fresh waters flowing into Queen Charlotte Strait are considerably mixed with salt water by the time they reach this strait. Freshwater input from shorter rivers and directly onto the three main basins is considerable, and has to be accounted for in any balance of freshwater input. Tidal and wind-forced mixing of fresh water with sea water is hugely variable and determines many of the high primary production regions in PNCIMA, as noted later. See Appendix C for more information on the oceanography of PNCIMA.

These physical processes determine the ecosystem structure. Each of these physical inputs changes in nature and strength throughout PNCIMA, so that the ecosystem itself differs throughout this area. Despite these areal shifts, we present below a brief summary of the general features common to much of PNCIMA, with individual areas discussed later.

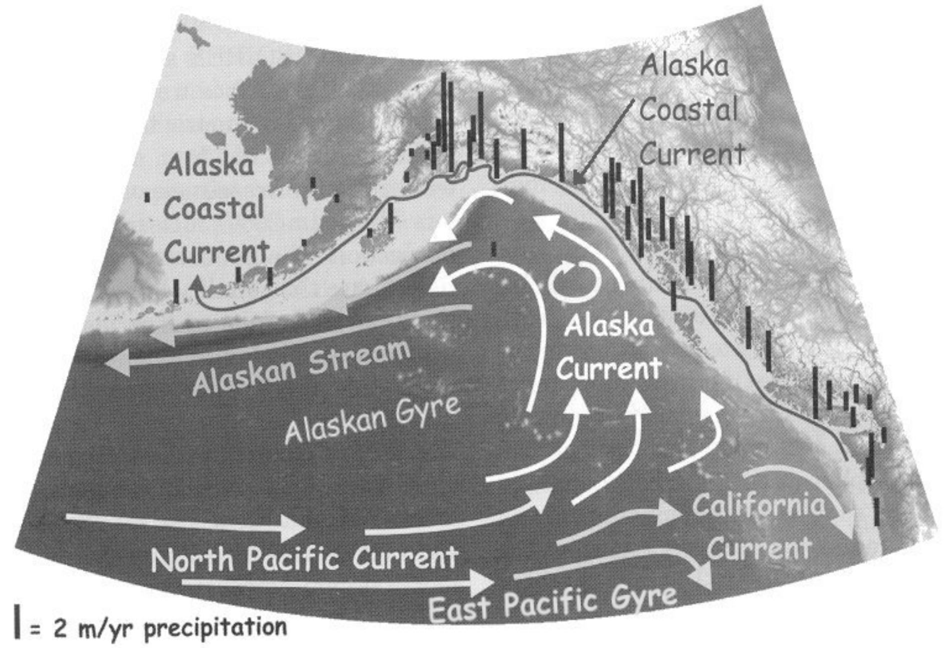


Figure 1.1 Surface circulation fields in the Gulf of Alaska (arrows) and average annual precipitation totals from coastal stations and the central gulf (black vertical bars) (adapted from Mundy and Olsson 2005 after; Baumgartner and Reichel 1975).

What regulates the biological productivity of this marine region?

The PNCIMA region is productive of plankton, fish and invertebrates. Ware and Thomson (2005) examined the primary productivity (growth rate of phytoplankton per year) of coastal NE Pacific and BC marine ecosystems, and concluded that resident fish yield was significantly correlated with the amount of primary production that was retained in these areas by physical processes. Using satellite observations of surface chlorophyll *a* concentrations for BC waters (Figure 1.2) from 1998 to 2005 as a proxy for the rate of primary production, and observations of zooplankton biomass and the total catch ("yield") of resident fish, they calculated that a significant linear relationship existed between mean average chlorophyll *a* concentration (in mg m^{-3}) and average annual resident fish yield (in metric tons km^{-2}):

$$\text{Long-term Fish Yield} = 0.08 + 0.437*[\text{chl.}a] \qquad (r^2 = 0.76, P = 0.015) \qquad (1)$$

This equation suggests that a sustained doubling of the annual average chlorophyll *a* concentration would lead to an approximate doubling of the annual yield (catch) of resident fish species. Resident fish species were defined to exclude species such as Pacific hake, Pacific sardine, and pink, chum, sockeye, and coho salmon, which are believed to reside or pass through the PNCIMA marine ecosystem for only short periods of their life.

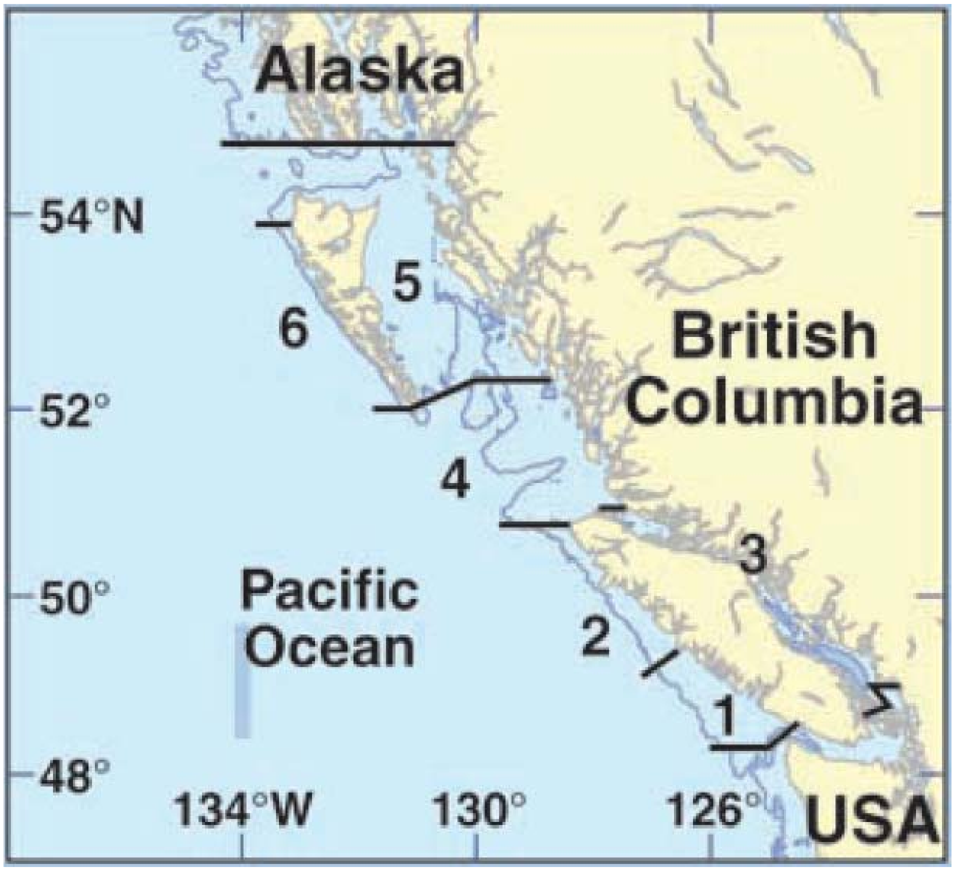


Figure 1.2 Regions of the BC coast examined by Ware and Thomson (2005) for comparisons of primary production and resulting catches of resident fish. 1: southern Vancouver Island shelf; 2: northern Vancouver Island shelf; 3: Strait of Georgia; 4: Queen Charlotte Sound; 5: Hecate Strait; 6: west coast Queen Charlotte Islands (from Ware and Thomson 2005).

For the coastal waters of BC, the relationship of chlorophyll to zooplankton (in mg dry weight m^{-3}) was not linear, whereas that between zooplankton and the long-term catch of resident fish was linear (Figure 1.3):

$$\text{Zooplankton} = 46.57 * [\text{chl.}a]\ 0.488 \qquad (r^2 = 0.85) \qquad (2)$$

$$\text{Long-term fish yield} = 0.055 * \text{Zooplankton} - 1.98 \qquad (r^2 = 0.79) \qquad (3)$$

This suggests that the amount of zooplankton in BC waters, and the subsequent amount of fish, can be estimated (on a long-term annual basis) from the amount of phytoplankton that is produced each year.

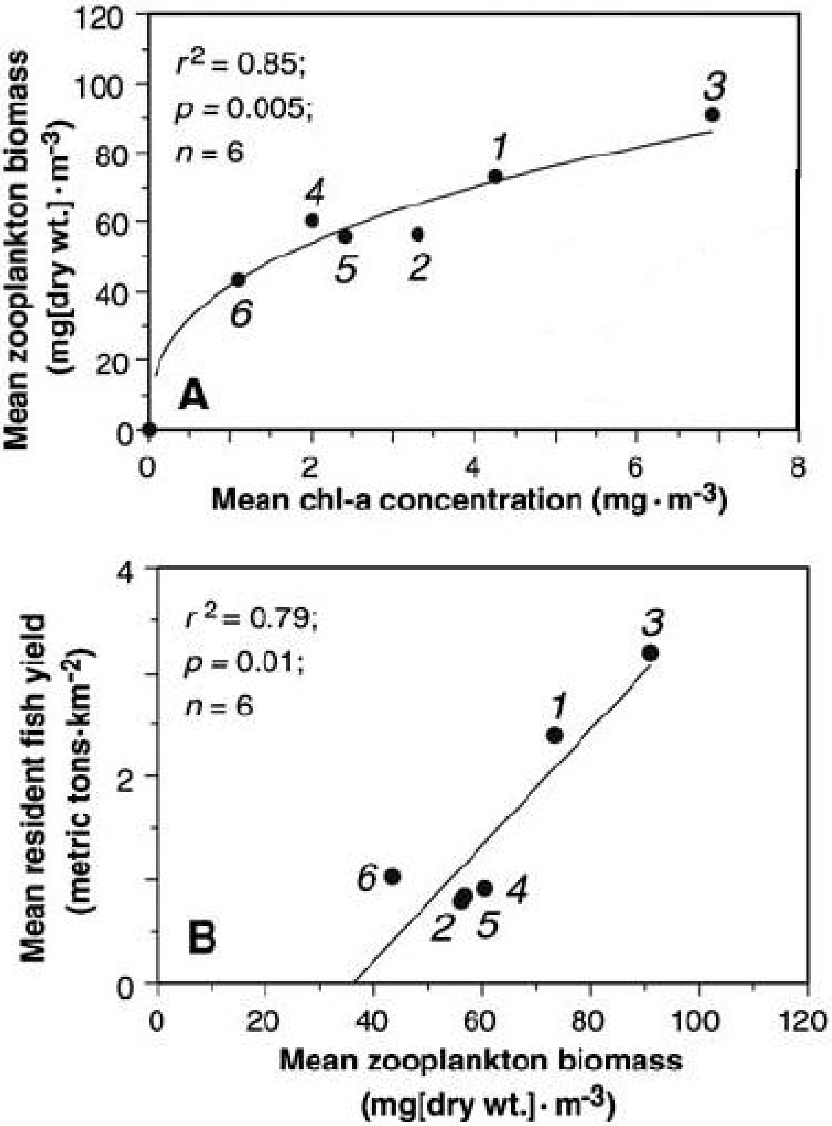


Figure 1.3 Relationships of chlorophyll *a* biomass to zooplankton biomass (top) and between mean zooplankton biomass and mean yield (catches) of resident fish populations (bottom) for the six regions of the British Columbia coast (see Figure 1.2) identified by Ware and Thomson (2005).

When compared among eight geographic regions from southern California to Kodiak, Alaska (Figure 1.4), Ware and Thomson (2005) found that the "Charlotte" region (equivalent to the PNCIMA shelf region) ranked sixth in terms of mean annual chlorophyll *a* biomass per unit surface area (with the region west of Vancouver Island ranking first). However, this "Charlotte" region ranked third in terms of its long-term annual fish yield per unit surface area, after the Vancouver Island and Columbia regions (Table 1.0). Ware and Thomson (2005) suggested that the higher fish yield per unit of chlorophyll in this "Charlotte" region is because more of this chlorophyll is retained on the continental shelf as a result of reduced upwelling compared with regions further south due to the presence of the Queen Charlotte Islands that form a barrier to movement of water into the deep ocean.

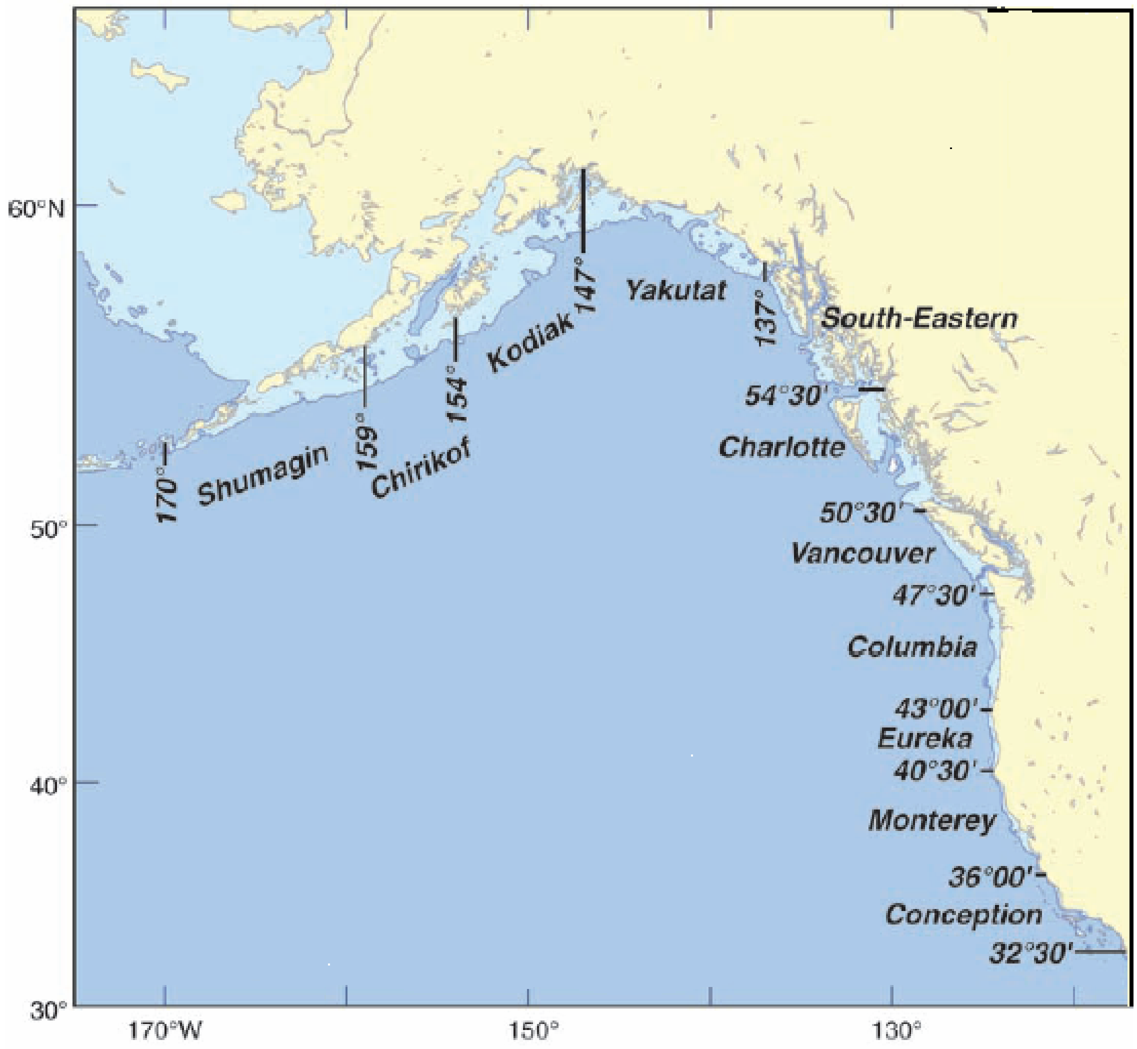


Figure 1.4 Regions of the coastal NE Pacific considered by Ware and Thomson (2005) for relationships between chlorophyll *a* biomass and long-term annual fishery yield of resident fish stocks (from Ware and Thomson 2005).

Table 1.0 Mean annual chlorophyll *a* concentrations (with temporal coefficients of variation for the period 1998-2003 in parentheses) and long-term annual fishery yields of resident species for various coastal regions of the NE Pacific (see Figure 1.2 and Figure 1.4)(from Ware and Thomson 2005).

Region	**Surface area (km^2)**	**Chl-*a* (mg m^{-3})**	**Resident fish yield (t km^{-2})**
Conception	60,046	1.38 (0.57)	0.06
Monterey	41,613	2.29 (0.54)	0.45
Eureka	18,692	2.20 (0.86)	0.66
Columbia	36,573	3.24 (0.68)	0.88
Vancouver	34,688	5.15 (0.66)	1.97
Charlotte	82,769	2.16 (0.69)	0.79
Southeast Alaska	43,342	2.79 (0.80)	0.60
Yakutat	76,430	1.57 (0.63)	0.27
British Columbia			
S. Vancouver Island (1)	11,312	4.25 (0.70)	2.39
N. Vancouver Island (2)	10,099	3.30 (0.71)	0.85
Strait of Georgia (3)	8,803	6.92 (0.57)	3.19
Q.C. Sound (4)	31, 408	2.00 (0.71)	0.92
Hecate Strait (5)	44,158	2.41 (0.68)	0.80
West coast Q.C. Islands (6)	7,203	1.10 (0.69)	1.03

When analysed at the finer spatial scale of six BC coastal regions (Figure 1.2), Ware and Thomson (2005) found that on a per unit surface area basis the three northern regions (Queen Charlotte Sound, Hecate Strait, west coast Queen Charlotte Islands) had below the average (3.34 ± 2.08 mg m^{-3}) chlorophyll *a* mean annual biomass for these six regions, and below the average (1.53 ± 1.01 t km^{-2}) long-term fish yield (Table 1.0). Within BC, therefore, ocean productivity is higher in southern BC than in the north, although the data are skewed by the very high chlorophyll *a* concentrations and fish yields on the southwestern continental shelf of Vancouver Island and in the Strait of Georgia.

Overall, these analyses of Ware and Thomson (2005) suggest that the PNCIMA region of the BC coast has moderate annual phytoplankton biomass, but high long-term fishery yields of resident fish populations, compared to other regions from southern California to Alaska. These analyses also indicate that, at least on large spatial scales, zooplankton biomass and higher fishery yields of commercial resident fish populations are directly related to the amount of mean annual primary production and resulting chlorophyll *a* biomass. Therefore, the (partial) answer to the question "What regulates the biological productivity of this region" is phytoplankton production and retention, so that any sustained process or event which changes phytoplankton production substantially will eventually have measurable effects on fish production in these systems. The obvious next question, however, is "What regulates phytoplankton production in this region?"

1.4 SPATIAL AND SEASONAL PATTERNS

We have selected eight sub-regions of PNCIMA based on physical and phytoplankton-related processes that are common to each of these sub-regions. Relevant to this discussion are three figures from Appendix D: Plankton (Figure 1.5). These images show the spatial and seasonal variability of phytoplankton concentrations at ocean surface, as inferred from spectral colour data collected by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor on the American Orbcom satellite. Individual regions in these images are discussed below as they relate to the physical forces of PNCIMA: winds, waves, tides, fresh water, heating and bathymetry.

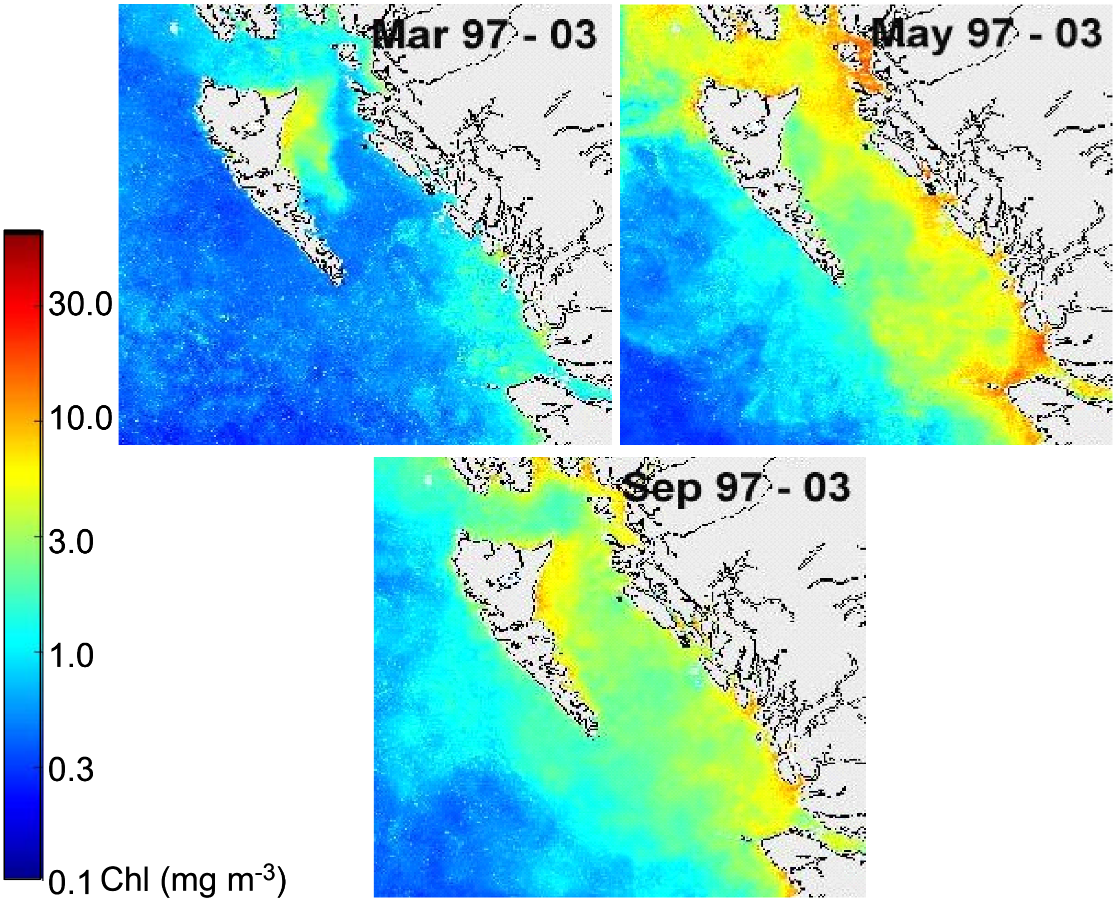


Figure 1.5 Aggregated monthly averaged satellite-derived chlorophyll data from 1997 to 2003 for March, May and September. Data reveal ocean-surface phytoplankton hotspots, and the fact that the shelf is quite productive (>1 mg m^{-3}) from March through to September (A. Peña, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2006).

An interesting seasonal cycle of phytoplankton concentrations in surface waters was detected by the SeaWiFS satellite. Spring phytoplankton bloom first arrives at NE Hecate Strait in March (as described later), then in eastern Hecate Strait and Queen

Charlotte Sound in May, with low plankton concentrations along western Hecate Strait in May. This May pattern partially reverses in September, when the western side of Hecate Strait holds higher concentrations of phytoplankton that the eastern side. We speculate these high spring levels are associated with relaxation of winter downwelling and mixing of outflowing fresh waters with high-nutrient sub-surface waters. By September, outflow of fresh water is at a seasonal minimum, and both downwelling relaxation and upwelling have turned off, dropping productivity along the eastern shore. However, shallow bottom depths along the west side of Hecate Strait might allow the early autumn storms to mix high-nutrient bottom waters to the surface.

The eight sub-regions are:

(a) Campbell River to Port Hardy,
(b) Queen Charlotte Strait to Brooks Peninsula,
(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance,
(d) Cape St. James,
(e) Western Hecate Strait,
(f) Dixon Entrance,
(g) West Coast Queen Charlotte Islands,
(h) Inlets.

(a) Campbell River to Port Hardy

This region comprises the channels of Seymour Narrows, Discovery Passage, Johnstone Strait and the eastern end of Queen Charlotte Strait, as illustrated in Figure 1.0. Tidal mixing gives these channels their unique status. These waters experience extreme tidal mixing, with Seymour Narrows likely holding the world record for most tidal mixing and dissipation in a single narrow channel. Waters are well mixed top to bottom in several hundred metres depth in many portions of these straits, yet these channels support an estuarine circulation. In Johnstone Strait this estuarine circulation is evident in the mean velocity and water properties structure. There is a mean seaward (westward) upper layer flow of about 0.2 m s^{-1}, strongest on the mainland side due to the Coriolis force, while the mean lower layer flow is landward (eastward) at about 0.1 m s^{-1}, strongest on the Vancouver Island side (Thomson 1981). As noted above in Section 1.0, these channels and the inlets receive relatively little attention in our report due to lack of ecological data.

They support excellent sports fishing for salmon, especially near Campbell River. This fishing is perhaps due to the containment of salmon in the narrow channels on their return to spawn. Many to most juvenile salmon from the Fraser River transit these channels on their outbound migration.

Because these channels are so well mixed, the primary productivity is expected to be relatively low. Phytoplankton in very turbulent waters spend too little time at surface to support strong blooms. This relatively low productivity is expected to permit the waters that are nutrient enriched by tidal mixing to exit this region into Queen Charlotte Strait with relatively high nutrient concentrations at surface.

Some recent studies have focussed on the Broughton Archipelago, where sea lice impact on pink salmon has been an issue that has stimulated significant research into the relative contribution of natural and fish farm sources of sea lice. These efforts and recommendations for future research are noted by Pennell and Ackerman (2006). This topic should provide a cautionary note on the difficulty in managing natural and aquaculture stocks of fish in the same region. After several years of research the scientific community has not reached consensus on the impact of sea lice from fish farms on the wild stocks of pink salmon (Pennell and Ackerman 2006). We refer readers to the ongoing research efforts in the Broughton Archipelago rather than attempt to provide another summary here.

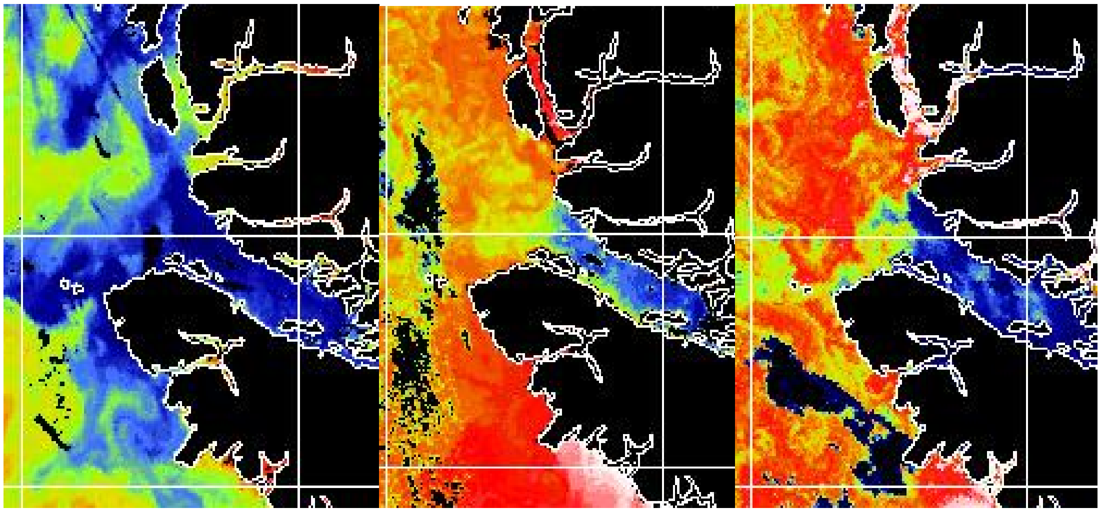
(b) Queen Charlotte Strait to Brooks Peninsula

These waters follow the northern shore of Vancouver Island, starting at the eastern end of Queen Charlotte Strait, through Gordon Channel, Cook Bank, Scott Islands, and finally along the west coast of Vancouver Island south to Brooks Peninsula (Figure 1.0). This region is marked by relatively high phytoplankton concentrations in May and September, as revealed by SeaWiFS imagery in Figure 1.5, which can be attributed to a combination of winds, tides, and nutrient input from inlets and channels. The individual physical features are:

- well mixed outflow in a thick surface layer from Johnstone Strait and Broughton Strait,
- fresher outflow in a shallow surface layer from Fitz Hugh Sound and Smith Sound,
- strong SE winds in winter and weaker NW winds in summer,
- tidal mixing at and near the Sea Otter Group of islands, as well as near the reefs and small islands between the Sea Otter Group and the mainland,
- tidal mixing over Cook Bank and near the Scott Islands,
- offshore-directed cold plumes from the Scott Islands and Brooks Peninsula in summer.

Compared to other PNCIMA regions, this highly productive region has lower retention of surface waters and their biota due to the westward flows over Cook Bank past Scott Islands in spring and summer when winds blow from the north.

Figure 1.6 presents satellite images of surface water temperature of this region in spring and summer.



(a) 19 May 2002 (b) 23 July 1994 (c) 21 September 1993

Figure 1.6 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Centre image is from the same day presented in Figure 1.7.

These three images of Figure 1.6 each show cooler water in Queen Charlotte Strait, likely due to cold outflow from channels to the SE. Nutrient measurements in summer reveal these waters of Queen Charlotte Strait to be rich in nitrate, with levels over 10 μM being among the highest observed in PNCIMA (Appendix C, Figure C.23). Comparison of nitrate and temperature images shows the highest nutrients in the coldest waters, supporting the concept that deep cold waters brought to the surface have highest nitrate levels. By contrast, the outflow from Fitz Hugh Sound and Smith Inlet is often warmer than surrounding waters, perhaps due to the presence of sediments to absorb sunlight, and to the shallow depth of this surface freshwater plume. Chlorophyll images of Figure 1.5 suggest highest concentration of phytoplankton in May are in the portion of the outflow from Fitz Hugh Sound closest to the cold waters from Queen Charlotte Strait. We can speculate these are where these two water masses mix, providing maximum surface nutrients and thinnest surface layers, both leading to high phytoplankton growth rates. The strong tidal flows and tidal mixing near the Scott Islands likely provide additional input of nutrients to surface waters to support the seabird colonies on the Scott Islands.

In summer we often observe westward flowing plumes of coastal (cool) waters into the Pacific, from regions at and between Brooks Peninsula and the Scott Islands. These are expected to have been set up by NW winds piling up water along the north shore of Vancouver Island. Current meters set on Cook Bank in the 1980s showed accelerating westward flow when winds blew from the NW, and accelerating eastward flow with winds from the SE, providing support for the causes of these plumes. Surface drifters deployed in spring and summer in Queen Charlotte Sound in the 1990s drifted to the south and southwest during the prevailing winds from the northwest. Many of these drifters departed Queen Charlotte Sound to the southwest, or grounded on Vancouver Island (Crawford *et al.* 1999). However, not one of the drifters that departed Queen Charlotte Sound grounded on Vancouver Island south of Brooks Peninsula, or even came close to shore here. This behaviour suggests little transport of free-floating life south from PNCIMA to shores south of PNCIMA along the west coast of Vancouver Island.

(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance

Storm winds of winter push flow alongshore at all depths along this region, and contain much of the fresh water up against the eastern islands (Figure 1.0). Return flow to the south is found at depth along the western sides of Hecate Strait, and is considered to be the source waters for Haida Eddies that form off SW Moresby Island in winter.

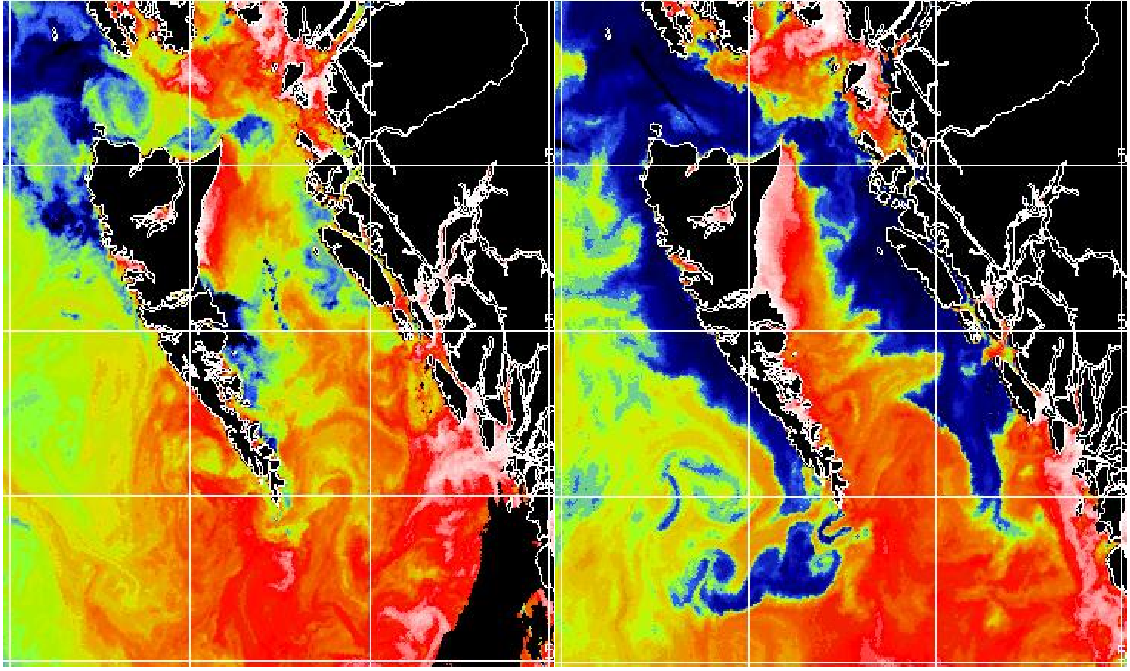
Bottom waters of the troughs of this system are warmest in winter, and may account for the winter spawning of many species of fish: Pacific cod for example. However, other factors such as food availability in spring can also be important. It is speculated that an eddy forms over North Bank in winter, and this eddy allows many of the ichthyoplankton of Pacific cod and other species to remain in Hecate Strait-Queen Charlotte Sound through the winter. This eddy would redirect to the north a portion of the return southward flow along the west side of Hecate Strait. Winter winds mix nutrient-rich water up from the bottom or near bottom, and when combined with Ekman downwelling, account for ample nutrient supply to all depths here in winter.

The high phytoplankton concentrations, noted above to lie between Fitz Hugh Sound and Cook Bank in May, are matched only by the high levels in Chatham Sound. These two regions receive the strongest outflow of fresh waters in spring, so we expect this outflow is linked to high chlorophyll concentrations. The Skeena River plume in Chatham Sound might mix with nutrient-rich waters below to produce the shallow, nutrient-rich surface layer needed for phytoplankton growth.

The Chatham Sound region of highest phytoplankton concentrations in May actually extends into northern Hecate Strait. This region receives Skeena Plume waters after they mix with deeper waters in Brown Passage and Edye Pass. Such mixing might provide the nutrient-rich, shallow surface layer to stimulate productivity. However, many other processes could enrich these waters, and we do not wish to speculate further.

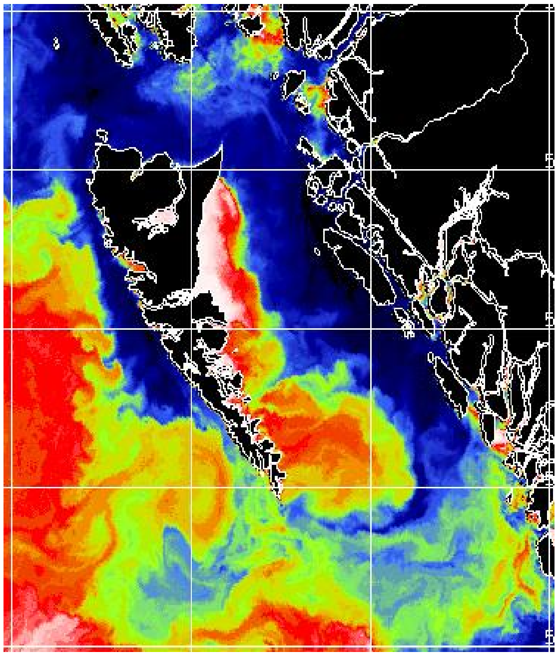
The central coast between Fitz Hugh and Chatham sounds (Figure 1.0) receives lesser flows of freshet waters, and the May chlorophyll images of Figure 1.5 reveal lower concentrations of phytoplankton in surface waters than in Chatham Sound and near Fitz Hugh Sound. Deeper colder water progressively penetrates into Queen Charlotte Sound and Hecate Strait troughs in spring through late summer, attributed first to relaxation of winter downwelling, then to some extent in mid-summer to upwelling winds blowing from the north along these straits. These deep waters are nutrient-rich, providing food for all bottom life including sponge reefs.

Along this eastern side of the region during spring and summer, higher surface concentrations of chlorophyll are maintained by an estuarine-like circulation effect driven by freshwater runoff from the coastal mountains and inlets (F. Whitney, DFO, Institute of Ocean Sciences, Sidney, BC, pers. comm., 2006). In this process, the summer relaxation of the winter downwelling winds and/or weak summer upwelling brings the deep nutrient-rich waters close to the surface where it is available for phytoplankton growth by entrainment into the brackish surface flows over the saltier water. Energy for entrainment can be provided by tides or winds. These colder waters are clearly present in Figures 1.7b and 1.7c.



(a) 26 May 1993

(b) 23 July 1994



(c) 4 September 1993

Figure 1.7 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Image (b) is from the same day presented in Figure 1.6, with slightly different colour scale.

Phytoplankton concentrations along this central eastern coast decrease through summer, despite the occurrence of strongest upwelling winds in July. Therefore it is not a combination of upwelling winds and freshet that account for the high phytoplankton concentrations in May in surface waters of this eastern coast. More likely it is the rich nutrients stirred to surface in winter that trigger this spring bloom, as occurs elsewhere in mid-latitude oceans. In this case, the rich phytoplankton concentrations seen by satellite in Chatham and outside Fitz Hugh sounds are attributed mainly to the shallow surface layer in the fresh water plumes.

(d) Cape St. James

Waters near Cape St. James deserve their own category. Flow at this cape exerts huge impact on primary and secondary productivity of surrounding waters, yet this impact is not observed in SeaWiFS imagery. Several factors are at play here:

- deep waters with very strong tidal mixing,
- persistent outflow from Hecate Strait past this cape,
- formation of Haida Eddies by winter outflow past this cape,
- close proximity of deep inflow to Hecate Strait.

Studies in the 1990s revealed strong and persistent outflow of surface water from southern Hecate Strait into the Pacific Ocean. This flow is confirmed to within 15 km of Cape St. James. Therefore any flow from Hecate Strait to the open Pacific Ocean passes close by this region. Once there, it mixes thoroughly with surrounding oceanic waters, forming cold surface plumes visible in satellite imagery for up to 120 km away from the cape. These plumes occasionally re-circulate at surface into Queen Charlotte Sound, as noted in drifter tracks (Crawford *et al.* 1995) and also in satellite imagery in Figure 1.7a (inflow appears as a relatively warm plume headed to the NE). This recirculation might be even stronger in sub-surface flows. The deep channel of Moresby Trough is close to this cape, so inflowing waters will likely entrain some of the waters mixed at the cape. Finally, the strong winter outflow from Haida Eddies can hold as much as the entire water volume of Queen Charlotte Sound and Hecate Strait combined. Fisheries and Oceans Canada (DFO) studies in the oceanic NE Pacific have found coastal species of zooplankton and nutrients in these eddies, as well as much of the winter supply of heat and fresh waters entering these two basins. Clearly Haida Eddies transport coastal waters and their properties out to 1000 km or more from this cape.

Given this high mixing rate, the lack of high chlorophyll concentrations observed by SeaWiFS need some explanation. We speculate on relevant factors here. Despite the strong mixing at this cape, there is no supply of fresh water to keep this mixed water at the surface, so much of the mixed water will sink below the euphotic zone. This lack of chlorophyll here underlines the need for fresh water in estuaries and coastal regions to support high productivity in mixed waters. Secondly, nutrient-rich water mixed to the surface here will advect away from the cape with two days and enter another domain. So phytoplankton spend too little time in this region and near the surface for primary productivity to develop.

(e) Western Hecate Strait

This is another unique region of PNCIMA. In an area of deep rocky fjords the shallow banks of this region offer unique ecology. For example, a rich supply of sediments is provided to NW Dogfish Banks by the eroding adjacent shores of eastern Graham Island. This shoreline erodes more rapidly than any other in Canada. Interestingly, second highest tides of BC are found here (tides at the head of Portland Canal are highest), and strongest wave-generated ocean mixing. Indeed, the combination of tidal mixing and wave-forced mixing keeps portions of this bank well mixed at almost all times. Lack of deeper cool water in summer, and deeper warmer water in winter assures this region is coldest in winter and warmest in summer of all PNCIMA regions on the continental shelf.

Biologically, this region is usually linked to McIntyre Bay in SE Dixon Entrance, due to the high concentrations of Dungeness crab in these two regions. McIntyre Bay is accreting, perhaps as the recipient of Dogfish Banks sediments or possibly locally derived sediments. We speculate that the presence of Dungeness crab are more likely due to the broad shallow banks than to any other factor. Their abundances go up and down over the years, with little predictability.

SeaWiFS imagery of Figure 1.5 shows that Dogfish Banks and the nearby regions of McIntyre Bay are the first to experience plankton blooms in spring, with strong growth in March. Although this season also experiences high sediment loads in surface waters here, the satellites are able to detect the unique spectral levels of plankton in reflected daylight, and these signatures indicate high levels of chlorophyll here.

This early development of chlorophyll biomass is predictable from knowledge of nutrient dynamics and the potential depth of vertical mixing. Higher chlorophyll concentrations over Dogfish Banks in northwest Hecate Strait occur because the depth of vertical mixing is limited by the shallow depths of the bottom, whereas in deeper areas winds are able to mix the water column, and its constituent phytoplankton cells, below the critical depth for phytoplankton blooms to occur (Perry and Dilke 1986). By May, the nutrients on the shallow bank are exhausted and phytoplankton concentrations decline. In addition, there appears to be little exchange of waters between Dogfish Banks and deeper regions to enable import of nutrients (Crawford *et al.* 1998). Deep areas have a greater store of nutrients, and in many cases import nutrients and are able to maintain higher phytoplankton concentrations later into the spring, especially along the frontal regions in this area (Perry *et al.* 1983).

Waters along the southwest side of Hecate Strait are deeper than on Dogfish Banks and only in September do the SeaWiFS images reveal more than average concentrations of phytoplankton. Lack of plankton in May might be due to lack of freshwater plumes to form shallow, nutrient-rich surface layers, since little runoff flows from the Charlottes compared to other shores.

(f) Dixon Entrance

In a region of north-south channels this strait clearly offers a unique aspect to PNCIMA. It is the deepest of the three basins, and its deep central axis extends into Clarence Strait and US waters to the north. Deep flows here are directed eastward year-round. But its most unique feature is the Rose Spit Eddy north of Rose Point at the NE corner of Graham Island. This feature was noted in early water property surveys of the region (Crean 1967), and also in the Hecate hydraulic model built in the 1960s at Pacific Biological Station (PBS) in Nanaimo. Several oceanic studies of the 1980s and 1990s observed this eddy in tracks of near-surface drifters and in dynamic height anomalies in both summer and winter. Finally, satellite images of sea surface temperature offer evidence for its existence. These numerous studies are offered as evidence, because theoretical and numerical studies offer only weak evidence for its presence. In physical oceanographic terms, this strait is sufficiently wide that the estuarine flow here will be out on the north side and in on the south side, both at surface, rather than out on the surface and in at subsurface depths as found in more narrow channels. With the Skeena River and Nass River plumes flowing usually to the north of Chatham Sound, and these outward and inward estuarine flows on the north and south sides of Dixon Entrance respectively, only a southward flow in the west is needed to complete the eddy. Forcing for such a flow is provided by NE winds in summer.

The eddy leaks considerable water, with outflow directed to the NW past Forrester Island or to the SW past Langara Island. Generally only one or the other of these routes is taken at any one time, with some evidence of influence of the wind on choice of routes (Crawford and Greisman 1987).

A second interesting feature is the strong internal semi-diurnal (twice-daily) tidal currents in Dixon Entrance, up to 60 cm s^{-1}, and much stronger than expected for the range of tides present. Internal tides are due to up-and-down motion of sub-surface waters in this basin, and are expected to be set up along the narrow ridge that runs through Celestial Reef in eastern Dixon Entrance.

(g) West Coast Queen Charlotte Islands

Here we have yet another unique region of PNCIMA, also unique to the North American West Coast. The continental shelf west of Moresby Island is the narrowest of British Columbia, with the least freshwater input. The shelf west of Graham Island is somewhat wider, with somewhat more freshwater input. Both coasts experience extreme pounding by winter waves. So it is not surprising that fisheries here are mainly for deep-water species along the continental slope. The remoteness of this region and numerous small islands allow seabird colonies to thrive.

(h) Inlets

As noted earlier, this overview does not include detailed consideration of inlet and fjord waters, largely because there is insufficient data in these areas and each inlet requires its own study. The inlets in PNCIMA are numerous, and require more attention for environmental assessment. Many inlets (Knight, Rupert, Neroutsos, Observatory, Seymour, and Rivers inlets, Alice and Kitimat arms, and Fitz Hugh Sound) have been studied for assessment of specific industries or fisheries issues.

These inlets are deep with slow tidal currents, and considerable freshwater input. As a result, the outflow plumes of fresh water are shallow, often 1-5 metres deep, and often form shallow outflows into Hecate Strait, Queen Charlotte Sound and Dixon Entrance, as well as the outer coast. Knight Inlet in the south has been the subject of many detailed studies of tidal flow and mixing at its sill, and this information is available for application to other inlets. However, mixing and biological processes in each fjord depend on the depth, shape and position of the sills, as well as prevailing wind directions, complex geography of the inlet, and freshwater input. Each inlet can be considered unique.

A case of interest is the abrupt decline of Rivers Inlet salmon populations in the late 1990s. Although there have been numerous studies of this region since then, the factors influencing this run are not well known. McKinnell *et al.* (2001) provided evidence that the collapse of some stocks within PNCIMA was due unknown events that influenced marine survival (see Appendix I: Salmon). This example, together with the continuing conflict over sea lice and fish farms in Broughton Archipelago, should warn us of the difficulties in assigning anthropogenic and natural causes of ecosystem change in PNCIMA before, during and even after human impact on this area.

1.4.1 Linkages to Zooplankton and Fish

Zooplankton are known to aggregate on bathymetric edges likely as a result of convergent processes but also partially in response to higher phytoplankton concentrations. There have been few direct observations of zooplankton distributions in PNCIMA, certainly in comparison to southwest Vancouver Island. However, as inferred from distribution patterns observed elsewhere and a limited amount of field data, euphausiid concentrations should be highest on the continental slope and along the margins of the deep troughs in Queen Charlotte Sound (see Appendix D: Plankton).

Within PNCIMA, groundfish are most abundant in Goose Island Trough, near Cape St. James, and at the southeast end of Dixon Entrance. Other significant aggregations are seen along bathymetric edges around Goose Island and Middle banks (North Bank) as well as the northern edge of Moresby Trough (Figure 1.8). This distribution pattern is supported by results of groundfish bottom trawl surveys (A. Sinclair, unpublished data). The DFO trawl survey program has recently been expanded to include Queen Charlotte Sound and to provide greater coverage of Dixon Entrance and Hecate Strait. While the dataset is much less extensive than that from the commercial fishery, the surveys provide information from areas not normally fished.

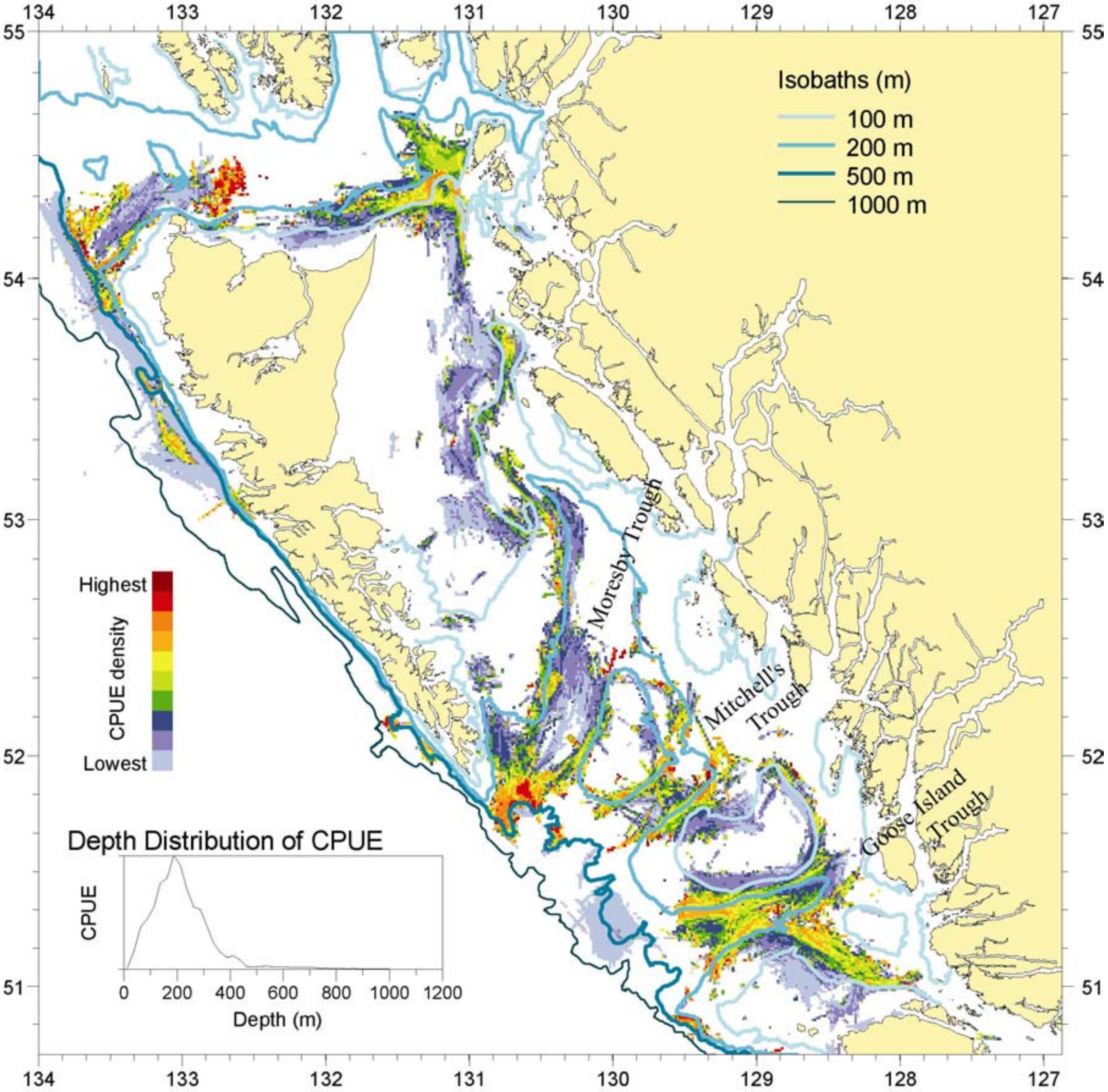


Figure 1.8 Spatial distribution of groundfish catch per unit effort (CPUE) in the bottom trawl fishery in PNCIMA, 1996-2004. It was assumed that CPUE is an index of relative biomass. The data were plotted using a 1 km^2 grid. The grids were colour coded by decile of the cumulative distribution, with the highest density coloured red and the lowest light blue. The line graph shows the depth distribution of CPUE (from Sinclair *et al.* 2005).

The main concentrations in Goose Island Trough and southeast Dixon Entrance are adjacent to the areas of highest phytoplankton concentrations. The combinations of estuarine flows in these two areas and the existence of bi-directional flows provide the mechanisms for enrichment from primary production, concentration of food supply, and retention of particles in these areas to explain the high abundance of fish there. In contrast, the central and southern portions of Hecate Strait at depths less than 100 m have lower fish biomass, are further away from an abundant source of primary production, and have relatively uniform bathymetry with fewer bathymetric edges to support large concentrations of euphausiids.

The Cape St. James area is the convergence of several flows that could concentrate food supply. As long as a feeding fish can maintain its position against the currents in this area, it will receive a much higher contact rate with food particles than in many other areas in PNCIMA.

There is much less information on the distribution of pelagic species. Pacific herring and Pacific sand lance are known to be abundant in PNCIMA. The distribution of herring spawning grounds are well known (see Chapter 2, section 2.5.1, Map 2.12, and Appendix H: Pelagic Fishes, Section 2.0), however their distribution during the feeding period of their life cycle is poorly understood. Both species are caught in bottom trawl surveys, but are poorly represented relative to their abundance in nature and relative to groundfish species for which the surveys were designed. Catches of both species are higher in Hecate Strait than in Queen Charlotte Sound. This is likely because the depths in Hecate Strait include more seafloor of the appropriate depth for these species. Within Hecate Strait, these pelagic species appear to be more abundant in the northern area than to the south. Thus, within Hecate Strait at least, the distribution of pelagic species is similar to that of groundfish.

The overlap in euphausiid and fish distributions is unlikely to be coincidental, but rather a clear trophic linkage. Both are influenced by bathymetry, which influences circulation, which is driven by tides and wind, and enhanced by the estuarine circulation.

1.4.2 Species Richness

The recent expansion of synoptic groundfish bottom trawl surveys in PNCIMA provides a new source of information on species richness in the area. The mean numbers of fish species taken per survey tow in the period 2003-2005 are plotted in Figure 1.9. The highest species richness values were seen adjacent to the southern central coast area and through Goose Island trough. These areas have a large range of habitat types including rugged reefs, highly variable bathymetry, exposed bedrock, as well as patches of smoother mud, sand, and gravel. The lowest species richness values occurred over the shallow banks (Goose Island, Middle, Dogfish) as well as in McIntyre Bay north of Graham Island. These areas have a more homogeneous habitat type dominated by outwash sand and gravel.

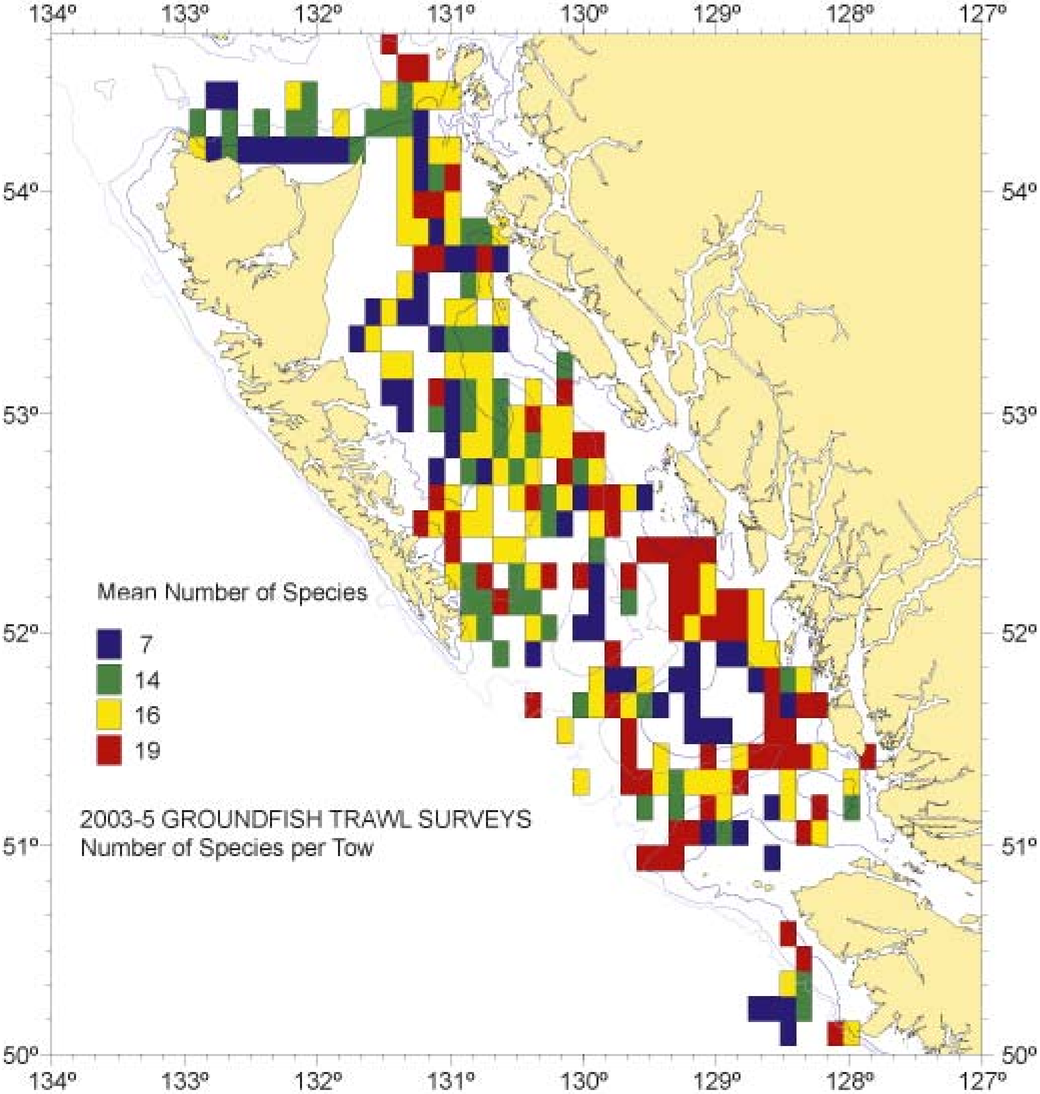


Figure 1.9 Spatial distribution of fish species richness (mean number of species per tow) sampled by bottom trawl surveys in PNCIMA 2003-2005. The grid cells were coloured according to the quantiles of the overall distribution. Cells with the highest richness are red, the lowest richness are blue.

1.4.3 Species Distributions

Sinclair *et al*. (2005) examined associations between surficial geology and the distribution of 21 groundfish species caught in bottom trawl fisheries in PNCIMA. Three main groups emerged. The first included shallow water species distributed over sand and gravel habitat that is exposed to considerable disturbance and reworking from tidal and storm energy. The species were rock sole, big skate, English sole, spotted ratfish, Pacific halibut, lingcod, Pacific cod, and petrale sole. This habitat type is likely to be less susceptible to anthropogenic disturbance. These species tended to have relatively short life spans and had the fastest growth rates. A second group occupied deeper waters and a soft silt and mud bottom type that was less exposed to disturbance from natural causes. The species were longnose skate, arrowtooth flounder, spiny dogfish, rex sole, sablefish, and Dover sole. Given the finer sediments and less exposure to natural disturbance, this habitat may be more susceptible to anthropogenic disturbance than the former. These species had intermediate life spans and growth rates. The third group was in deep water over firm glaciomarine mud and glacial till habitats. All species in this group were from the genus *Sebastes* (including boccacio, yellowtail, silvergray, rougheye, redbanded, yellowmouth rockfish and Pacific Ocean perch) and were the slowest growing and longest lived group. A fourth group could be added to this list of species/geological associations, the inshore rockfish species which includes copper rockfish, quillback rockfish, and yelloweye rockfish. These species are taken in hook-and-line fisheries in shallow coastal reef areas. These habitats are often covered with thick epifauna and macrophyte communities that provide a buffer from natural forces such as waves and storms. However, the epifauna and macrophytes are highly susceptible to anthropogenic removal. As with the other *Sebastes* species, these have long life spans and slow growth rates. An interesting fifth component is the Dungeness crab which is found in abundance in the shallowest area of northern Hecate Strait and McIntyre Bay where the sand bottom is constantly being reworked by tides and storms. This species has a shortest life history and fastest growth rate of all the species listed here, surviving for only five to six years.

The general pattern here is for species with greater scope for growth, *i.e.,* high growth rates and short life spans, to occupy habitats that are more resilient to disturbance.

1.5 TROPHIC CONNECTIONS

Three general food web systems can be defined for the PNCIMA region: phytoplankton-based systems; nearshore (macrophyte)-based systems; and detritus-based systems. Strictly speaking the latter (detritus-based) systems are also derived from phytoplankton or macrophyte production, but enough marine organisms feed directly or indirectly on detritus to warrant its own food web, at least in the context discussed here. Almost nothing is known about the microbial loop in this region, although studies have been conducted to the south off Vancouver Island and in the Strait of Georgia. Elsewhere and on theoretical grounds it has been suggested that the microbial loop can divert an important fraction of primary productivity away from higher trophic levels. If some of this microbial production does make its way to higher trophic levels, it does so by increasing the number of trophic links, which decreases the efficiency of the transfer of energy, thereby decreasing the overall production of these higher trophic levels (Ware 2000).

Information on plankton and detritus-based food webs in the PNCIMA region is largely based on direct observations of stomach contents (mostly from groundfish and some pelagic species) and on model studies using ECOPATH (Christensen and Walters 2004). There are several significant unknowns in both of these approaches to food-web analyses. Direct observations are effort-intensive, and tend to be conducted for only a short period of time on selected surveys. They rarely provide extensive coverage of species throughout the entire region or in all seasons. Model studies using ECOPATH require values for many parameters for all groups in the model; these are based on observations as much as possible, but adequate data for most species are lacking. Estimates from similar taxonomic groups and from elsewhere are used to provide possible values, and simulation studies are usually conducted to evaluate system sensitivity to key parameters. In addition, marine ecosystems are unusual (compared with terrestrial ecosystems) in that most species go through very large changes in body size, shape, and habitats between egg, larval, and adult stages. Larval and adult stages of the same species could easily be considered as different species, with predators and prey changing roles as they grow. Such complex life history changes are rarely included in food web models or stomach content analyses, but may be important at stabilising or de-stabilising marine ecosystems.

The ECOPATH modelling approach is described by Christensen and Walters (2004). In the model constructed for northern BC (broadly equivalent to the PNCIMA region), 53 functional groups were defined. These groups range, with varying degrees of resolution, from phytoplankton, detritus and macrophytes to copepods and euphausiids, to small and large crabs, to forage fishes, to juvenile and adult stages of pelagic and demersal fishes, to seabirds and whales (Ainsworth *et al.* 2002). These analyses illustrate the clear separation between those groups that feed within a phytoplankton-based food web, and those groups that feed within a primarily detritus-based food web.

Using observations of stomach contents of demersal fishes collected during surveys in 1985 and 1987, Pearsall and Fargo (2007) identified three main types of feeding: benthivores, planktivores, and piscivores. They further identified five main feeding strategies: euphausiid feeders, shrimp feeders, benthic (macro- and meiobenthos) feeders, macrobenthic feeders, and piscivores. They found that benthic feeders showed more stability among locations and seasons in their diets than did piscivores. Ontogenetic variability in diet was also more apparent for the piscivores, with juveniles often feeding to a larger extent on macrobenthic organisms than the adults. Appendices to this report (*e.g.*, marine plants, invertebrates) also present schematic food web diagrams illustrating linkages among various groups of species.

Nearshore systems are defined as those for which organic carbon is largely derived from terrestrial sources and/or macrophytes. These regions are limited by depth, in particular to depths shallow enough for the euphotic zone to support the growth of macrophytes (typically to about 35 m in these coastal regions; Sloan and Bartier 2000). The most important macrophytes in the PNCIMA region are kelps and eelgrasses. Estimates of the productivity of giant kelp (*Macrocystis* sp.) in California found that photosynthesis was greatest near the sea surface, was reduced to 5-10% of this surface value at 4 m depth, and was reduced to 0.5-2% of surface values at 8 m depth (Mann 1982 p.59). Estimates of the daily net production of giant kelp beds in California have found sustained growth rates of 1-4% of biomass per day (Mann 1982 p.59); the production to biomass (P/B) ratio estimated by Ainsworth *et al.* (2002) for macrophytes in northern BC was 5.3 yr^{-1} (the P/B ratio estimated for phytoplankton was 179 yr^{-1}, *i.e.*, over 30 times the growth of macrophytes). However, relative to the area over which phytoplankton are distributed, a rough estimate suggests that phytoplankton contribute substantially (5,000-10,000 times) more primary productivity to the PNCIMA region than do macrophytes.

Macrophyte and terrestrial organic carbon serve as critical food sources for the nearshore food-web. They directly support echinoderm and gastropod mollusc invertebrates such as sea urchins and abalone, which in turn are fed upon by fish and sea otters (where they occur). Macrophytes are also critically important as habitat structure-forming organisms, *i.e.,* kelp and eelgrass beds. These provide surface habitat for crustaceans (such as kelp crabs) and for particular life stages of commercial finfish such as herring eggs. They also create an environment for many species of invertebrates and finfish to live within by providing cover and shelter, in particular for juvenile fishes like herring and salmon. They act to increase the supply of drifting phytoplankton and algae by slowing local currents and generating turbulence.

A schematic example of these plankton, detritus, and macrophyte-based food webs for the PNCIMA region is illustrated in Figure 1.10.

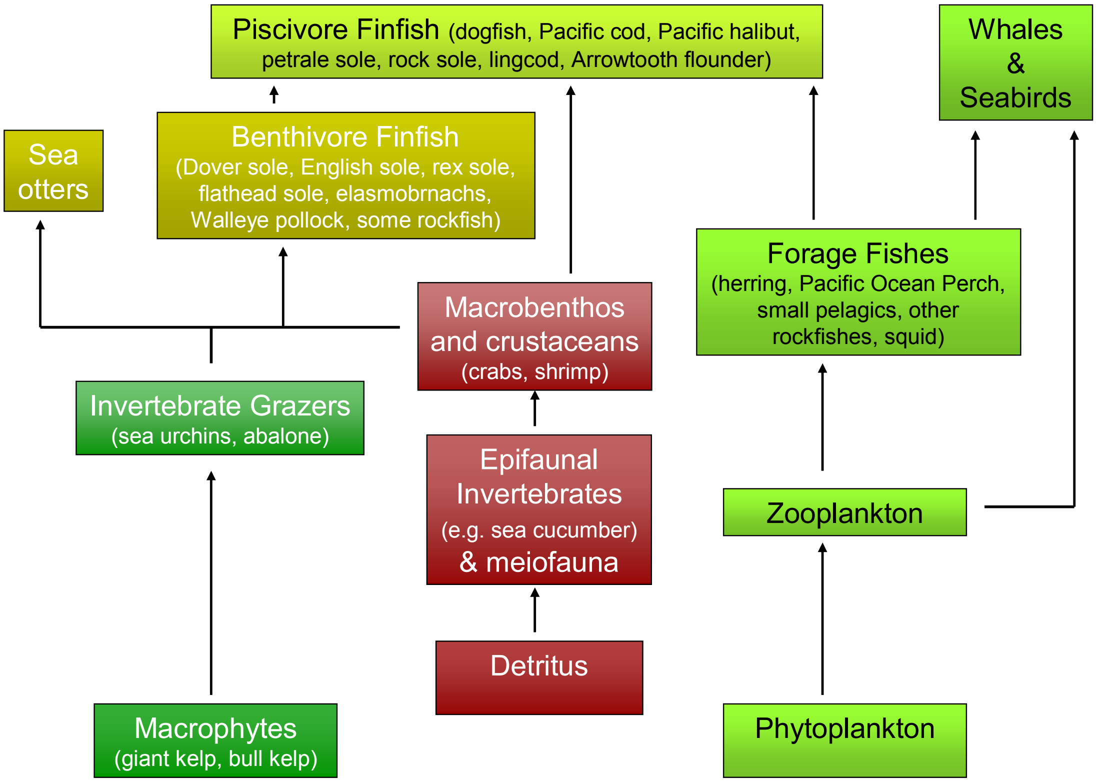


Figure 1.10 Schematic food webs for the PNCIMA region.

Ainsworth (2006) used the ECOPATH model of the PNCIMA region to explore the system's responses to environmental forcing over the past several decades. He created a "primary production forcing anomaly" pattern at the base of the (ECOPATH) food web that "matched" the temporal dynamics of the system. This pattern was negatively correlated with sea surface temperature (Spearman rank correlation coefficient, $r_s = -0.57$), and indicated reduced primary production from 1975 to 2000 compared with the period from 1950 to 1975. These simulations suggest that primary production and herring recruitment anomalies (another variable for which data could be compared with model outputs) were correlated with environmental time series such as sea surface temperature, the Pacific Decadal Oscillation (PDO) and other regional climate indices, and are therefore linked to the large-scale climate dynamics of the North Pacific. Ainsworth (2006) also concluded that in the northern BC marine ecosystem, lower trophic level dynamics are dominated by bottom-up controls (*i.e.,* climate effects on plankton productivity) whereas higher trophic levels also included top-down (*i.e.*, predator, and fishing) interactions. He concluded that strong predator controls (influences) do not cascade down to the lowest trophic levels of this ecosystem.

The number of linkages in these food web models and diet studies suggests that several important prey items exist within the web, in particular herring, other forage fishes, and large zooplankton such as euphausiids. There is no indication of an overall "wasp-waist" food web structure (*e.g.*, Cury *et al.* 2000), in which energy flows are funnelled through one or a few key species in the middle of the trophic web. The lack of such a feature suggests a more stable trophic structure than might occur in wasp-waist systems such as upwelling areas, and a trophic structure that should be more resilient to natural and human disturbances. However, individual species may have preferences for one or a few key prey items which dominate their diets, either because of spatial or temporal overlaps, behavioural characteristics of predator and prey, and critical biochemical or energy contents. If these prey items are severely reduced in abundance, disappear entirely, or somehow shift their distributions or behaviours so as to become unavailable to these predators, the predator populations may be severely affected. This suggests that, whereas the food web in the PNCIMA region overall may not display a "wasp-waist" structure, such a structure may exist for certain species. For example, the diets of killer whales in this region was composed of salmon (96.7%), the bulk of which (72.2%) were chinook (Ford and Ellis 2005). Such a structure may also exist for large whales such as humpback and blue whales in the PNCIMA region, which feed largely on euphausiids. Identifying which species might be affected in this way, and which prey species might play "wasp-waist" roles, could be done using food web models such as ECOPATH.

1.6 MIGRATORY SPECIES

Section 1.3 discusses the productivity of "resident" species of the PNCIMA region, *i.e.,* those species which spend all of their life within the central and north BC marine ecosystems. Like much of the coastal and continental shelf regions of the northern NE Pacific, however, the PNCIMA region produces a large number of fish which leave the region as juveniles and return as adults, such as Pacific salmon. The region also receives a considerable number of species which migrate to or through it from elsewhere. Such migratory species include marine birds, fish, and marine mammals such as pinnipeds and whales.

The PNCIMA region is on the migratory route for many species of birds which summer in the Arctic. They use the offshore, nearshore, and inter-tidal resources of the PNCIMA region to fuel their migrations to and from their Arctic feeding grounds. Juvenile salmon (and adult salmon during their return migrations) also use the resources of this region during their migrations north along the North American coast. Observations since the late 1990s have found that juvenile pink, chum, and sockeye salmon are quite abundant in the PNCIMA region from June to November (Figure 1.11), likely representing continual migrations of fish from sources to the south (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2006). Marine mammals such as pinnipeds (*e.g.,* Stellar sea lion) and Mysticete whales (*e.g.,* humpback, fin, and blue whales) migrate into the PNCIMA region in certain seasons to feed on abundant zooplankton (especially euphausiids) and forage fish (*e.g.,* herring).

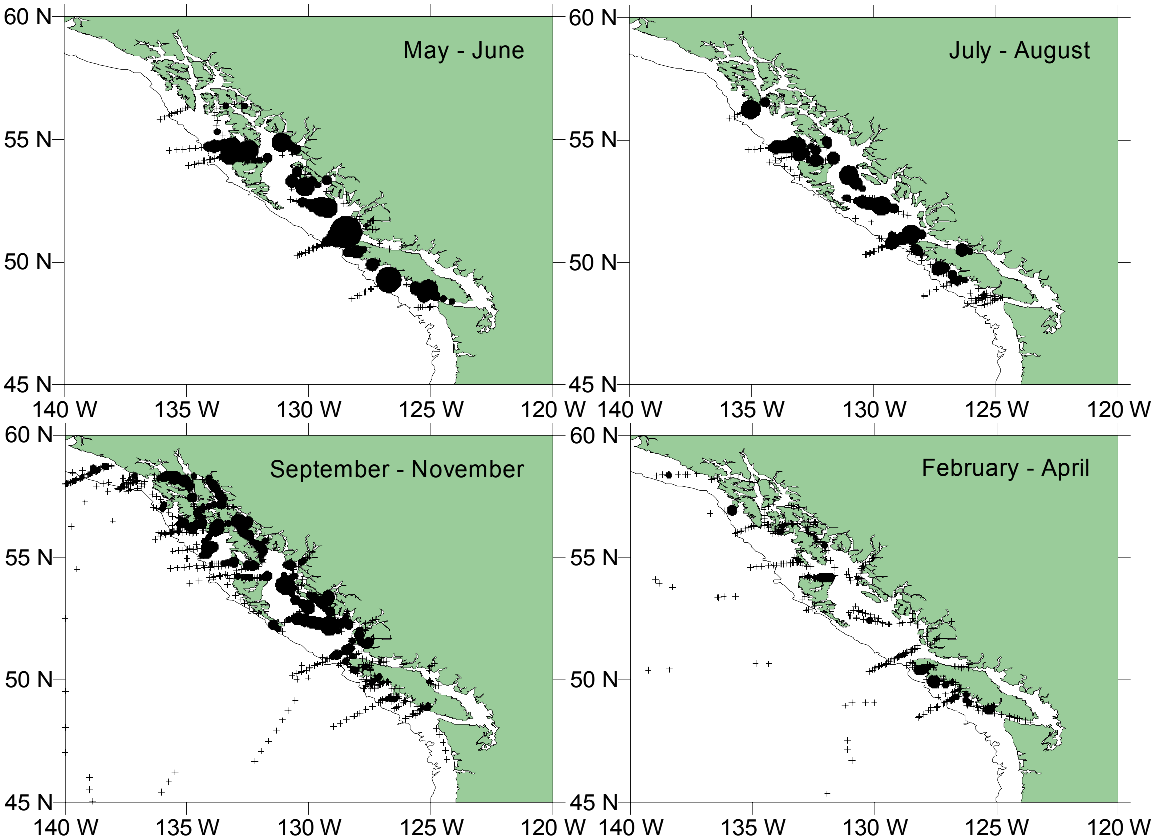


Figure 1.11 Seasonal distribution of juvenile sockeye salmon (*Oncorhynchus nerka*) in the PNCIMA region from surveys conducted since 1998 (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Migrations of marine fish into the PNCIMA region occur in a different fashion to the migrations of marine birds and mammals. With the exception of Pacific hake, whose life history has evolved to include summer migrations from California to BC waters to feed on euphausiids, most other species migrate into the PNCIMA region in association with changes in environmental conditions – in particular when conditions become unusually warm. Such migrations are most obvious during El Niño conditions (*e.g.*, Wing *et al.* 2000) but can also occur during other warm periods (*e.g.,* DFO 2005). Most of these species are pelagic fish or invertebrates such as Pacific sardine, northern anchovy, and ocean sunfish. The timing and duration of their appearance in PNCIMA waters also tends to be less regular than for seasonal migratory species such as birds, mammals and Pacific hake, but they tend to be most evident during summer of warm years.

These species represent three different groups and strategies for the use of the PNCIMA region by "non-resident" species. These strategies are:

- *stop-over* migrants, such as marine birds migrating to the Arctic and salmon originating from rivers to the south which migrate through the PNCIMA region on their way north as juvenile and south as adults;
- *destination* migrants, such as whales, Stellar sea lions, and Pacific hake which migrate into the PNCIMA region from elsewhere to feed, usually during spring and summer; and
- *environmental* migrants, such as warm water zooplankton and pelagic fish and invertebrates which extend their ranges and distributions northwards with warm conditions and retract southwards with cool conditions.

It is evident that the extent and dynamics of use of the PNCIMA region will be different for species in each of these categories, and will depend on the factors driving the migrations.

The net impact of such migratory species on the PNCIMA region is unclear. For example, do these migratory species represent an import and net gain of energy into the PNCIMA region from other regions, and is this net import critical to the functioning and sustainability of the PNCIMA ecosystems? Or, do these migratory species represent a net loss of energy from PNCIMA to other regions, so that the PNCIMA region has an important role in supporting external ecosystems? Such questions represent significant unknowns as to how the PNCIMA marine ecosystems are connected with other adjacent and distant marine ecosystems.

A reasonable starting hypothesis is to suggest that migratory species represent a net loss of energy from PNCIMA and an export to other ecosystems. Most obvious are *stop-over* migrants which use the PNCIMA region to feed and refuel during their long-distance migrations but which do not reside long enough within the PNCIMA system to become significant prey for resident species. Large *destination* migrants may represent a similar loss of energy from PNCIMA as there are few resident predators on these species in the PNCIMA region.

There is, however, a fourth category of migrating species which do play a very significant role in importing energy and nutrients largely derived outside of PNCIMA into the region. These are the Pacific salmon that originate from the lakes and rivers within the terrestrial boundaries of PNCIMA, migrate through the coastal and shelf ecosystems to the open NE Pacific, and return to their natal streams as adults to die (Figure 1.12). As a result of this migration they import significant quantities of "marine-derived" nutrients, (*i.e.,* nutrients that were obtained while feeding and growing in the open ocean) to the terrestrial ecosystems of coastal central and northern BC. With the excessive rainfall in this region these coastal terrestrial ecosystems tend to be nutrient poor; nutrients derived from salmon migrations provide an important ocean-terrestrial link that re-supplies these essential nutrients to terrestrial systems.

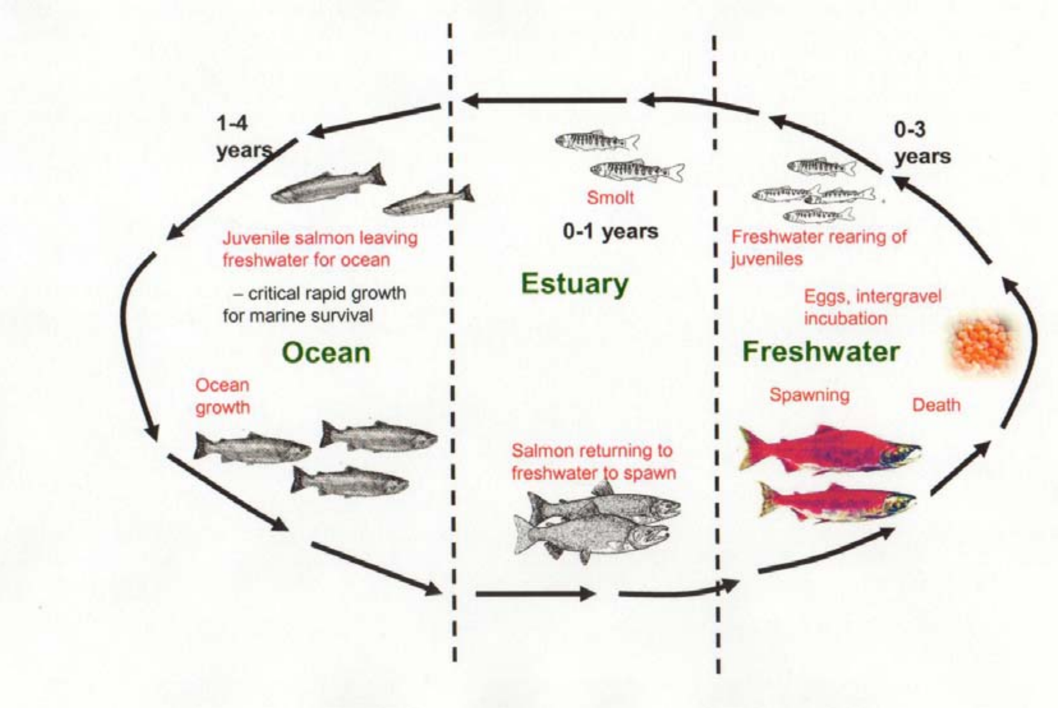


Figure 1.12 Typical life-cycle of Pacific salmon showing the ocean-terrestrial connection and the export of marine-derived nutrients to terrestrial ecosystems (from Johannes *et al.* 2003).

1.7 TEMPORAL PATTERNS OF PRODUCTION

Temporal patterns of the production and biomass of lower trophic level organisms such as phyto- and zooplankton for a generic location in the open waters of the Hecate Strait – Queen Charlotte Sound region have been modeled by Ware and McQueen (2006c). They developed a simulation model that tracks the flow of biomass from phytoplankton through to copepods, euphausiids, and other zooplankton. The model is forced by water temperature, hours of sunlight, wind mixing, and upwelling (using upwelling-favourable winds as a proxy); note that they excluded from their model any winds that were not upwelling-favourable, as they believed these generally are not conducive for the production of phytoplankton. Freshwater flows and their effects on the vertical stability of the water column were not included. The model simulates daily phytoplankton production from 1 March to 30 November of each year. The model is fully described in Ware and McQueen (2006b).

Using input data from the past 4 decades, the model estimates that primary production averaged about 223 g C m^{-2} yr^{-1}, which would make this region less productive than the Strait of Georgia but much more productive than the oceanic Gulf of Alaska. Primary production was low during the 1960s in their simulation, increased through the 1970s to the early 1990s, and then declined slightly in the mid-1990s (Figure 1.13). The strongest driver of these decadal-scale patterns was the average upwelling wind speed during the production season ($r^2 = 0.58$; Figure 1.13), which was increasing during the 1970s and 1980s, although the moderate value of the regression coefficient indicates that many other factors, such as sunlight, wind mixing and zooplankton grazing, also play important roles in regulating primary production. The principal production season in this region runs from March to November.

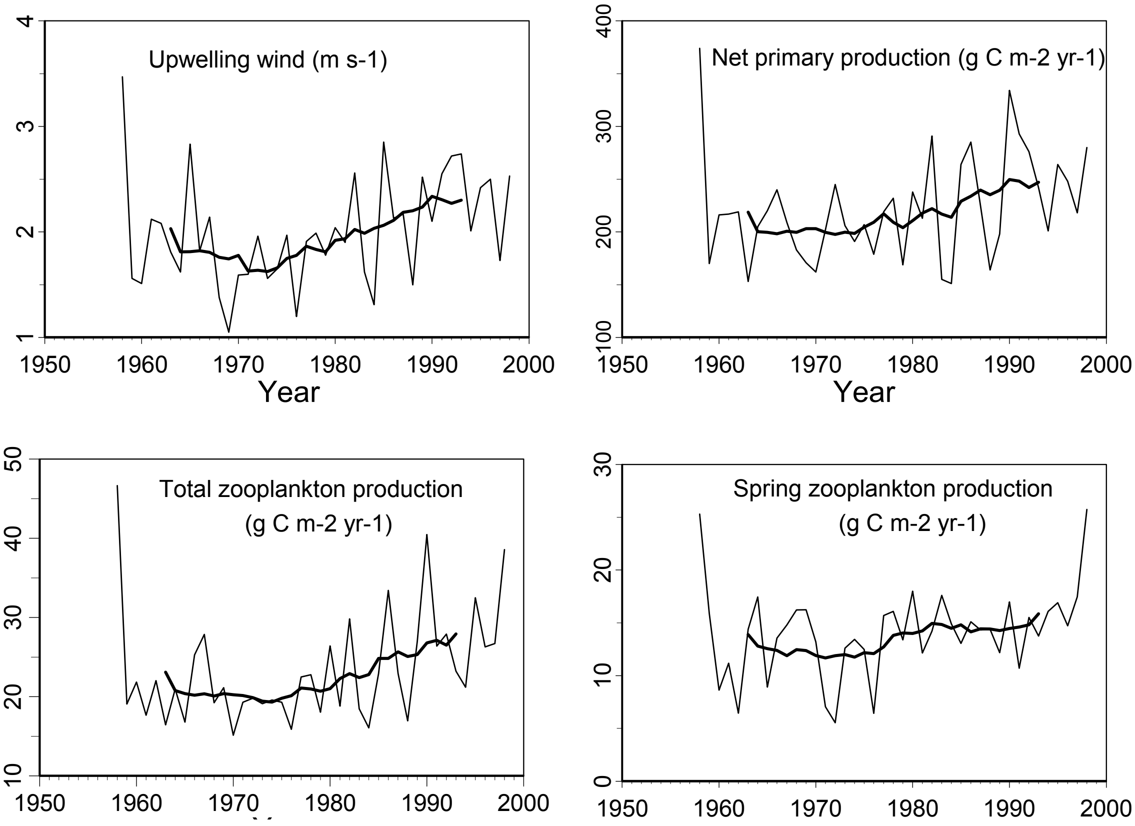


Figure 1.13 Annual (March to November) average upwelling-favourable wind speed, modelled net primary production, total zooplankton production, and spring zooplankton production, 1958-1998, from the Hecate Strait lower trophic level model of Ware and McQueen (2006c). Heavy line is a decadal-scale (11 year) moving average.

Upwelling-favourable winds are expected to bring more nutrients into near-surface waters along the east side of Hecate Strait and the west coast of the Queen Charlotte Islands in summer. However, it is important to remember that the Ware and McQueen (2006c) study identified upwelling winds only by the direction of the wind, not by the ocean processes associated with this wind. The strength of upwelling is not well known, and other processes associated with NW winds might have equal or greater impact on primary production in some regions. For example, Coriolis force directs surface currents to the right of the wind in the Northern Hemisphere. Studies of winds and surface drifters in the three major basins (Dixon Entrance, Hecate Strait and Queen Charlotte Sound) found the surface flow was on average about 35° to the right of the wind (Crawford *et al.* 1996; 1999). Thus NW winds would push waters away from an eastern shore. This water could be replaced by deeper waters (upwelling) or the surface flow could be mainly surface outflow from inlets such as Fitz Hugh Sound and Chatham Sound. Either process would push nutrient-rich waters into the regions we note later as more highly productive.

As expected, total zooplankton production and spring zooplankton production also followed similar decadal patterns, although the decadal trend is not as pronounced (except at the end of the 1990s) in the spring zooplankton time series. Annual total zooplankton production was reasonably well correlated with the net primary production ($r^2 = 0.76$). Zooplankton converted primary production into zooplankton biomass with an efficiency of about 10%. The model suggests a significant ($r^2 = 0.42$) positive relationship of this zooplankton ecological efficiency with the sea surface temperature (SST), such that the ecological efficiency was less than 9% for SST less than 11 °C, and was greater than or equal to 12% for SST greater than 12 °C. Ware and McQueen suggest this implies that zooplankton become more efficient grazers at warmer temperatures, and occurs in the model because grazing rates of zooplankton increase exponentially with temperature. In contrast to total zooplankton production, the spring zooplankton production was most well correlated ($r^2 = 0.63$) with the average SST, and only very weakly correlated ($r^2 = 0.09$) with the annual net primary production, suggesting that late winter-spring conditions and phytoplankton production may have a greater influence on spring zooplankton than annual conditions.

Ware and McQueen (2006a) compared their model output (updated to 2002) with observed data for the period since 1998. They found the correlation between chlorophyll *a* concentrations derived from the model and chlorophyll *a* concentrations that were observed from the SeaWiFS satellite to be $r^2 = 0.37$. Comparisons of the model outputs with observed annual anomalies in the nestling growth rates of Cassin's Auklet chicks on Triangle Island off the northwest tip of Vancouver Island were most highly correlated with the date of the spring phytoplankton bloom ($r^2 = 0.86$) and with the modeled copepod production rates. These results are broadly consistent with observations of the responses of seabird populations to ocean climate changes at the northwestern tip of Vancouver Island (Bertram *et al.* 2005; Hedd *et al.* 2006). Correlations between model estimates of spring zooplankton, copepod and euphausiid production and the growth rates of Pacific herring populations in Hecate Strait and Queen Charlotte Sound were about $r^2 = 0.37$.

The NASA SeaWiFS Ocean Biology Processing Group has made available satellite ocean colour data obtained since 1997, resolved to monthly time scales and 9-km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml)[1]. For the PNCIMA region, the mean monthly and annual mean (January to November) chlorophyll *a* concentrations are shown in Figure 1.14. They indicate relative constancy of the mean annual chlorophyll concentration from 1998-2005, except for 2002 which had very high chlorophyll during spring. The data also indicate that peak spring (April-May) chlorophyll concentrations are significantly (t-test, P=0.018) higher from 2002-2005 (mean = 2.8 mg m^{-3}) compared with 1998-2001 (mean = 1.8 mg m^{-3}).

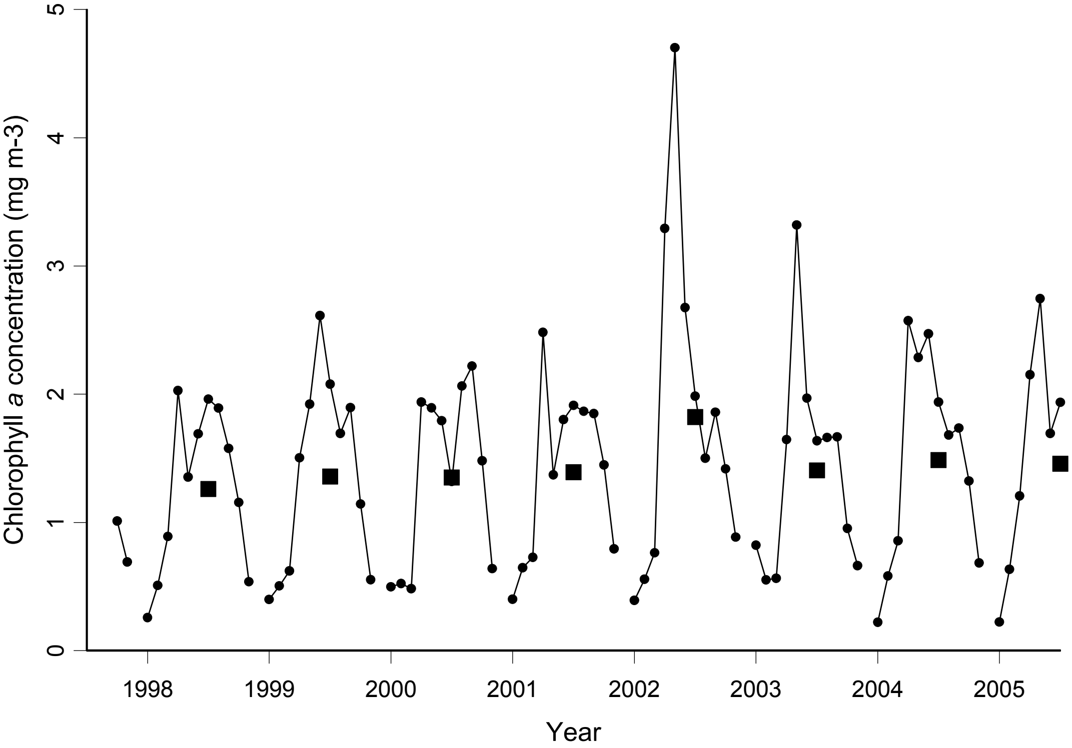


Figure 1.14 Monthly mean chlorophyll *a* biomass (mg m^{-3}) for the PNCIMA region as measured by the SeaWiFS satellite sensor at 9 km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml). Note no data are available for December of any year. Large squares represent the annual average chlorophyll *a* biomass calculated from monthly averages from January to November of each year.

The long-term catches of “resident” finfish (which excludes Pacific hake, sardine, and pink, chum, sockeye, and coho salmon), as used by Ware and Thomson (2005), from 1920-2004 show the very high catches of pelagic species (herring) during the 1960s, followed by their decline, the closure of the herring reduction fishery, and the

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[1] The images and data used in this study were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

introduction of most groundfish fisheries since the 1970s (Figure 1.15). These patterns should be comparable with the time series of plankton as produced by the model of Ware and McQueen; however, the catch series is too highly regulated by management actions and such a comparison inferring direct control of annual variations in fish yields by annual plankton production would be meaningless.

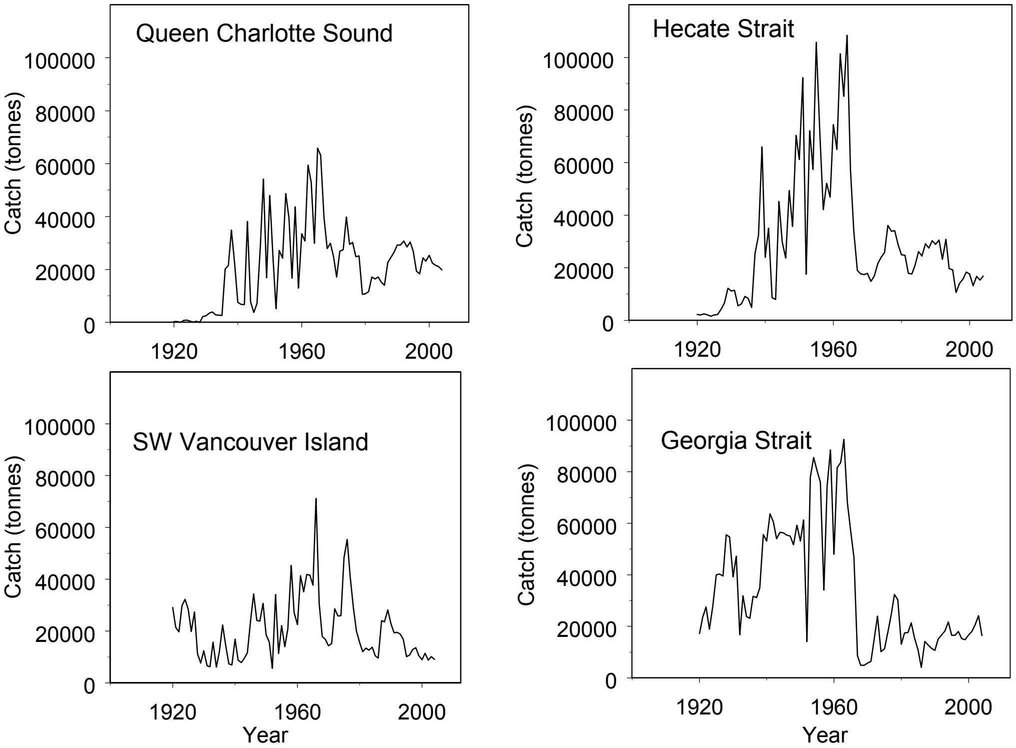

Figure 1.15 Annual catches of "resident" fish (all finfish species excluding Pacific hake, Pacific sardine, pink, chum, sockeye and coho salmon) from 1920-2004 in two southern regions and two PNCIMA regions of the BC coast.

The longest series of fishery independent indices of groundfish species biomass in PNCIMA are available from the Hecate Strait Assemblage Survey which began in 1984 and was carried out approximately every two years until 2003. Twenty-one individual species time series were selected for comparative analysis. Cluster analysis was used to group time series with similar temporal trends. Four clusters emerged (Figure 1.16). One group comprising 7 species (arrowtooth flounder, Pacific sanddab, Dover sole, slender sole, flathead sole, spotter ratfish, and rex sole) showed an increasing trend over the entire time series with an approximate four-fold increase in biomass (Figure 1.17). Two other groups showed an initial period of increase, followed by a decline to the late 1990s, and an increase in the early 2000s. These 2 groups accounted for 12 species. The final group that included Pacific cod and spiny dogfish, showed a downward trend throughout the time series.

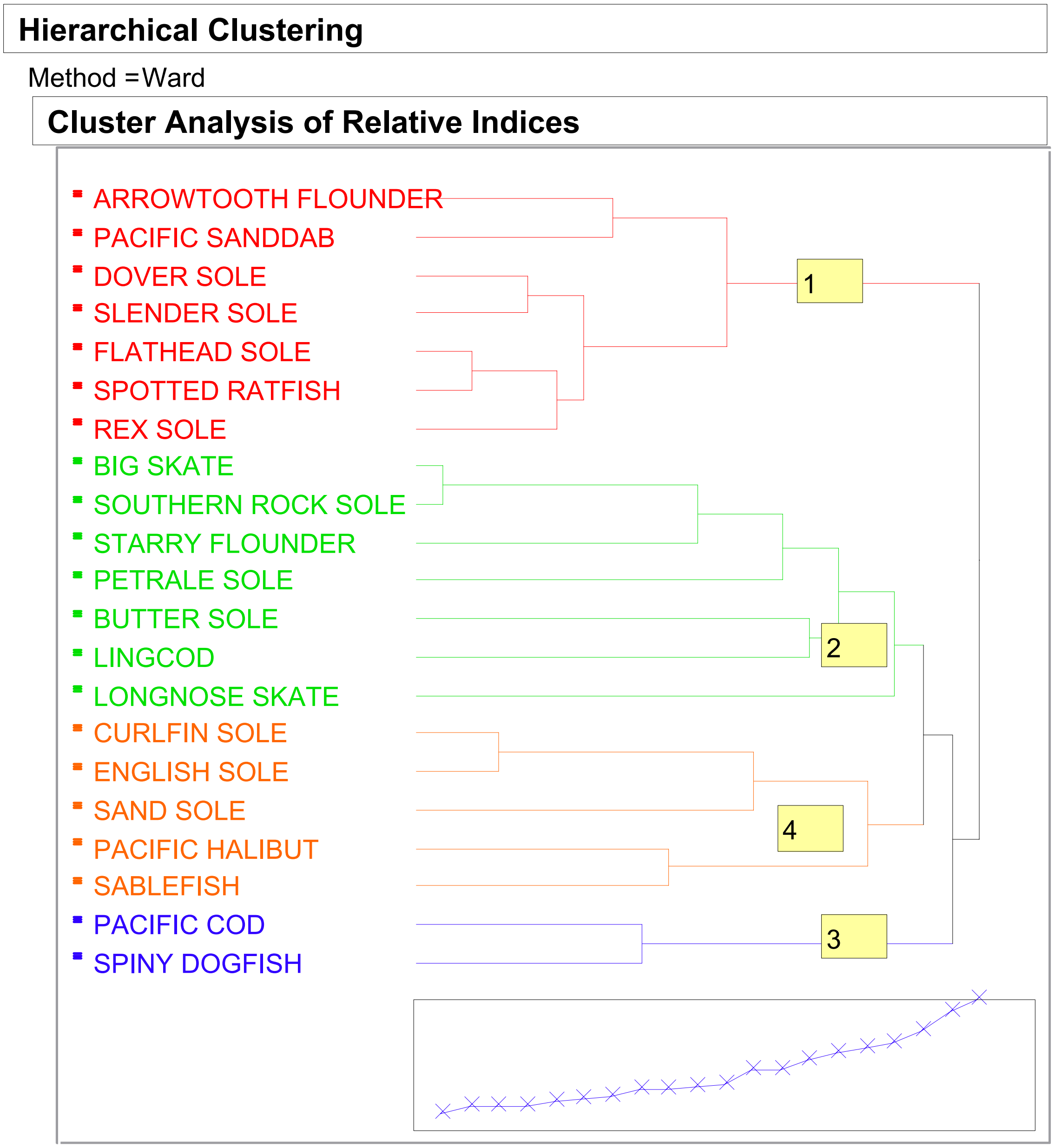

Figure 1.16 Dendrogram from a cluster analysis of relative biomass indices for 21 groundfish species taken in the Hecate Strait Assemblage Survey, 1984-2003. The line graph in the bottom right indicates the dissimilarity at each cluster join. The species time series were standardized to the individual series means. Agglomerative clustering was used with Ward's method. Four clusters were identified.

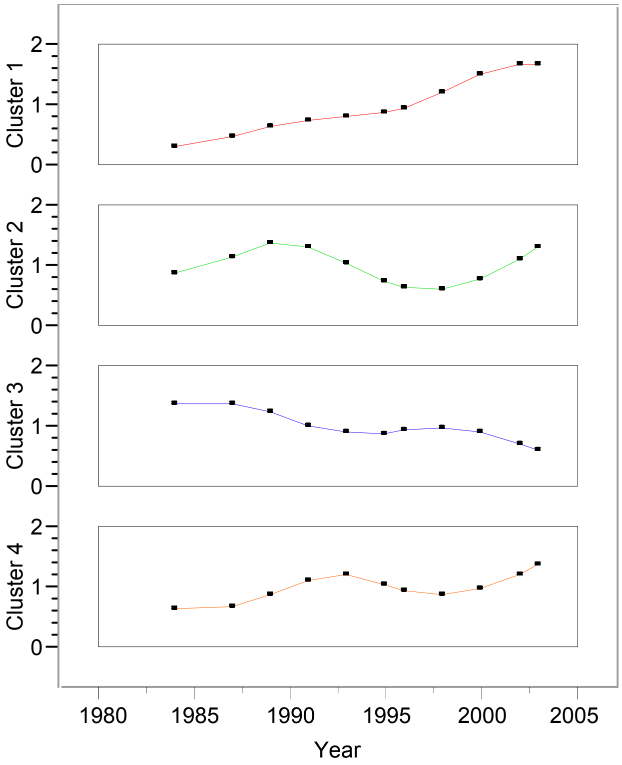

Figure 1.17 Smoothed time series of relative biomass of 4 species clusters identified in a cluster analysis of the Hecate Strait assemblage survey results, 1984-2003.

There is some correspondence between these trends in biomass with trends in primary and secondary production in PNCIMA, modulated to a certain extent by fishing. The Ware and McQueen (2006c) model predicts a generally increasing trend in primary and secondary production in PNCIMA over the time period of this survey. This supports the monotonic increase in biomass of the first cluster. The species in cluster 1, with the exception of Dover sole, are of limited commercial value and are mainly bycatch in the groundfish fisheries in the area. The species in the second and fourth clusters, on the other hand, are more important commercially. The intermediate decline in biomass in these time series corresponds to a period of intense fishing effort by bottom trawlers in Hecate Strait (Figure 1.18). The increases in biomass in the most recent years in these time series correspond to a reduction in fishing effort and a continuing increase in primary and secondary production.

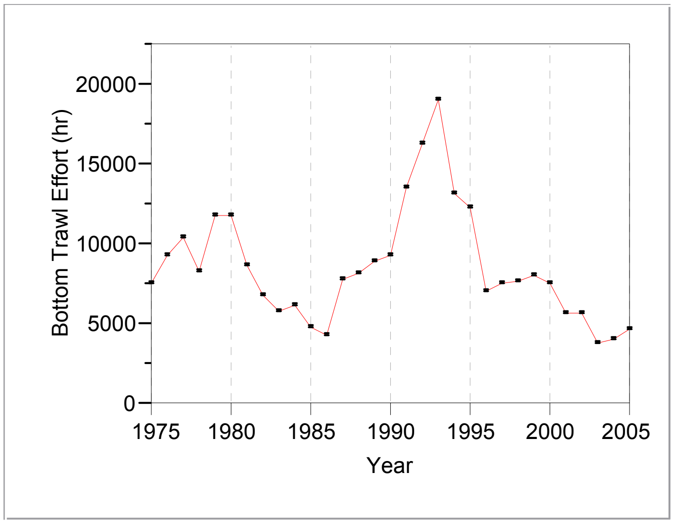

Figure 1.18 Nominal fishing effort (hours) by bottom trawlers in Hecate Strait (PFMC Areas 5CD) at depths less than 150 m, 1975-2005.

The trend in Pacific cod biomass is quite different from the trends described above. Pacific cod recruitment is inversely correlated with pressure-adjusted sea levels at Prince Rupert in their natal winter. This sea level is proxy for flow through the strait and the advection of eggs out of Hecate Strait following spawning. A recruitment mechanism related to advection/retention of eggs and larvae has been proposed (Tyler and Crawford 1991) and confirmed with more recent data (Sinclair and Crawford 2005). These analyses found greater statistical support for the advection/retention mechanism than for growth during juvenile stages. Advection characteristics in the area were not favourable to good cod recruitment in the 1990s. This was exacerbated by intensive fishing for the species. It may be that Pacific cod responds to a different recruitment mechanism than the majority of groundfish species in PNCIMA.

There has been an increasing trend in abundance of many marine mammal populations in PNCIMA. This includes several baleen whale species, many of which visit PNCIMA during their feeding seasons. Sea lion and seal populations are on the increase, as are the reintroduced sea otters. The exception would be the resident killer whale populations which are still at very low abundance in PNCIMA. Those species that have been increasing had all previously been the subject of intense removals by humans, either for commercial reasons or were culled. However, these removals ceased several decades ago. It is difficult to tell whether their recent increases in abundance are a response to increased production in the area or a response to reduced harvest. But, these animals feed at several different trophic levels and their increases in abundance may have some effect on the trophic balance in PNCIMA.

1.8 SUMMARY

The geological environment forms the underlying habitat of the area and significantly affects the physical functioning of PNCIMA.

- The steep and rugged coastal mountains affect climate, rainfall and watershed function.
- The valleys and fjords that cut into these mountains and extend to the adjacent seafloor result in the dominance of estuarine circulation in the nearshore environment and create a sediment-starved shelf.
- The abundant mainland islands create many kilometres of protected and semi-protected coastline and waterways.
- The Queen Charlotte Islands act as a retentive barrier to outflow of water from PNCIMA.
- The glacially scoured continental shelf with its cross cutting troughs form several bathymetric edges and affect currents and circulation in the area.
- The dominant, glacially derived sediments are likely to be a controlling factor in benthic habitats.
- The Queen Charlotte Basin beneath the continental shelf has the potential to contain significant oil and gas reserves.

The proximity of the Pacific Ocean moderates BC's coastal climate, producing relatively warm winters and cool summers compared to the interior of British Columbia.

- Two large scale pressure systems over the northeast Pacific control much of the PNCIMA weather and climate. The Aleutian Low tends to dominate in winter. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC and Alaskan coasts. The North Pacific High dominates in summer and tends to deflect storms northward during this time. These pressure systems and their associated winds also drive the main ocean circulation patterns of the northeast Pacific.
- PNCIMA is located in a transition zone between a northerly area dominated by the Alaskan current system and a southern area dominated by the California current system.

The combined influences of a semi-enclosed basin, varied bottom topography, and fresh water input set PNCIMA apart from other areas of the North American west coast.

- Most of PNCIMA is relatively enclosed geographically, with the Queen Charlotte Islands enclosing most of its northern portion, resulting in little advection of water to the deep ocean in summer. As a result, plankton are more likely to be retained in these basins, not lost to the ecosystem. This contrasts with upwelling regions to the south off California, or regions of SE Alaska where shelf waters are swept offshore in summer.
- Most of the advection out of PNCIMA that does occur is in winter from Dixon Entrance, and at Cape St. James into Haida Eddies. It may be that nutrient-rich oceanic waters replace the advected water in time for the spring blooms.
- High phytoplankton abundance is often associated with areas of high freshwater input. However, the lack of strong tidal mixing of river outflow into deep water near fishing banks sets PNCIMA apart. In PNCIMA, we find less river flow discharging into poorly mixed waters, and although some regions such as Chatham Sound and Fitz Hugh-Smith Sound outflows support plankton production, they do not have sustained, strong productivity. Interestingly, the northeast sector of Hecate Strait supports high fish biomass. This is adjacent to channels where Skeena River water goes through deep well-mixed channels on its way to Hecate Strait, so this mixing might be a factor.
- The steep edges of Dixon Entrance and the three troughs that transect Queen Charlotte Sound and Hecate Strait focus convergent processes that are likely to enhance zooplankton and subsequent fish production.
- There is strong seasonal variability that exceeds interannual variability.
- The area is less affected (in general) by large-scale industrial activities; fishing is the major human forcing to which this system is exposed.
- Retention: In northern to central Hecate Strait, the outflow in spring and summer is likely low. Regions such as Chatham Sound and eastern Dixon Entrance also experience relatively little outflow of plankton, due to estuarine recirculation in Chatham Sound and the Rose Spit Eddy in eastern Dixon Entrance.

As a working model, northern BC waters can be examined using the “triad” approach of Bakun (1996), which suggests that productive marine ecosystems require an optimal combination of three processes: enrichment (of nutrients), concentration (of nutrients and plankton to levels which promote feeding), and retention (of nutrients and food long enough for predators to utilise the resource). In the PNCIMA region:

- *enrichment* is achieved by upwelling (or a weakening of downwelling winds), by the estuarine flow characteristics of freshwater runoff from the coastal inlets, and tidal and wind mixing – all of which act to bring nutrients closer to the surface where they can be accessed by phytoplankton (and macrophytes in the nearshore region);

- *retention* is achieved by the general topography and relatively weak upwelling of the region, in particular the Queen Charlotte Islands, which block extensive advection of water and its constituents into the deep ocean; and
- *concentration*, which is achieved by bathymetric and hydrographic features and their interactions with the circulation.

This model implies that any process, natural or human, that interrupts any of the three aspects of this triad will impede and possibly reduce the productive capacity and resilience of this ecosystem. For example, the productivity of the system as a whole is influenced by the extent of upwelling favourable winds; should these winds change as a result of natural climate changes (as has happened in the past) then they will have an impact on the productivity of the entire ecosystem. The spatial pattern of plankton productivity will be affected by changes in the hydrological regime; if freshwater runoff changes in timing or amount it can be expected to impact the degree of nutrient entrainment into the upper layers by estuarine processes and the locations at which these processes occur. An example is continuing decrease in glacier size with climate warming. High melt rates at present provide more flow in spring and summer than we can expect in the future once these glaciers have disappeared.

From the analyses currently available, the overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components of the food web, as long as other species occur within the same functional group. Overall, the food web does not appear to display a “wasp-waist” structure, in which energy flows predominately through one or a few species at intermediate trophic positions. However, trophic pathways to individual species may be more constrained (*e.g.,* krill to whales); it is unknown which species may be critically sensitive to the reduction or elimination of which other species.

The ecosystem does receive a large biomass of migratory species: of stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that invade PNCIMA when conditions are unusually warm. These species provide an input of energy and food, but also result in an export of energy from the system. Calculations of the net effect have not been conducted that we are aware of. However, it is likely that there will be a net loss of energy from the system since many of the migratory species (*e.g.,* salmon, birds) pass through the region relatively rapidly and do not stay long enough to be significant prey for resident species. Pacific salmon play a significant role in transferring nutrients from marine to terrestrial coastal ecosystems in the PNCIMA region.

There appears to be a spatially dependent trophic linkage from phytoplankton to fish in PNCIMA. This is consistent with what Ware and Thomson (2005) describe for the North American Pacific coast as well as for the entire BC coast. In PNCIMA, phytoplankton biomass is highest at the southeast end of Dixon Entrance where the freshwater input of the Skeena River is highest, and in the entrance to Queen Charlotte Sound in the south where the high-nutrient inflow from Queen Charlotte Strait mixes with fresher runoff from Fitz Hugh and Smith sounds. These same areas also support the high biomasses of groundfish and pelagic fish.

There is evidence from the model of Ware and McQueen (2006c) that the trend in phytoplankton production in PNCIMA has been upward since the late 1970s. The results from the Hecate Strait Assemblage bottom trawl survey suggest a simultaneous increase in biomass of several groundfish stocks. This upward trend is most clear for a group of lightly exploited species. The trends for other more heavily exploited species was interrupted by a pulse of high fishing in Hecate Strait in the early 1990s. This correspondence supports a largely bottom-up control on groundfish production when fishing is not a factor. An exception may be Pacific cod, which appears to be more strongly influenced by advection of eggs and larvae.

1.9 UNCERTAINTIES AND KNOWLEDGE GAPS

We have tried, in the preceding pages, to pull together a very rudimentary portrait of how PNCIMA works. Some of the linkages we have described are embarrassingly simplistic, and many are very likely to be completely wrong. Hopefully this will prompt others to show where we are wrong and why.

Clearly there are many, many things we do not understand about how PNCIMA works. It would be futile to try and summarize the depth of our lack of understanding. What follows are some points we gleaned from the other sections of this report, what was brought to our attention during discussions with others, and what we thought were important issues to focus on in the near future. This list, by no means whatsoever, should supersede any other list of uncertainties and knowledge gaps that has been developed through other processes.

Terrestrial bedrock geology is quite well understood at the PNCIMA area scale in BC and the level of detail is constantly improving. Submarine bedrock geology is less well constrained. Current knowledge of seafloor sediments and substrate material is patchy and limited by the need to extrapolate between widely spaced sampling points. The advent of multibeam sonar technology is providing extremely accurate information but will take many years to complete a shelf-wide map. The variability in the transport, deposition and erosion of submarine sediments is also poorly constrained but our understanding is likely to improve with technological advances.

While the exact timing of large earthquakes can not be predicted, current techniques allow a high degree of certainty that the subduction zone off of the west coast of Vancouver Island is currently locked and will likely produce an earthquake around magnitude 8 within the next few hundred years or so. The transform fault off the Queen Charlotte Islands is known to produce the occasional magnitude 8 earthquake, but the frequency of this is not well known.

Climate prediction on all time scales is difficult. The complexity of ocean-atmosphere systems and their interaction also prevents sufficient understanding for accurate predictions, although new observational programs are improving climate models through the collection of near real time oceanographic data. Thus, although it is known that climatic conditions are critical to ecosystem function, and that they vary significantly on various time scales, predictive capabilities need to be improved.

Modelling of climate and coupled climate-ocean conditions is limited by computing capacity (most of these efforts require supercomputers), by the complexity of the climate itself, and by a lack of monitoring data, especially over and within the Pacific Ocean. Advances in this area will improve climate prediction capabilities.

A recent analysis was made of BC's climate observation capacity. The 'Review of the Adequacy of Climate Related Observation Networks' (M. Miles and Associates 2003), found that, according to World Meteorological Organization standards, BC is severely lacking in climate and stream gauging, sediment discharge stations, and climate station density and is somewhat lacking in monitoring of evaporation, hydrometric networks and snow course density monitoring. Deficiencies are most common in areas that are remote, high elevation, or have small watersheds. This would describe most of the PNCIMA area. These deficiencies are specifically discussed in terms of the ability to verify and support climate modelling efforts.

Virtually all that is reported here on phytoplankton distribution and bloom timing was taken from satellite imagery that has several drawbacks. These images cover only the surface ocean. As such, they cannot detect deep chlorophyll layers and may underestimate production in well mixed areas where phytoplankton are drawn away from the surface. The images also measure standing stock and may underestimate production in areas where grazing is high. There is a definite lack of field observations of primary production in PNCIMA that should be addressed.

Zooplankton are poorly sampled in PNCIMA. While we have inferred a spatial and temporal linkage between phytoplankton and fish, it must pass through zooplankton. We have little information on when and where zooplankton and ichthyoplankton feed. This is needed to confirm our inferred linkage and to better understand the pathways through which energy flows through these different trophic levels.

Most of the information presented here on fish distribution pertains to adults and is dominated by commercially important species. Comparatively little is known about the distribution of juveniles of these same species, and less yet on larval distributions and spawning locations of these species. However, the available information indicates important ontogenetic differences in life history and distribution.

Information on food web linkages and who eats whom is severely lacking, having been collected only for groundfish species in limited seasons during two years in the 1980s.

We have said little in this report on the ecology of the west coast of the Queen Charlotte Islands. This is because very little is known about this region. The shelf is very narrow with the slope descending rapidly to well over 1000 m along much of this edge. This coast is isolated, poorly charted, and with few refuges from the often severe weather. For that reason, it is probably the least disturbed coastline in PNCIMA. It is tempting to conclude that production in this area is relatively low, however little information is available.

1.10 ACKNOWLEDGEMENTS

We wish to thank the authors of the other sections of this PNCIMA ecosystem overview and others who participated in our workshop held at the Institute of Ocean Sciences on March 9-10, 2006 for sharing their ideas and impressions of the PNCIMA ecosystem. We also thank Barbara Lucas for her editorial comments.

CHAPTER 2: HABITAT USE AND FUNCTIONAL AREAS IN THE PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA

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2.0 INTRODUCTION

This chapter provides a geographical presentation of habitat use for many of the large and/or commercial species in the Pacific North Coast Integrated Management Area (PNCIMA; Figure 2.0). It also summarizes the highlights of habitat use detailed in the appendices to this report - Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA).

In general, little is known about the functional habitat use for most life history stages for marine species in British Columbia (BC). Where it is known, maps show migration routes, spawning areas, rearing areas, foraging areas, and other important habitat areas.

Some of the maps used in this chapter were initially developed in the early stages of the process to identify Ecological and Biologically Sensitive Area (EBSAs) for PNCIMA. Clarke and Jamieson (2006) used a modified Delphic approach with species specialists to identify important areas based on criteria for uniqueness, aggregation, fitness consequences, naturalness, and resilience (Fisheries and Oceans Canada 2005). Functional habitat uses identified during the EBSA process have been indicated in the maps in this chapter, along with any additional habitat information available.

For some species, such as benthic invertebrates, their adult habitat is indicative of most benthic life stages because they move little as adults. The majority of our knowledge of marine species comes from fishery assessments of commercially-harvested species, resulting in bias towards them in fished areas and against non-commercial species and unfished areas.

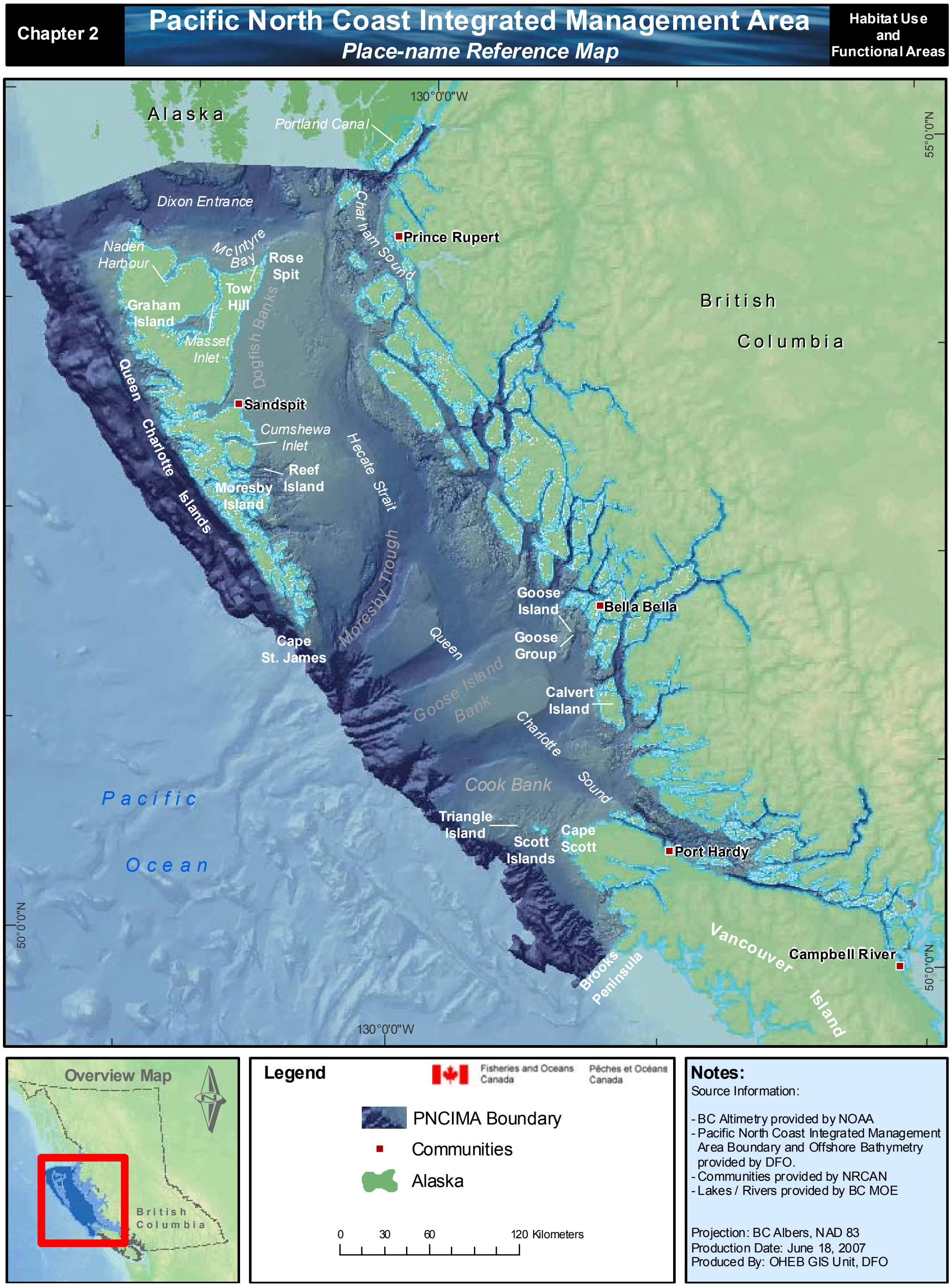

Figure 2.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 2.

2.1 PLANKTON

Plankton are commonly grouped into three categories: phytoplankton, zooplankton, and bacterioplankton. Phytoplankton supply their own food, through photosynthesis, and thereby provide most of the food energy that supports the rest of the marine food web (see Appendix D: Plankton). Bacterioplankton break down particulate detritus, releasing dissolved nutrients. Both these groups are grazed by zooplankton, which include single celled organisms and the larval and juvenile stages of many benthic and pelagic species. Larval and juvenile zooplankton are discussed in detail in the appendices to this Ecosystem Overview for PNCIMA.

Plankton concentrations vary spatially and temporally, as does the species composition. PNCIMA appears to have moderately high phytoplankton biomass over most of the continental shelf from spring through fall, with very high levels at the entrance to some inlets and fjords. Euphausiid zooplankton, a key prey for some fish and birds, are associated with the three steep-sided troughs in Queen Charlotte Sound. A combination of nutrient enrichment, localized concentrations (*e.g.,* along bathymetric edges), and retention of critical life stages can provide biologically productive pelagic habitats (Bakun 1996).

Plankton are affected by the climatic conditions detailed in Appendix B: Meteorology and Climate and are subjected to the currents detailed in Appendix C: Physical and Chemical Oceanography.

2.2 MARINE PLANTS

Benthic marine plants include two important habitat-forming macrophyte groups, kelp and eelgrass. Temperate kelp beds are one of the most productive ecosystems in the world (Mann 1982). Kelp beds are important spawning and nursery areas for fish and invertebrates, and contribute a significant amount of fixed carbon to the nearshore ecosystem (Duggins *et al.* 1989). Selected kelp beds in PNCIMA were surveyed by the BC Ministry of Agriculture, Fisheries and Food between 1976 and 1996 (BC MAFF 1996). Surveys were conducted using fixed wing aircraft and field trips to the kelp beds to verify species and densities. Biomass estimates for those beds were reported by Lindstrom (1998) and are included in Appendix E: Marine Plants. Kelp beds were extensive in surveyed areas (Map 2.0), but required digital enhancement to increase their visibility on a Large Ocean Management Area (LOMA) scale. Detailed digital maps are available for each area from the Habitat Branch of Fisheries and Oceans Canada.

Eelgrass, *Zostera marina* and *Z. japonica*, form extensive meadows in soft sediments in the lower intertidal and shallow subtidal, mostly in protected waters, such as heads of inlets. These beds provide important habitat and sometimes food for waterfowl, crab, herring and juvenile salmon (BC MSRM 2002). They also stabilize sediments and contribute to nutrient cycling in both direct and indirect ways (Phillips and Menez 1988;

Dunster 2003). An eelgrass bed mapping atlas is available online (Community Mapping Network 2006), but the beds are too small to show on a LOMA scale. Additional eelgrass maps that may be of interest are detailed in Appendix E: Marine Plants.

The Coast Information Team (CIT 2003) identified saltmarsh vegetation, eelgrass beds and kelp beds as the major nearshore habitats because of their high biological productivity and sensitivity to human impacts and because “these categories are recognized ecologically, are protected by policy, and are the best surrogates at this scale to represent a range of habitats” (CIT 2003).

Estuaries are also highly productive habitats where terrestrial, freshwater, and marine ecosystems meet. Although they account for less than 3% of the BC shoreline, they are used by 80% of all coastal wildlife (NRTEE 2005). In BC, 442 large estuaries have been identified from existing mapping products (Pacific Estuary Conservation Program 2004). Of these, MacKenzie *et al.* (2000) has surveyed twenty eight central and north coast estuaries. Their objectives were to acquire site specific information about estuarine ecosystems based on plant community types, to describe the range of estuary types, including biological and geomorphogical information, to create a site classification, and to identify estuaries with particularly high habitat value or rare ecosystems.

2.3 INVERTEBRATES

Invertebrates inhabit the full range of marine environments, intertidal to great depths, benthic to pelagic, mud to rock, and even upon other species. A detailed description of invertebrates species is available in Appendix F: Invertebrates.

Many marine invertebrates are sedentary or move little in their environment, except during larval stages. Some, such as corals and reef forming sponges, form habitat for other species. Coral and sponges may provide essential habitat for some benthic organisms, including many juvenile and some adult fish species (especially rockfish). Important concentrations of coral and sponge have been identified (Ardron 2005), along with occurrences of coral in PNCIMA (Map 2.1) (Etnoyer and Morgan 2003; Jamieson *et al.* in press). Siliceous hexactinellid sponges form reefs in deep waters in Queen Charlotte Sound (Conway 1999).

Commercial molluscs include clams, scallops, abalone, squid and octopus. Clams are found intertidally and subtidally throughout PNCIMA (Table 2.0) on a scale too small for mapping. Their habitat use is summarized in Table 2.1. Geoduck occur throughout the coast in unconsolidated substrates (C. Hand, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Commercial crustaceans include euphausiids, shrimp and prawns, and crabs. Shrimp spawn in late autumn to early winter. Females carry their eggs on their abdomen until the eggs hatch in early spring. The timing of hatching varies by species and by area. It is important to protect breeding females long enough for them to release the eggs (Fisheries and Oceans Canada 2006; Dunham and Boutillier 2001). Larvae are pelagic for approximately three months before they settle. The limited migration activity of adult prawns results in the existence of hundreds of separate stocks. However, meta-populations that share larvae may exist for prawns and shrimp because their lengthy pelagic larval stage may allow dispersal and exchange between populations (Booth 2000; Stocker *et al. eds*. 2001). Nearshore juveniles that occur predominately in channels and near estuaries may be particularly sensitive to habitat alterations (Johannessen *et al.* 2005).

Crab larvae are pelagic, while the adults are benthic. Crabs are soft-shelled when moulting, and then are particularly susceptible to predation and injury. Juveniles tend to moult more frequently per year, whereas adult crabs tend to moult annually; mating occurs when the females moult. Fertilized eggs remain attached to the female's abdomen for 4-5 months until they hatch, usually in late winter to early spring. During the egg incubation period, females often bury in the substrate to protect their eggs. Larvae are planktonic for approximately 4 months before reaching an active swimmer stage. Chances of survival are highest at settlement if the megalopa metamorphoses into a juvenile crab in water less than about 50 m depth. Juvenile crabs of less than 70 mm survive best in lower intertidal and shallow subtidal waters, where they sometimes overwinter. Because juveniles are concentrated in nearshore areas, including coastal estuaries, they are especially susceptible to human activities (Booth 2000).

High concentrations of Dungeness crabs are found in some areas of PNCIMA (Map 2.2). Larvae are found throughout the coast at particular times of year, in the spring around Vancouver Island and in the summer around the Queen Charlotte Islands (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). An ocean gyre off the north coast of the Queen Charlotte Islands retains larvae in productive areas off McIntyre Bay, Rose Spit and Tow Hill (G. Jamieson, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Naden Harbour, Masset Inlet, Portland Canal, and the Prince Rupert region are areas of high adult concentrations.

Two species of Tanner crab occur in PNCIMA, *Chionoecetes tanneri* and *C. bairdi*. *C. tanneri* are found in deep waters of the continental shelf break (Map 2.3). Surviving larvae are likely found only at depth (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). High concentrations of *C. tanneri* are found in the two circled areas in PNCIMA, and further south, off the west coast of Vancouver Island. *C. bairdi* are found in most mainland inlets at depths of 50-70 m, but they do occur as deep as 400 m (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Table 2.0 Summary of clam habitat in British Columbia.

Common and Scientific Name	Distribution	Preferred Habitat	Growth Rate	Spawning Time	Food Sources	Notes
Butter Clam *Saxidomus gigantea*	Common in protected beaches in bays and estuaries throughout BC.	Lower 2/3 of intertidal zone to max. 15 m subtidal depth. Typically in beaches of porous sand, broken shell, gravel and mud. Burrow to max of 25 cm. Permanent burrows.	Slow growing. Legal size 38 mm, (5-6 yrs. Strait of Georgia;7-8 yrs. Alert Bay; 9^{+}yrs. north coast). Max. age, 20^{+}yrs. Max. size, 130 mm.	Sexually mature at 38 mm (~3 yrs). May in Strait of Georgia, later in north coastal areas.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	
Manila Clam *Venerupis philippinarum*	Currently range from Laredo Inlet in the central coast to California on protected beaches.	From 1 m intertidal zone to well above mid-intertidal level. Does NOT inhabit subtidal. Mixed substrates of gravel, sand or mud. Permanent burrows.	Harvestable at 38 mm, 3-4.5 yrs of age in the central coast. Sexually mature 2-3 yrs Max. size 75 mm, approx. 10 yrs. Max. age 16 yrs. in BC.	August in central coast. Mid June and Sept. in Strait of Georgia.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	Require surface temperatures of 14°C or greater to permit gametogensis, spawning and larval development. Intentional introduced in north and central coasts but failed to produce sustainable populations. Natural recruitment in central coast probably from Quatsino Sound. Limited competition with native clams.
Native Littleneck Clam *Protothaca staminea*	Common in protected beaches in bays and estuaries along the coast, and near rocky outcrops on outer coastal areas.	Slightly above mid-intertidal to a max. subtidal depth of 12 m. Firm gravel beaches. Associated with Butter clams. Burrow 3-8 cm below surface, max. depth 15 cm. Permanent burrows.	Rapid growth to 5 yrs. of age, then decreases. Legal size, 38 mm (5-6 yrs. in the north coast, 3.5 yrs. south coast). Max. age, 14 yrs. Max. size, 70 mm (~10 yrs.).	Sexually mature at 2 yrs. (25 mm). Spawn April to October.	Suspension feeder, mainly phytoplankton, as well as zooplankton and detritus.	Growth varies from beach to beach and between tide levels on any given beach.

Table 2.0 Continued…

Common and Scientific Name	Distribution	Preferred Habitat	Growth Rate	Spawning Time	Food Sources	Notes
Razor Clam *Siliqua patula*	Surf-swept beaches from Aleutian Islands, AK to California. In BC, two major stocks Long Beach on WCVI and on beaches east of Masset on the northeast coast of Graham Island, QCI.	Mid-tide level to 20 m subtidal depth. Sandy, exposed beaches. Burrow just below surface max. 25 cm; can burrow to depth >60 cm in less than a minute. Do NOT form permanent burrows.	Variable, fastest at lower beach levels. Legal size 90 mm reached in 1-2 yrs. on WCVI 3-4 yrs. on QCI. Max age, 10 yr. Max size, 18 cm.	Sexually mature after 1 yr. (south) and 3 yr. (north). July and early Aug. on Queen Charlotte Islands. May and June on Long Beach, WCVI.	Filter feeder, mainly planktonic diatoms, but also zooplankton and detritus.	Currently found only on QCI in PNCIMA region.
Varnish Clam *Nuttallia obscurata*	Well established in Strait of Georgia and Barkley Sound. Most northern occurrence published to date is Cameleon Harbour in Johnstone Strait, but species is actively spreading.	High intertidal. Sand/gravel beaches, particularly loose sand.	Unknown but speculated to be similar to Manila clams. Max size, 69 mm. Max weight, 61 g.	Timing unknown.	Filter feeder, mainly plankton, but also organic detritus.	Associated with Manila and littleneck, softshell (*Mya arenaria*), and *Macoma* clams. Compete with Manila clams over high intertidal zones. Varish clams dominate high intertidal and Manilas mid intertidal.
Cockle *Clinocardium nuttallii*	Common throughout BC but not abundant in any one location.	Shallow burrow, often large adults are exposed. Prefers muddy substrates which are not common in BC (restricted estuaries, bays and channels.	Moderately fast Shell size of 60 mm ~ 3 yrs. of age. Max size , 120 mm.	Cockles are hermaphroditic, unlike the other species mentioned here.		
Soft-shelled clam *Mya arenaria*	Found throughout BC primarily in estuaries.	Soft substrate mud-sand. Mid to upper intertidal area.	Max size, 150 mm.			Commercially harvested of the east coast of North America.

(Fisheries and Oceans Canada 2000a; DFO 2001b; 1999c; 1999d; 2001c; 2001e; Stocker *et al. eds*. 2001; Jamieson and Francis 1986)

Table 2.1 Habitat use for selected invertebrate molluscs in PNCIMA.

IT = Intertidal, ST = Subtidal, BE = Benthic, PE = Pelagic, PL = Planktonic, SP = Sponge Reef, SG = Seagrass Beds, KE = Kelp Beds, ES = Estuaries, MU = Mud, SA = Sand, GR = Gravel, SH = Shell, RO = Rocky.

			Life History Function				
Group	**Common Name**	**Scientific Name**	**Migration**	**Spawning**	**Rearing Larvae**	**Rearing Juvenile**	**Foraging**
Bivalves	Geoduck	*Panopea abrupta*		IT, ST, BE, MU, SA, GR	PL	PL	IT, ST, BE, MU, SA, GR
	Horse Clams	*Tresus capax*		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
		Tresus nutallii		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
	Butter Clam	*Saxidomus gigantea*		IT, ST, ES, MU, SA, GR, SH	PL		IT, ST, ES, MU, SA, GR, SH
	Manila Clam	*Venerupis philippinarum*		IT, MU, SA, GR	PL		IT, MU, SA, GR
	Littleneck Clam	*Protothaca staminea*		IT, ST, ES, GR	PL		IT, ST, ES, GR
	Razor Clam	*Siliqua patula*		IT, ST, SA	PL		IT, ST, SA
	Varnish Clam	*Nuttallia obscurata*		IT, SA, GR	PL		IT, SA, GR
	Cockle	*Clinocardium nuttallii*		MU	PL		MU
	Soft-shelled Clam	*Mya arenaria*		IT, ES, MU, SA	PL		IT, ES, MU, SA
	Pink Scallop	*Chlamys rubida*		IT, ST, MU, SA, GR, RO	PL		IT, ST, MU, SA, GR, RO
	Spiny Scallop	*Chlamys hastata*		IT, ST, GR, RO		PL	IT, ST, GR, RO
Gastropods	Northern Abalone	*Haliotis kamtschatkana*		IT, ST, KE, RO	PL	IT, ST, KE, RO	IT, ST, KE, RO
Cephalopods	Opal Squid	*Loligo opalescens*	IT, ST	IT, ST, MU, SA, GR, SH, RO		IT, ST	IT, ST
	Neon Flying Squid	*Ommastrephes bartrami*	PE	PE	PE	PE	PE
	Giant Pacific Octopus	*Octopus dofleini*		BE	PL	BE, SE, MU, SA. GR, SH, RO	BE, SE, MU, SA. GR, SH, RO

Commercial echinoderms include sea cucumbers and sea urchins, which occur benthically throughout British Columbia's coastal waters. Sea cucumbers inhabit a range of habitats, including eelgrass beds, mussel beds, and sheltered rocky substrates. Sea urchins are commonly found along rocky shores with various habitat preferences; kelp beds, moderately strong surf, and open waters. Sea urchin depths range from the low tide line to 1157 m (Stocker *et al. eds*. 2001; DFO 2001d; 2001a; Fisheries and Oceans Canada 2002b; Parker 2002; Perry *et al.* 2001; 2002; Perry and Waddell 1999; Rogers and Neifer 2002; Workman 1999).

Breeding season in sea urchins appears to be triggered by environmental factors such as number of days of bright sunshine, phytoplankton blooms, and warm ocean temperatures (Cameron and Fankboner 1986), which may be affected by climate change. Red sea urchins spawn between March and September, green sea urchins between February and March, and purple sea urchins between October and December. Larvae are planktonic for approximately two months prior to their settling on suitable substrate. Juvenile abundance for red sea urchins has been found to be highest where large numbers of adult red sea urchins are present, as the juveniles may sometimes hide from predators beneath the adult spine canopy (Stocker *et al. eds*. 2001). This association is thought to be important in the recruitment success of juveniles to legal harvesting size (Johannessen *et al.* 2005). Green sea urchins are often found with red urchins, though their distribution tends to be patchy. They are thought to be more mobile than red urchins and may make seasonal migrations between deep and shallow waters (Stocker *et al. eds*. 2001). Although fishing for green sea urchins is focused on only a few locations in PNCIMA, they do occur in other areas, and are usually found at depths <20 m. (I. Perry, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4 GROUNDFISH

Our biological understanding of the life histories of many species of groundfish is limited due to their occurrence at depth, even though many are of significant commercial interest. Stock assessment personnel have for the last few years been assembling information on what is known for some species of groundfish in an area roughly equivalent to the PNCIMA region. These data include spatial distribution of commercial catch and catch per unit effort (CPUE, see Figure 1.8), which can identify hot-spots for species aggregations (Johannessen *et al.* 2005). Recent trawl surveys also provide a fishery-independent assessment of groundfish distribution (Map 2.4). Habitat characteristics, such as depth and substrate, appears to be correlated with certain species (e.g., Sinclair *et al.* 2005). Information remains limited for topics which cannot be determined from catch data, such as the location of spawning and rearing grounds, migratory pathways, and critical habitat. For more detailed information, see Appendix G: Groundfish.

2.4.1 Rockfish

There are approximately 40 species of rockfish in BC. In general, rockfish are slow growing and long lived (some over 100 years), taking between five and ten years to mature sexually. The primarily benthic fish are non-migratory, making mostly only localized movements, but some may make seasonal depth migrations. From an ecosystem perspective, considering the many rockfish species and their life stage habitat preferences, the entire coast from subtidal to depths of at least 2000 m could be considered important rockfish habitat (R. Stanley, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Rockfish habitat has thus not been mapped here.

Rockfish are typically grouped into three depth zones: inshore (0-182 m or 0-100 fathoms), shelf (91-182 m or 50-100 fathoms) and slope (>182 m or >100 fathoms) (Table 2.2).

Tables 2.2 – 2.4 provide biological information on species associated with the three rockfish zones listed above. Only commercially important species have been examined in detail in this section due to lack of information on other species. Species unique to the PNCIMA region were noted where applicable; however, most rockfish are distributed throughout the coastal waters of BC (Johannessen *et al.* 2005).

Table 2.2 Commercially important rockfish species (*Sebastes*, *S.*) are listed according to these zones.

Inshore Rockfish		**Shelf rockfish**		**Slope rockfish**	
Tiger	*S. nigrocinctus*	Silvergrey	*S. brevispinis*	Pacific Ocean Perch	*S. alutus*
Yelloweye	*S. ruberrimus*	Canary	*S. pinniger*	Yellowmouth	*S. reedi*
Quillback	*S. maliger*	Yellowtail	*S. flavidus*	Rougheye	*S. aleutianus*
Copper	*S. caurinus*	Widow	*S. entomelas*	Redstripe	*S. proriger*
China	*S. nebulosus*			ShortspineThornyhead	*Sebastolobus alascanus*
				LongspineThornyhead	*Sebastolobus altivelis*

(Bonnet *et al.* 2006)

Inshore Rockfish

In general, inshore species are slow growing, late maturing, long-lived, sedentary as adults, and are associated with specific rocky reef habitats. They mate in the fall and release free-swimming larvae in the early spring. Larvae are pelagic until they settle and generally reside in reefs. Inshore species tend to experience good recruitment every 15-20 years.

Due to declines in the abundance of some inshore rockfish populations, Rockfish Conservation Areas (RCAs) were instated to protect and preserve rockfish biomass (Map 2.5). BC has a total of 89 RCAs covering 2,338 km^2 (Fisheries and Oceans Canada 2004). These protected areas do not prohibit all activities within them.

Table 2.3 Inshore rockfish species (*Sebastes*, *S.*) summary information (sources at end of Table 2.5).

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Yelloweye *S. ruberrimus*	Gulf of Alaska to Baja California.	Shallow waters in the spring, although they are caught mainly in deeper waters. Common around reefs with caves and crevices. 15-366 m.	Mate in fall and spawn in spring.	117	18 yrs (Size Unknown)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Quillback *S. maliger*	Gulf of Alaska to Avila California.	Rocky reefs around caves and crevices, in inlets and shallow rock piles. 9-274 m	Mate in fall and spawn in spring.	76	12 yrs (23-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Copper *S. caurinus*	Kenai Peninsula, Alaska to Baja California.	Offshore rocky reefs and in shallow bays to often >20 m, up to 90 m. Prefer rocky to rock/sand bottoms with irregular bathymetry.	Mate in fall and spawn in spring.	45	8 yrs (41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
China *S. nebulosus*	Prince William Sound, Alaska to San Miguel, California.	Along the bottom of the ocean floor around offshore reefs with crevices and caves. 3-128 m.	Mate in fall and spawn in spring.	u	Age Unknown (28-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Black *S. melanops*	Amchitka Island, Alaska to Huntingbeach California.	Occur in large aggregates around rocky reefs and soft bottom substrates. Midwater habitats usually around kelp or other cover. Occasionally found in offshore open waters. 0-367 m.	Mate in fall and spawn in spring.	u	Females: 11 yrs Males: 10 yrs (36-41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Tiger *S. nigrocinctus*	Prince William Sound, Alaska to Point Buchon, California.	Deep waters near rocky crevices and caves. 24-274 m	Mate in fall and spawn in spring.	u	u	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u

Table 2.4 Slope rockfish species summary information (sources listed at end of Table 2.5).

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Yellowmouth *S. reedi*	Gulf of Alaska to northern California. Second most abundant slope rockfish in terms of catch in BC.	100-430 m.	April/May.	70-100	9 yrs 38 cm	Large catches taken from Goose Island and Mitchell's gullies in the QCS.	Average	Expected to decline until next major recruitment occurs.
Rougheye *S. aleutianus*	Japan and Kamchatka Peninsula to Bering Sea and Aleutian Islands, down to southern California.	Prefer boulder fields along the continental slope shelf. 25-2,830 m.	April.	147	Age Unknown Females: 47 cm Males: 45 cm	Significant landings come from Goose Island and Moresby gullies in the QCS.	Low	Uncertain, but thought to remain low for some time.
Shortraker *S. borealis*	Japan, the Okhotsk Sea, and SE Kamchatka to the Bering Sea and Aleutian Islands and down to California.	25-875 m. Larger solitary individuals found on silt or cobble bottoms near boulders.	April..	120	Age Unknown 45 cm	Trawling activity occurs along WCVI. Hook and line activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Not expected to increase in the near future.
Redstripe Rockfish *S. proriger*	Bering Sea to southern California	Areas of high relief and rocky bottoms. 12-425 m.	May-July.	48	Age Unknown 28 cm	Bottom and midwater trawling activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Declining.
Shortspine Thornyheads *Sebastolobus altivelis*	Northern Baja to the Bering Sea to the Commander Islands, north of Japan.	Uniformly distributed along soft sediments, near rocks or other high-relief structures. 90-1460 m. Migrate into deeper waters as they increase in size.	Spawn in spring. Produce jelly egg mass (20,000-450,000 eggs), which float to surface where development and hatching occur. Pelagic for 14-15 months then settle to depths of 100 m and then migrate to deeper waters.	62 (AK) 100^{+}(Cal.)	16 yrs (AK) 28 yrs (Cal.) 23-25 cm	This species represents approx. 90% of catch from the Goose Island, Mitchell's and Moresby gullies in QCS and Hecate Strait.	u	u
Pacific Ocean Perch *S. alutus*	Southern California to the Bering Sea and southwest to the Kurile Islands.	Prefer rocky, high relief substrate, but are commercially found/harvested over cobble substrate. Live at depths of 40-640 m.	Spawn in March/April in the QCS. Juveniles pelagic for 2-3 yrs. Fecundity: 90,000-510,000 eggs.	100	Females: 8 yrs, 35 cm Males: 6-8 yrs, 34 cm	Hecate Strait and QCS dominate fishing areas for perch – mostly in QCS. Three main locations are the Goose Island, Mitchell's and Moresby gullies.	Stable	Slowly declining.

Table 2.5 Shelf rockfish species summary information.

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Widow *S. entomelas*	Southern California to the Gulf of Alaska. Commercial abundance ranges from northern California to central BC. Distribution is difficult to predict.	High relief near edge of continental shelf. 50-375 m.	Spawn late winter or early spring.	58	Females: 14 yrs. Males: 5 yrs. 43 cm	QCS represents a large proportion of coast wide landings. Fishing hot spots include Triangle Island in the winter and Goose Island Bank in the summer.	u	u
Silvergray *S. brevispinis*	Southern California to the Bering Sea. Center of commercial abundance in BC.	High relief near the edge of the continental shelf Commercial fished between 100-375 m.	Mate in spring and spawn mid-summer.	80	Females: 15 yrs. Males: 8 yrs. 38-51 cm	Four stocks in BC, three occur in the PNCIMA region, Hecate Strait, QCS, and WCVI.	abundant in QCS	u
Canary *S. pinniger*	Baja California to the Gulf of Alaska. Center of commercial abundance is northern California to central BC.	High relief areas near the edge of the continental shelf. Around reefs and over soft bottoms. 50-375 m.	Mate in mid-fall and spawn late winter or early spring.	60	Between the ages of 5 and 14 yrs. 58 cm	Two stocks in BC, QCS and WCVI. Most landings come from the central coast of WCVI (60-70 %) and QCS.	u	u
Yellowtail *S. flavidus*	San Diego, California to the Gulf of Alaska. Center of commercial abundance is northern California to northern BC.	Adopts both a near- and off- bottom habitats. Around offshore reefs to depths of 549 m. Have a homing instinct.	Mate in mid-fall and spawn late winter or early spring.	50	Between the ages of 5 and 14 yrs. 36-46 cm	Two stocks, Boundary (southern WCVI to northern Washington, 3C) and Coastal (central WCVI to Alaska, 3D, 5A-5E). Majority of landings come from QCS and south and central WCVI.	Low	Declining

(Fisheries and Oceans Canada 2000b; DFO 1999l; 1999g; 1999h; 1999f; 1999j; 1999e; 1999k; 1999i; 1999a; 1999m; Gotshall 1981; Lamb and Edgell 1986; Stein and Hassler 1989).
u – Information unknown.

2.4.2 Roundfish

Pacific Cod

Pacific cod are a relatively short-lived, fecund species. In the PNCIMA region, Pacific cod densities appear to be highest in the deep troughs in Queen Charlotte Sound, around Goose Island grounds, and southeast Dixon Entrance. They tend to be commercially abundant at depths of 18-130 m but do occur in waters up to 550 m, and prefer sandy or muddy bottoms (Westrheim 1996). Pacific cod exhibit little movement within a given area but do undergo seasonal migrations from shallower waters in the spring and summer to deeper waters in the fall and winter. Spawning occurs once annually between February and March. Eggs are demersal, are slightly adhesive, and are commonly deposited on shell, coarse sand, sandy gravel, muddy sand, and cobble (Westrheim 1996). Hatching occurs after 15-17 days, depending on water temperatures. Larvae are then planktonic and settle near the bottom (at depths of 5-11 m) and incubate for 10-17 days depending on water temperatures. It is during this time that Pacific cod are especially susceptible to environmental changes (Booth 2000). Important spawning and rearing areas are shown in Map 2.6.

Walleye Pollock

Walleye pollock are considered the most abundant fish species in the North Pacific Ocean. In BC, pollock are present throughout the coast. They are semi-demersal and are most abundant along the continental shelf and slope at depths between 100-400 m. However, during various stages of their lifecycle, they may also be found nearshore, in large estuaries, coastal embayments and open ocean basins. Schooling pollock spawn in March and April at depths between 50-300 m and are usually associated with an increase in abundance of Pacific hake (Shaw and McFarlane 1986). Eggs are released into the water, and both planktonic eggs and juveniles appear in the upper water column up to 60 m deep. Schools of juveniles make diel migrations to surface waters at night to feed on plankton and return to deeper waters during the daytime. Juveniles may be found in a variety of habitats including eelgrass beds (over sand and mud substrates), and gravel and cobble bottom types. In addition to the spawning and rearing areas identified during the EBSA process (Map 2.7), past reports have indicated spawning in inlets on east Moresby Island as well as in midwater inlets along Hecate Strait and Queen Charlotte Sound (Shaw and McFarlane 1986).

Pacific Hake

In BC there are two Pacific hake stocks, a non-migratory inshore stock in the Strait of Georgia and a migratory stock offshore of the west coast of Vancouver Island (WCVI), which sometimes extends into PNCIMA. Offshore hake range from southern California to Queen Charlotte Sound with annual migrations into Canadian waters in early spring to late fall (February to November). They are generally found schooling near the bottom or at midwater depths (200-1000 m) over the continental shelf, primarily off of WCVI in Canada. In the past, high levels of biomass have been detected in the PNCIMA region around Brooks Peninsula (Scagel and McFarlane 1995). However, the overall abundance here is generally low compared to numbers off of the WCVI. Significant numbers of hake were observed in PNCIMA in 1998 and 2005, and in 2006 were higher than WCVI (W. Crawford, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2007). The extent to which offshore hake in California move northwards appears to be dependent on water temperatures (specifically the northern extent of warm waters). In El Niño years, larger numbers of hake were observed to migrate into Canadian waters and were found to migrate further north, even as far as Hecate Strait and Dixon Entrance (Map 2.8). An increase in juveniles along the WCVI also suggests that a shift in settlement patterns may also occur during these events (Dorn *et al.* 1999).

Lingcod

Lingcod range from California to Alaska in the eastern Pacific Ocean, centered in BC. They are largely non-migratory and reside in rocky areas at depths of 3-400 m, but are most commonly found between 10-100 m. Lingcod are generally associated with clean waters over rocky substrate, (*i.e.,* where there is an abundance of rocky outcroppings, crevices, caves, or boulders) at shallow depths and high relief bedrock at intermediate depths (LaRiviere 1981; Cass *et al.* 1990; Jamieson and Dixon 2001). They are also commonly associated with 75-100% substrate cover by sessile invertebrates and algae, and with strong currents (up to 4-6 km hr^{-1})(Jamieson and Dixon 2001). In the PNCIMA region, densities appear to be highest in northern Moresby Trough, the southern edge of Dixon Entrance, and around Goose Island Bank.

Mating season starts with the onset of adult males migrating to near shore in October (prior to female migration) to establish nesting sites. Nests may be found intertidally down to 100 m depth, but are most commonly found between 5-25 m in rock crevices or on ledges where there is a strong current to oxygenate the egg masses. Spawning occurs annually from December to March, during which time females migrate nearshore to deposit egg masses in the nesting sites previously established by the males. Males then fertilize the egg mass and remain behind to guard the nest until the eggs hatch in early March to late April. Females return to deeper waters shortly after spawning. Once hatched, larvae remain planktonic for 6-8 weeks, reaching approximately 4-5 cm. Larvae settle onto bottom substrates in inshore waters, usually near kelp or eelgrass beds. Juvenile rearing habitat is eelgrass beds and sandy/flat bottom habitat from 0-75 m (J. King, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Juveniles, unlike adults, are often found on flat substrates in shallower waters, and later move to areas of high relief and rockiness as they mature. The benthic dispersal of lingcod is believed to be limited, as lingcod have been found to colonize and recruit in localized areas. An area of the northern coast of Vancouver Island is known spawning and rearing habitat (Map 2.9); other areas are not well known (J. Fargo, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Sablefish

Genetically, sablefish appear to represent a single stock, but movement of adults is limited. In BC, two populations, Alaskan (north) and west coast (south), are separately managed, and these have been delineated based on varying recruitment and growth differences. The distribution of adult sablefish is depth dependent, with older individuals and males most abundant at greater depths (Haist *et al.* 1999).

Spawning occurs both within and outside of the PNCIMA region along the continental slope at roughly 1000 m or greater depths, between January and March. In April/May, larvae rise to surface waters over the shelf and then migrate inshore for approximately 6 months. Young sablefish rear in nearshore waters and shelf habitats until 2-5 years of age, at which point they migrate back to offshore waters and into the fishing grounds (Fisheries and Oceans Canada 2002c).

Juveniles are highly mobile and can move between nursery areas in Hecate Strait to the Gulf of Alaska and the Bering Sea. Spawners, larvae and juveniles can be found in almost all areas of PNCIMA, depending on the strength of recruitment (R.A. Kronlund, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4.3 Flatfish

Sole and Flounder

Dover sole: Dover sole are a deep-water species commonly found along muddy bottoms in deep troughs and are generally found in deeper waters during the winter than in the summer (Sinclair 2002; Fargo and Kronlund 1997). In Hecate Strait they spawn annually in deep waters off the west coast of the Queen Charlotte Islands during the late fall and winter at depths between 800-1000 m (Map 2.10) (DFO 1999b; Westrheim *et al.* 1992). Larvae undergo a prolonged pelagic phase offshore in surface waters along the continental shelf for up to 2 years, before they gradually move into deeper waters along the slope as they grow and reach sexual maturity (Fargo and Kronlund 1997; Jacobson and Hunter 1993). As adults, females are generally found in deeper waters than males, and larger Dover soles are generally found deepest, where oxygen concentrations are lowest (Jacobson and Hunter 1993).

English sole: English sole are found between 5-150 m depth, preferring shelf waters and, unlike other flatfish species, are not generally found in deeper waters during the winter months (Sinclair 2002). English sole are associated with sandy-mud substrates and show preference for water temperatures between 7 -10 ^{o}C (Fargo *et al.* 2000).

English sole spawn annually between September and March with peak spawning activity occurring in October/November. Older individuals tend to spawn latest in the fall. They exhibit extreme sexual dimorphism and are non-intermittent spawners (Fargo *et al.* 2000). Fertilized eggs hatch after 6-10 days, depending on water temperatures and salinity. Pelagic larvae drift for 6-10 weeks, many in shallow (0-20 m) bays or estuaries, where they stay until they reach approximately 2 cm. One of the primary English sole nurseries in BC is in the nearshore shallow waters off the east coast of Graham Island (Map 2.10) (Fargo *et al.* 2000). After metamorphosis is completed, individuals settle to the bottom and continue to develop. Between the ages of two and three, they slowly migrate into deeper waters and, by four years of age, they are mixed with adults.

Petrale sole: Petrale sole are found at depths from 18-750 m in areas with sandy substrate (Booth 2000; Eschmeyer and Herald 1983). Petrale make extensive seasonal movements. They are generally found in deeper waters during spawning in the winter, and in shallower waters, particularly around Goose Island, during feeding in the summer (Sinclair 2002; Forrester 1969).

Petrale spawn annually during the winter months off the WCVI and the northern tip of the Queen Charlotte Islands (Map 2.10). Females release eggs into surface waters where they are fertilized and float freely during incubation. After approximately 8 days (varying with water temperature and salinity), the eggs hatch and the larvae remain planktonic, drifting in ocean currents until they reach nursing grounds. Key nursery grounds in the Hecate Strait and Queen Charlotte Sound area are along the eastern boundary of Goose Island Bank and to a lesser extent along Cape Scott (Cook) Bank, Horseshoe Grounds, and “Ole Spot” in area 5C (Map 2.10) (Ketchen and Forrester 1966).

Rex sole: Rex sole are usually found in sand or mud bottom substrates at depths of 18-640 m. The catch distribution, which is higher on the shelf in the troughs and around the edges of banks, suggests they are most abundant at about 60 m (Johannessen *et al.* 2005). According to Hosie (1975), spawning occurs between January and June along the offshore area of Oregon, with peak activity in March/April. Spawning location varies by year.

Rock sole: Rock sole adults show little preference among substrates, although in BC they are most abundant over gravel substrates at depths between 18-55 m (Fargo *et al.* 2000; Booth 2000). Rock sole are essentially a shallow water species (5-80 m) and so adult populations may be separated by the deep troughs found in Queen Charlotte Sound and Hecate Strait (Sinclair 2002; Fargo *et al.* 2000). Rock sole are non-intermittent spawners. They spawn annually, usually at 20-40 m depths, with peak spawning occurring in March/April. Rock sole have separate localized spawning and summer feeding areas. The primary spawning area is located off Cumshewa Inlet near east Moresby Island (Map 2.10). An important nursery area is around Reef Island just south of Cumshewa Inlet (Strong *et al.* 2002). After spawning, adults migrate to feeding grounds in central Hecate Strait. Fertilised eggs are demersal and adhesive, hatching after approximately 10-15 days (Ketchen 1982). Larvae exhibit diel movement and are commonly found in waters between 5-10 m deep during the day, when they feed on copepod nauplii, and at around 30 m depth at night. Wind and tidal currents transport larvae until they settle to the ocean bottom at about 2 cm length. For the first year, juveniles remain in waters between 5-20 m deep, and by 2-3 years of age, have moved to waters 20-80 m deep.

Arrowtooth flounder: Arrowtooth flounder juveniles occur in waters along the continental shelf until an age of 4, after which they migrate into deeper waters to join the adults along the continental slope. Adults are generally found in areas where there is coarse sand substrate, whereas juveniles are often associated with sand or mud substrates. Arrowtooth flounder typically inhabit waters 50-900 m deep and show preference for bottom temperatures of 7-8 ^{o}C. They spawn in the fall and winter months in waters ≥350

m. Their eggs are pelagic; incubation is 3-4 weeks. Larvae are planktonic for 4 weeks before settling as juveniles. As with many other flatfish species, arrowtooth flounder migrate seasonally from deep, winter spawning grounds to shallow, summer feeding grounds. Important spawning and feeding areas in the PNCIMA region have not been identified.

Pacific Halibut

Pacific halibut are commonly found throughout BC's waters along the continental shelf and slope from relatively shallow waters to at least 1000 m (Carl 1971). Mature fish may undergo extensive movement (as far as 3200 km); however, most tend to stay on the same grounds and make only seasonal migrations from shallow feeding areas in the spring to deeper spawning grounds in the winter (Fisheries and Oceans Canada 2002a; Carl 1971). Halibut spawn in waters along the continental shelf at depths between 180-450 m during the winter (November to March; Map 2.11). The PNCIMA region has some locally important spawning grounds including around the Goose Group, around Cape St. James and areas in northern Hecate Strait and Dixon Entrance (Map 2.11) (Fisheries and Oceans Canada 2002a; Carl 1971). Incubation occurs for 15-20 days as eggs rise to the surface. Larvae develop and may be transported by ocean currents great distances in a counter-clockwise direction around the Northeast Pacific Ocean (International Pacific Halibut Commission 1987). Young fish then settle to the ocean bottom in shallow feeding areas before they migrate back into more southerly and easterly waters at 2-3 years of age.

2.5 PELAGIC FISHES

2.5.1 Herring

Pacific herring spawning migrations move from offshore feeding grounds (west coast of Vancouver Island and Hecate Strait in the north) to the inshore spawning grounds during October to December. Herring congregate in large schools over the winter awaiting gonad maturation (Hay 1985; Fisheries and Oceans Canada 1994; Haegele and Schweigert 1985). In BC, herring spawn in late winter, from February to as late as July, with the majority of spawning occurring in March from the high tide line down to 20 m depth (Fisheries and Oceans Canada 1994), although some spawning can be as deep as 60 m. Spawn deposition occurs in high-energy environments on both bottom substrate and vegetation. Temperature and salinity are important in determining when and where herring spawning occurs. Eggs are generally tolerant to temperatures ranging from 5-15 °C and a salinity range of 3-33‰ (Haegele and Schweigert 1985). Eggs hatch in 10-21 days, and larvae concentrate in the surface layer near shore, aggregated by surface currents. Beginning in the late larval stage, herring undergo a diurnal migration, descending to deep water during the day, and rising to the surface at night. Migration of juvenile herring begins in some areas in the fall of their first year and in other areas not until the following summer. Adults are most commonly found in deeper waters (around 100 m). Important areas for herring were identified during the EBSA process; the life history function associated with each area is identified on Map 2.12. Spawning beds from digitized archived surveys for the years 1930-2002 are also shown (McCarter *et al.* 2005).

2.5.2 Eulachon

Major eulachon spawning and larval rearing areas are shown in Map 2.13. Eulachon summer feeding areas are much more extensive than the areas identified during the EBSA process and shown on Map 2.13. Additional areas include: the offshore banks immediately SW and W of Calvert Island (Calvert Island and Pearl Rock Ground) where the eulachon bycatch in shrimp fishing was severe in the late 1990's; the Cape Scott ground; the SE edge and NE corner of the Goose Island bank; the SE edge of Middle Bank (North Bank); the entire 50-100 fathom edge from Rose Spit, Two Peaks, White Rocks, Butterworth edge, Bonilla Island down to the Horseshoe ground and SE to Cape St. James; and the entire Chatham Sound. More information on pelagic species can be found in Appendix H: Pelagic Fishes.

2.6 MARINE MAMMALS AND TURTLES

2.6.1 Cetaceans

For most cetaceans, there is limited knowledge of habitat use within PNCIMA. Canada's Pacific waters are a year round home for some species, while part of annual migration routes or summer feeding grounds for others. It is not clear how important PNCIMA is to the health and stability of cetaceans overall, due to limited data for most species regarding their distribution and their habitat use. Spatial data on cetaceans are being compiled, largely from opportunistic sightings, but also from historical whaling records and habitat modeling. These data sets have been used to produce maps with high levels of uncertainty. Life history functions associated with some areas are identified for gray (Map 2.14), humpback (Map 2.15), and northern resident killer whales (Map 2.16). Important habitat for northern resident killer whales has been identified (Map 2.16), while potential critical habitat for killer whales is still being assessed (Ford 2006). Areas of importance for blue whales (Map 2.17), fin whales (Map 2.18), sei whales (Map 2.19), and sperm whales (Map 2.20), have been identified in the EBSA process (see also Appendix J: Marine Mammals).

2.6.2 Pinnipeds

Steller sea lions and harbour seals remain in BC waters year round. BC waters are also a major migration route and provide vital feeding grounds for California sea lions, northern fur seals and northern elephant seals (Johannessen *et al.* 2005). The PNCIMA region includes all of BC's Steller sea lions rookeries (Map 2.21). Cape St. James and the Scott Islands are critical areas for Steller sea lions. Important areas for feeding and foraging for northern fur seals have also been identified (Map 2.22).

2.6.3 Sea Otters

Sea otters have a small population with limited range in PNCIMA (Map 2.23). Their typical habitat is shallow (<40 m), nearshore areas (within 1-2 km of shore) (Reidman and Estes 1990). Kelp beds are important habitat for resting and foraging. Clam beds also provide valuable foraging habitat.

2.6.4 Reptiles

Leatherback turtles nest on beaches in tropical waters, and make long migrations to their feeding areas that include BC waters. The very limited knowledge of leatherback distribution in BC is from anecdotal reports, opportunistic sightings, and recent cetacean/sea turtle surveys. Sightings within PNCIMA are located on Map 2.24, along with important feeding areas.

2.7 ACKNOWLEDGEMENTS

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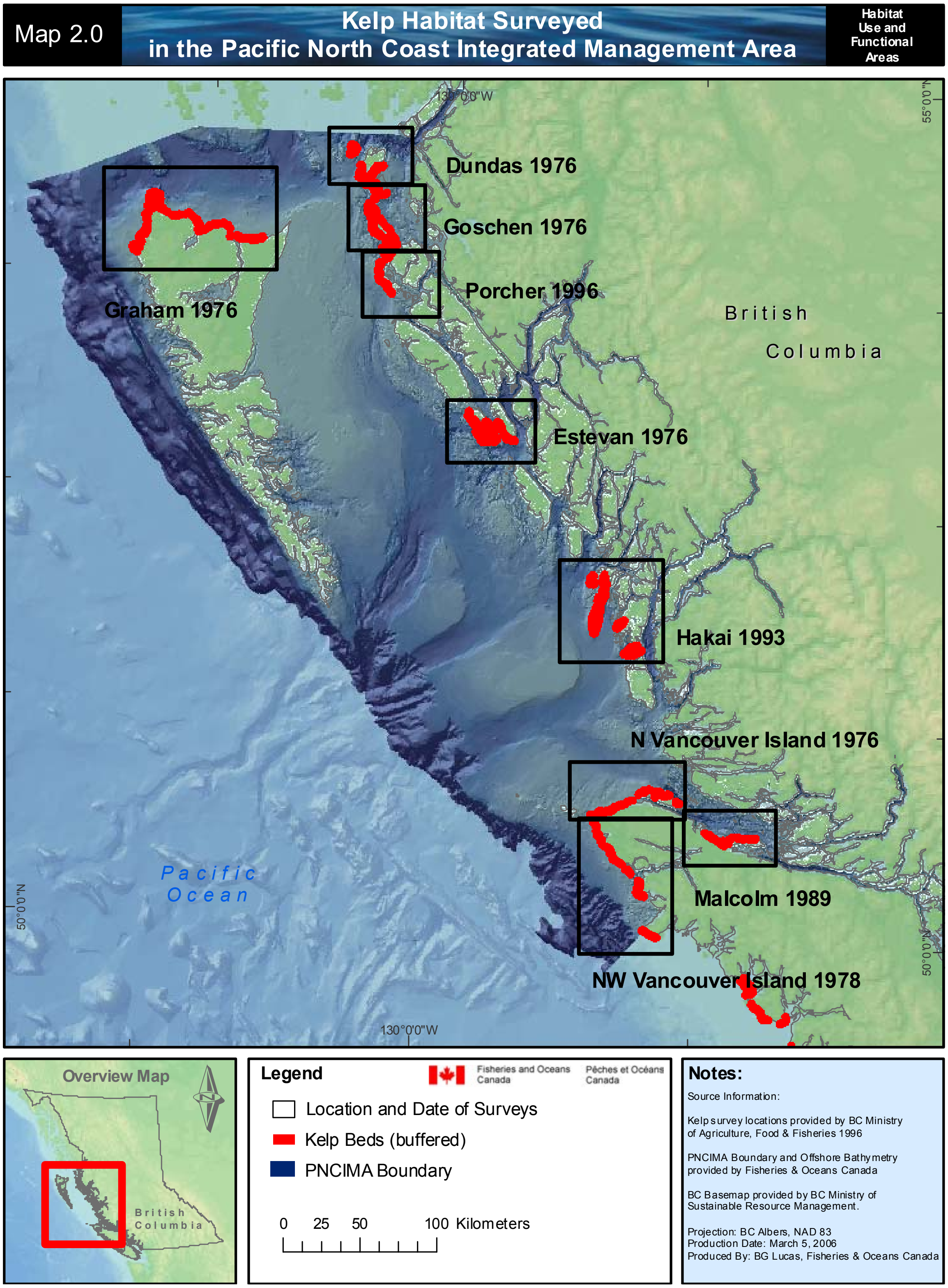
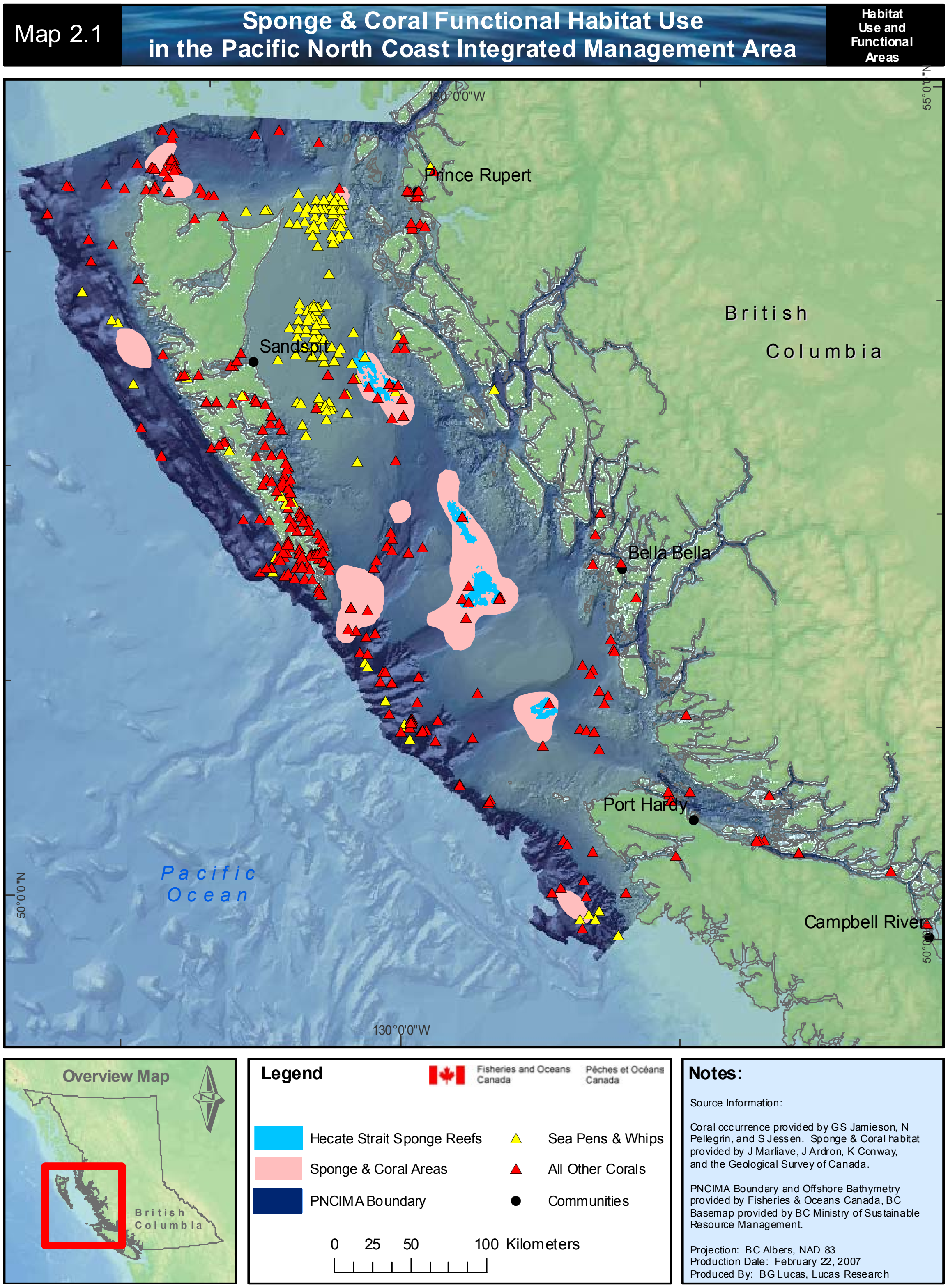


Map 2.0 Kelp habitat surveyed in PNCIMA (data from BC MAFF 1996).



Source Information:

Coral occurrence provided by GS Jamieson, N Pellegrin, and S Jessen. Sponge & Coral habitat provided by J Marliave, J Ardron, K Conway, and the Geological Survey of Canada.

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada, BC Basemap provided by BC Ministry of Sustainable Resource Management.

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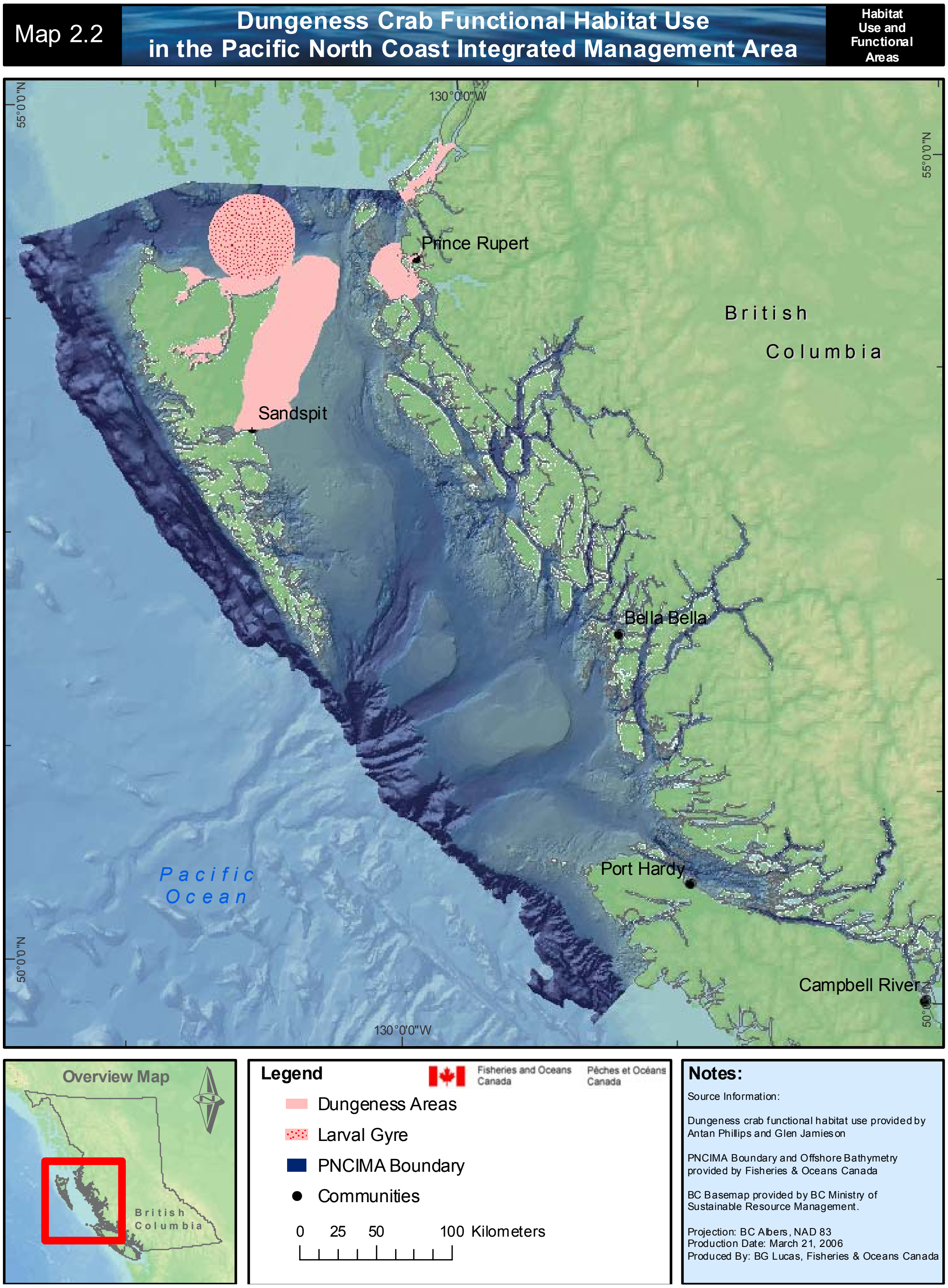
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.1 Sponge and coral functional habitat use in PNCIMA.



Source Information:

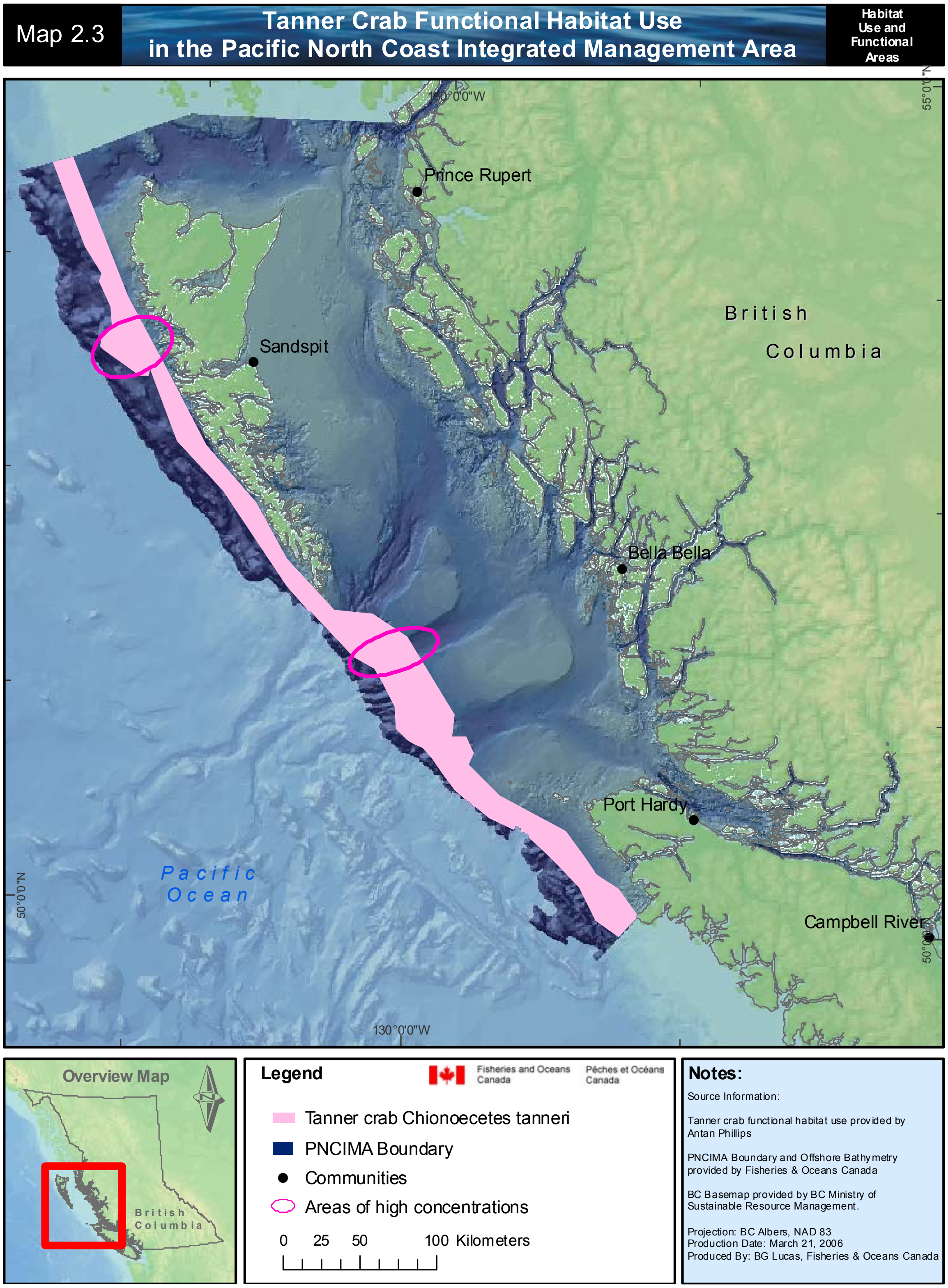
Dungeness crab functional habitat use provided by Antan Phillips and Glen Jamieson

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 21, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.2 Dungeness crab functional habitat use in PNCIMA.



Notes:

Source Information:

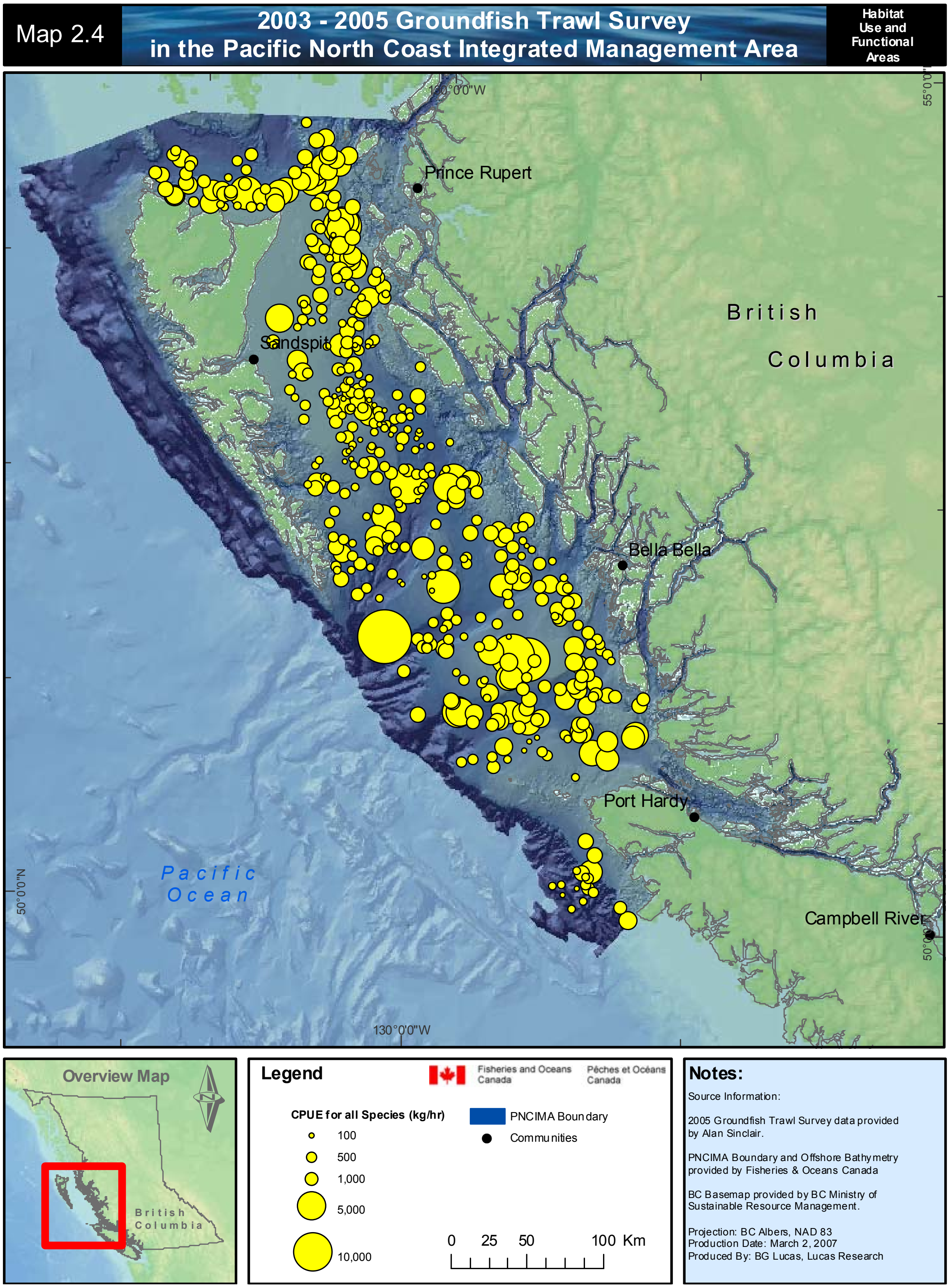
Tanner crab functional habitat use provided by Antan Phillips

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

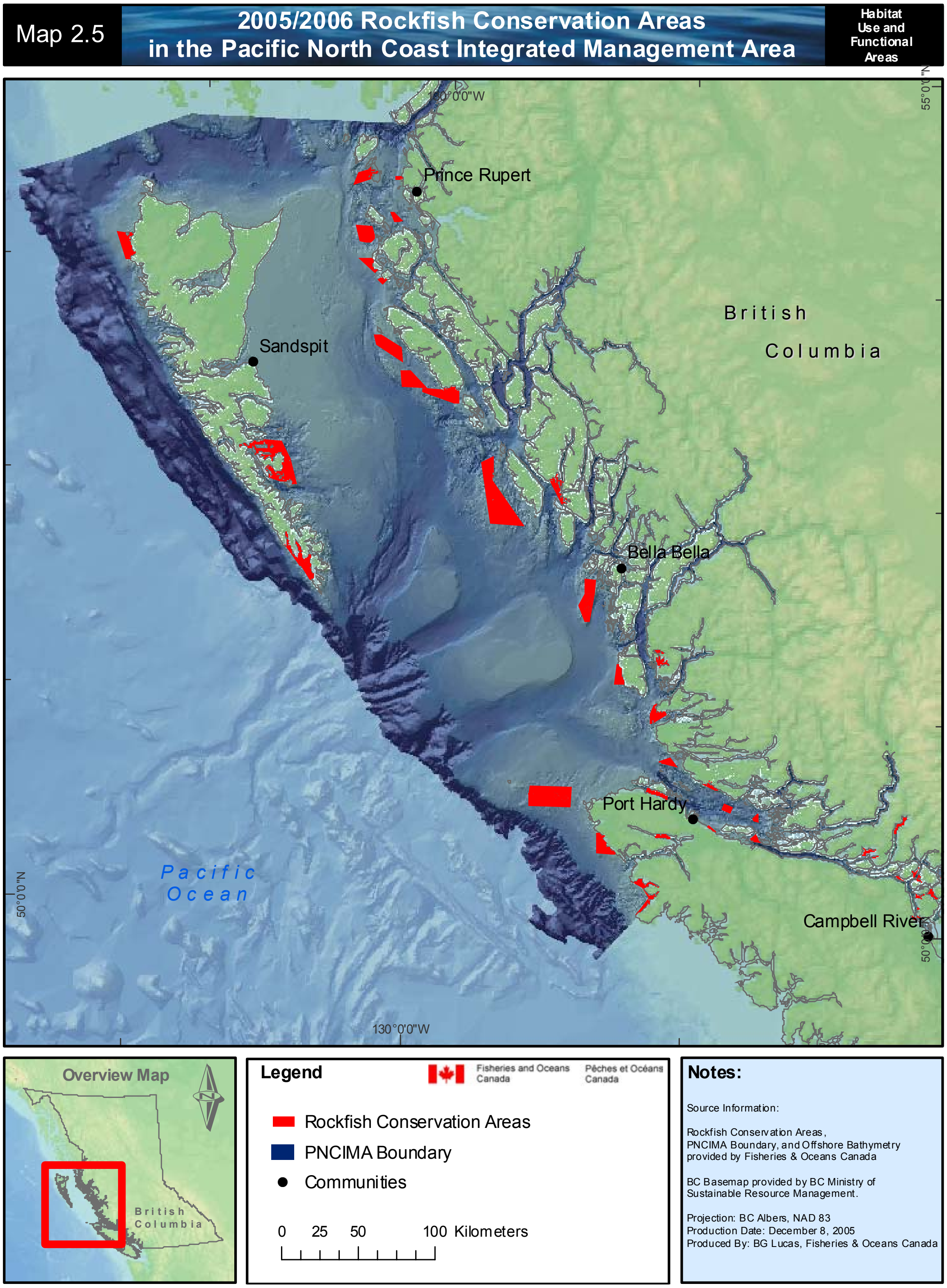
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 21, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

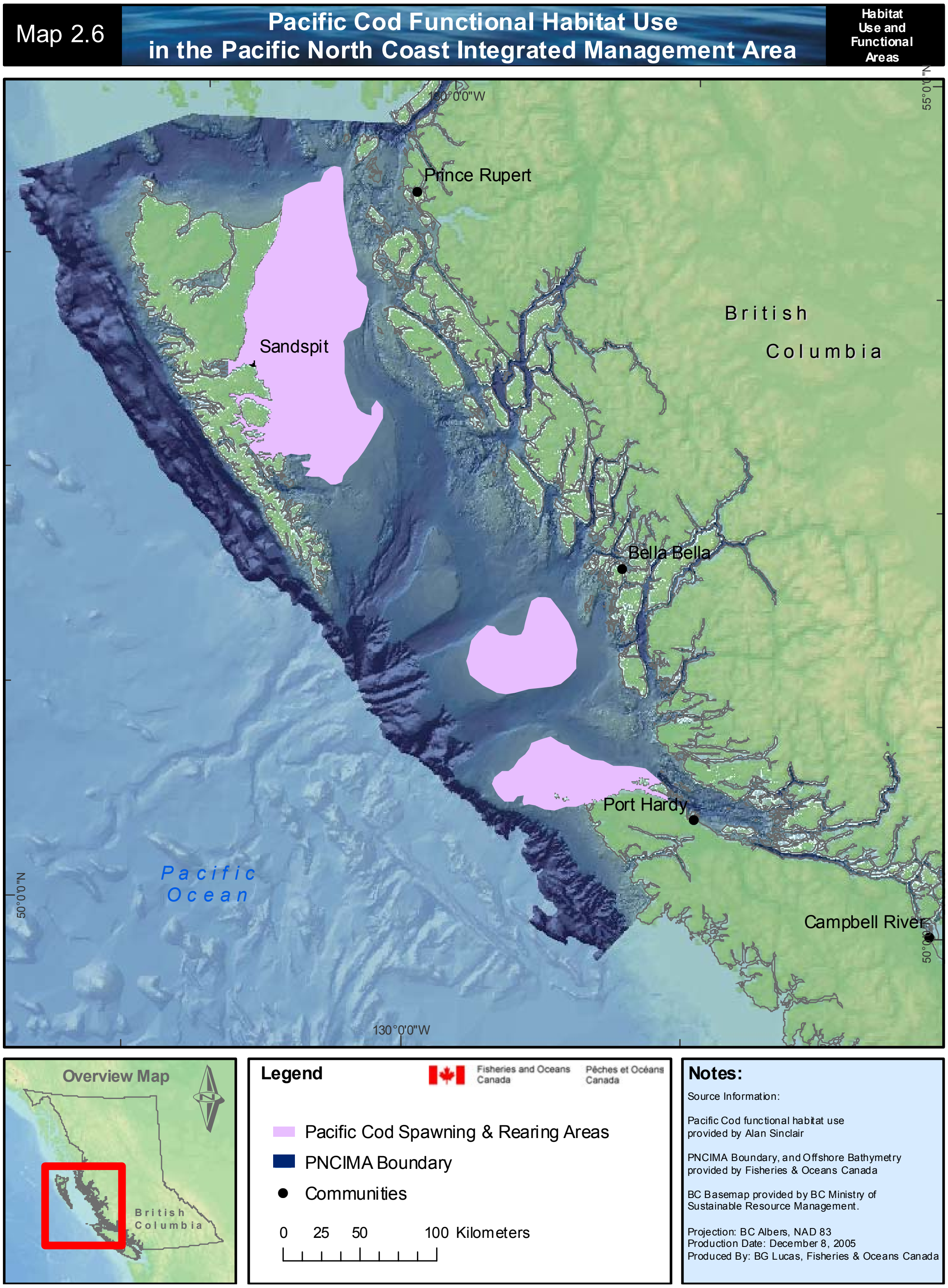
Map 2.3 Tanner crab functional habitat use in PNCIMA.



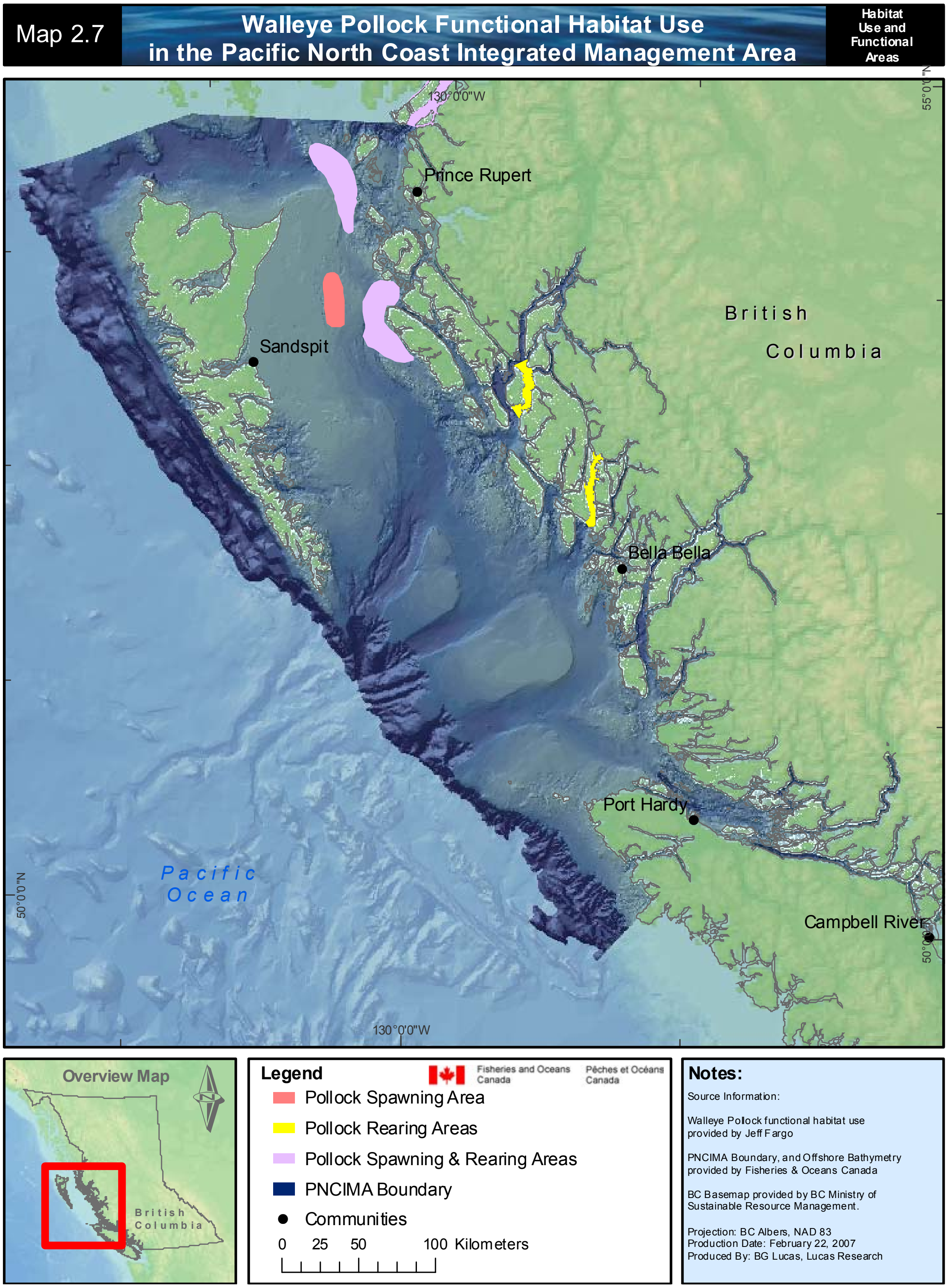
Map 2.4 Catch per unit effort (CPUE) for all species in the 2003-2005 groundfish trawl surveys in PNCIMA (A. Sinclair, unpublished data).



Map 2.5 2005/2006 rockfish conservation areas.



Map 2.6 Pacific cod functional habitat use in PNCIMA.



Notes:

Source Information:

Walleye Pollock functional habitat use provided by Jeff Fargo

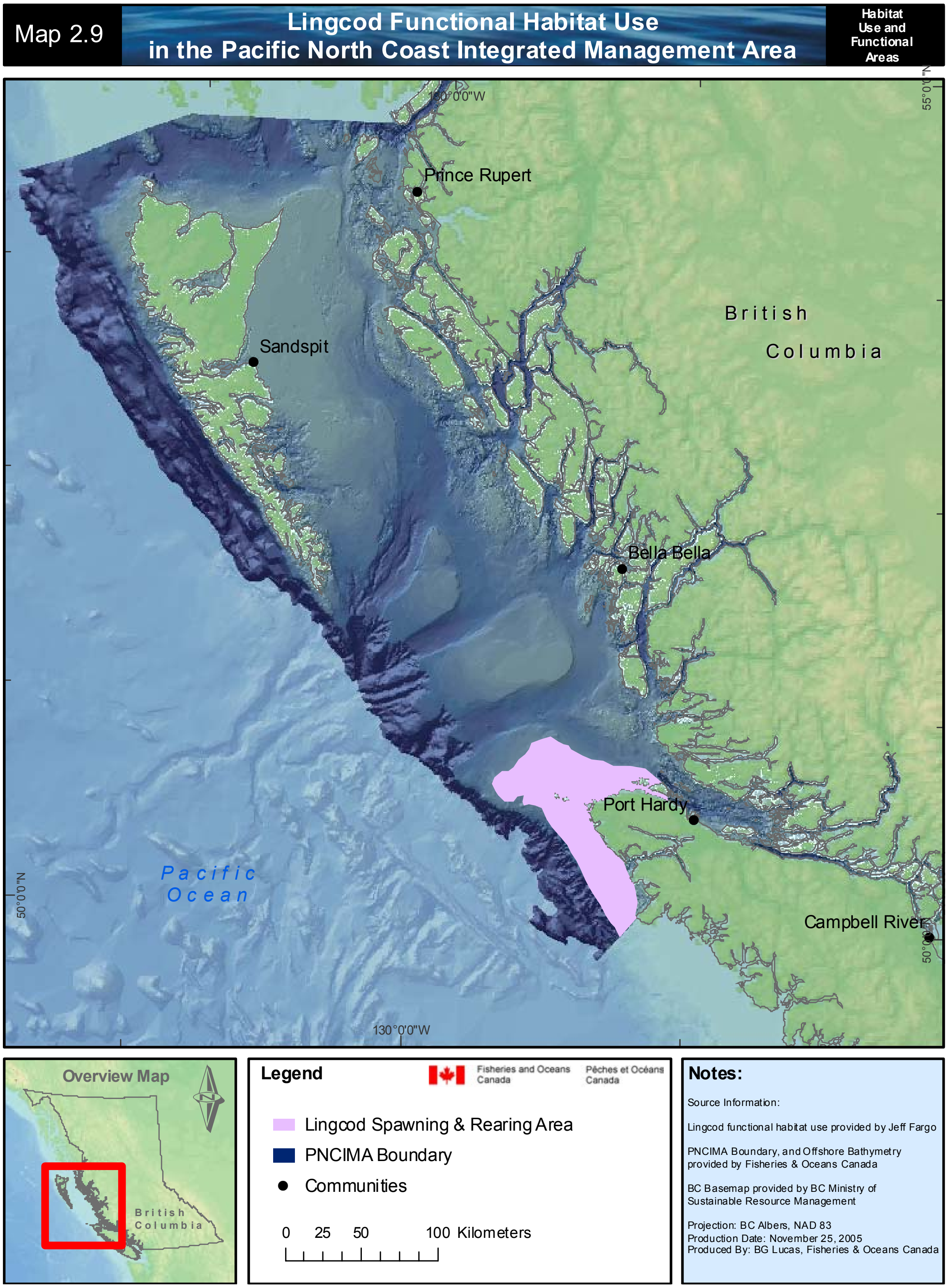
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

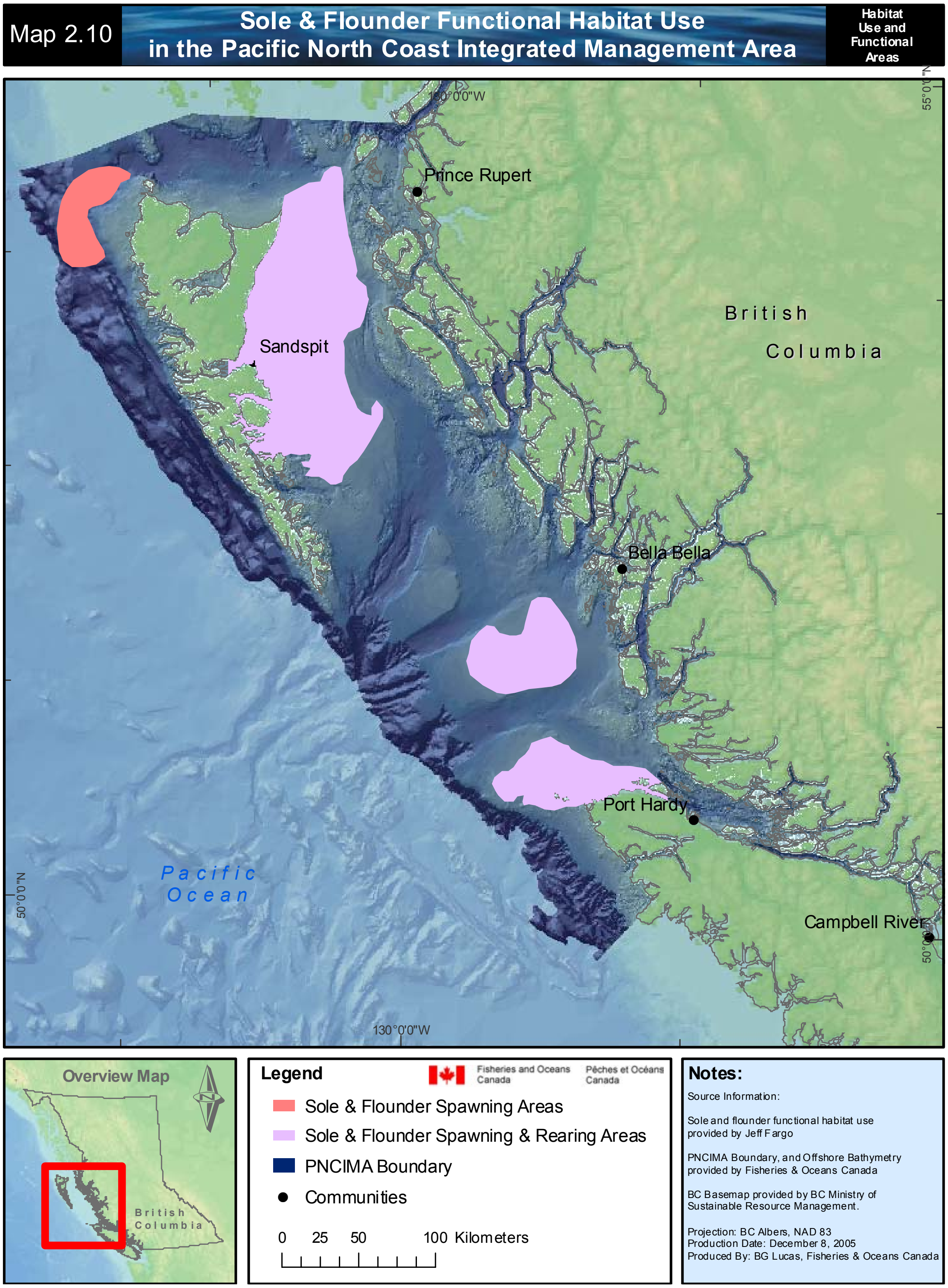
Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.7 Walleye pollock functional habitat use in PNCIMA.

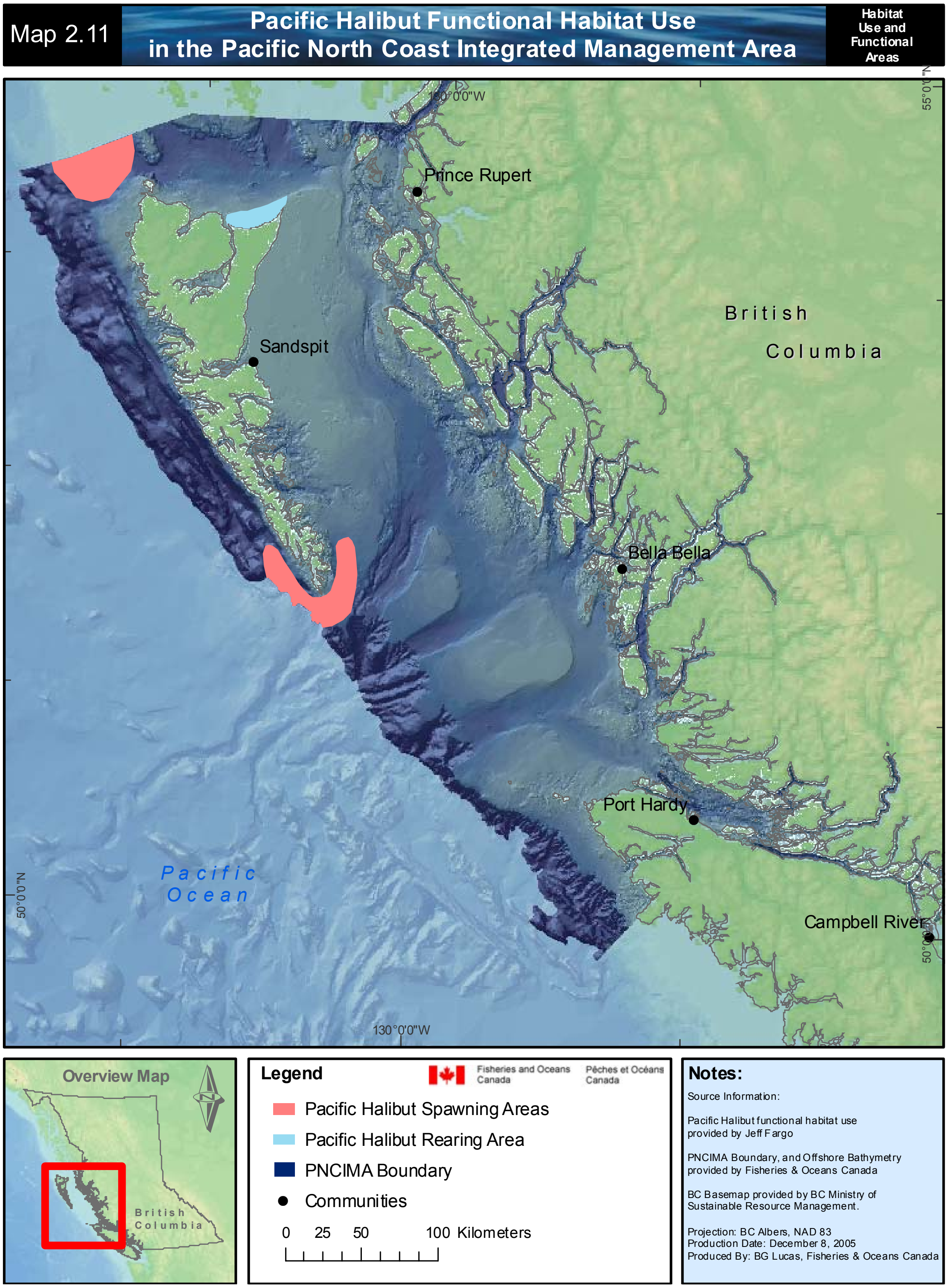
Map 2.8 Hake functional habitat use in PNCIMA.



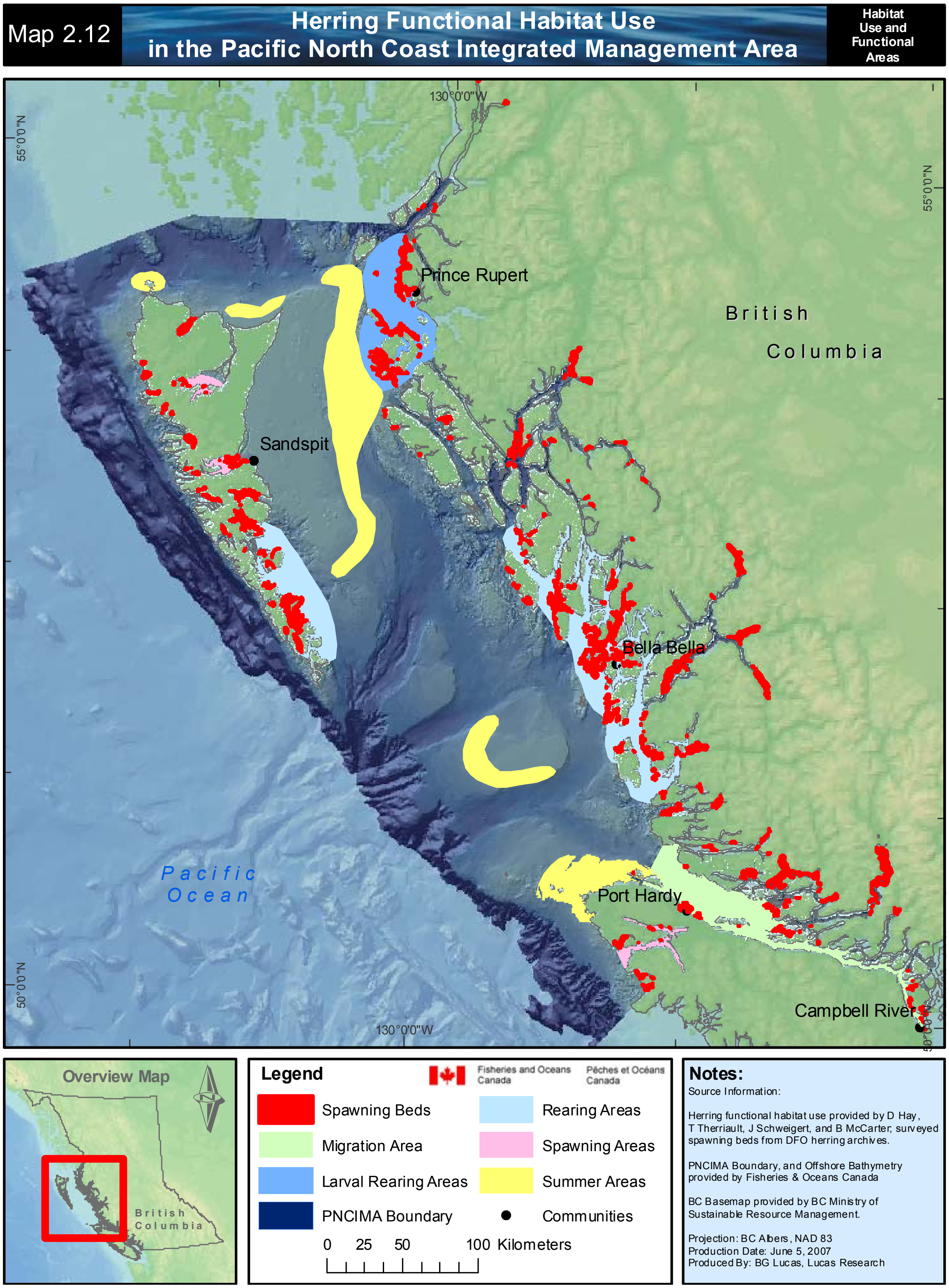
Map 2.9 Lingcod functional habitat use in PNCIMA.



Map 2.10 Sole and flounder functional habitat use in PNCIMA.



Map 2.11 Pacific halibut functional habitat use in PNCIMA.



Notes:

Source Information:

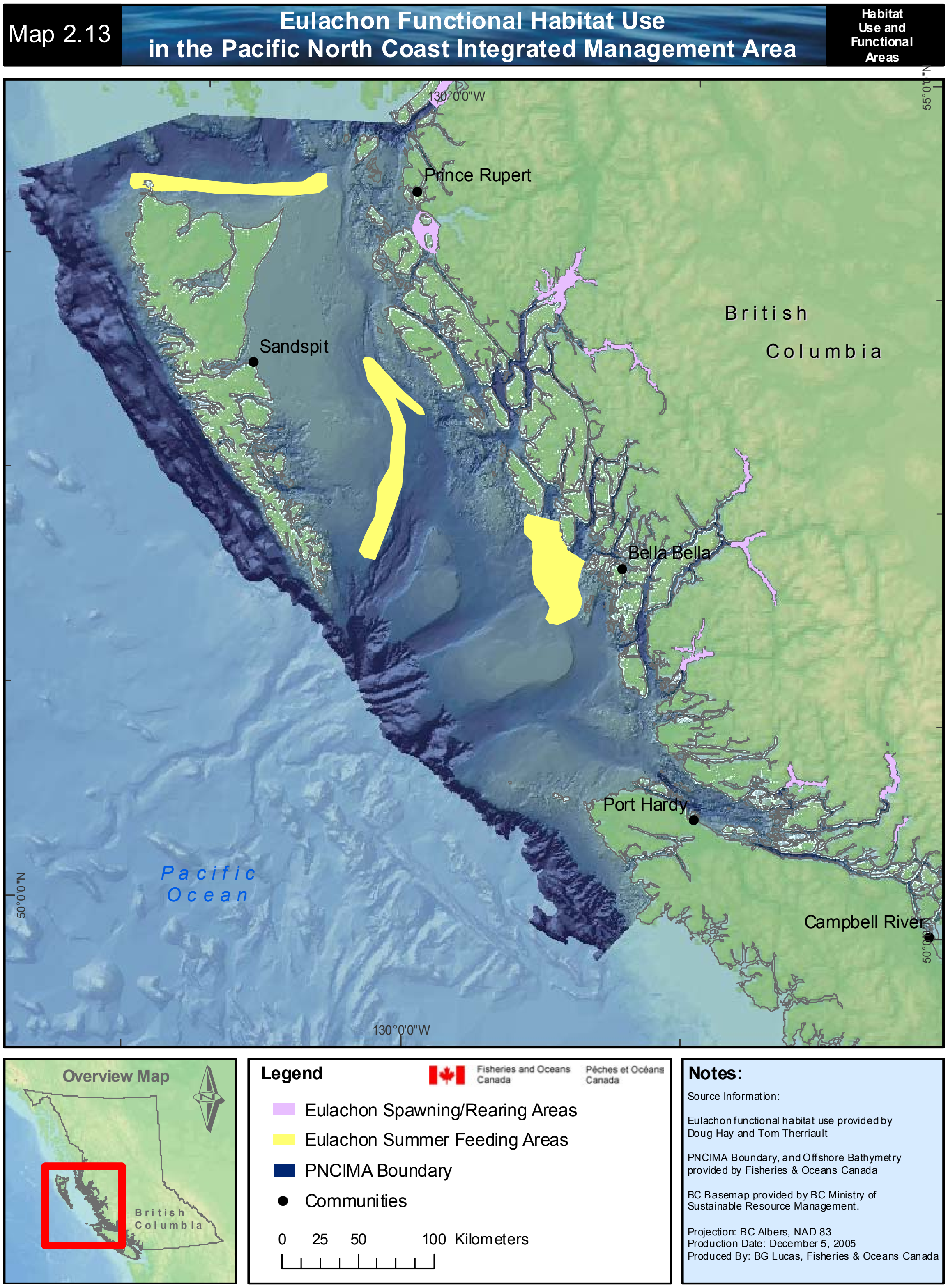
Herring functional habitat use provided by D Hay, T Therriault, J Schweigert, and B McCarter, surveyed spawning beds from DFO herring archives.

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: June 5, 2007
Produced By: BG Lucas, Lucas Research

Map 2.12 Herring functional habitat use in PNCIMA.



Notes:

Source Information:

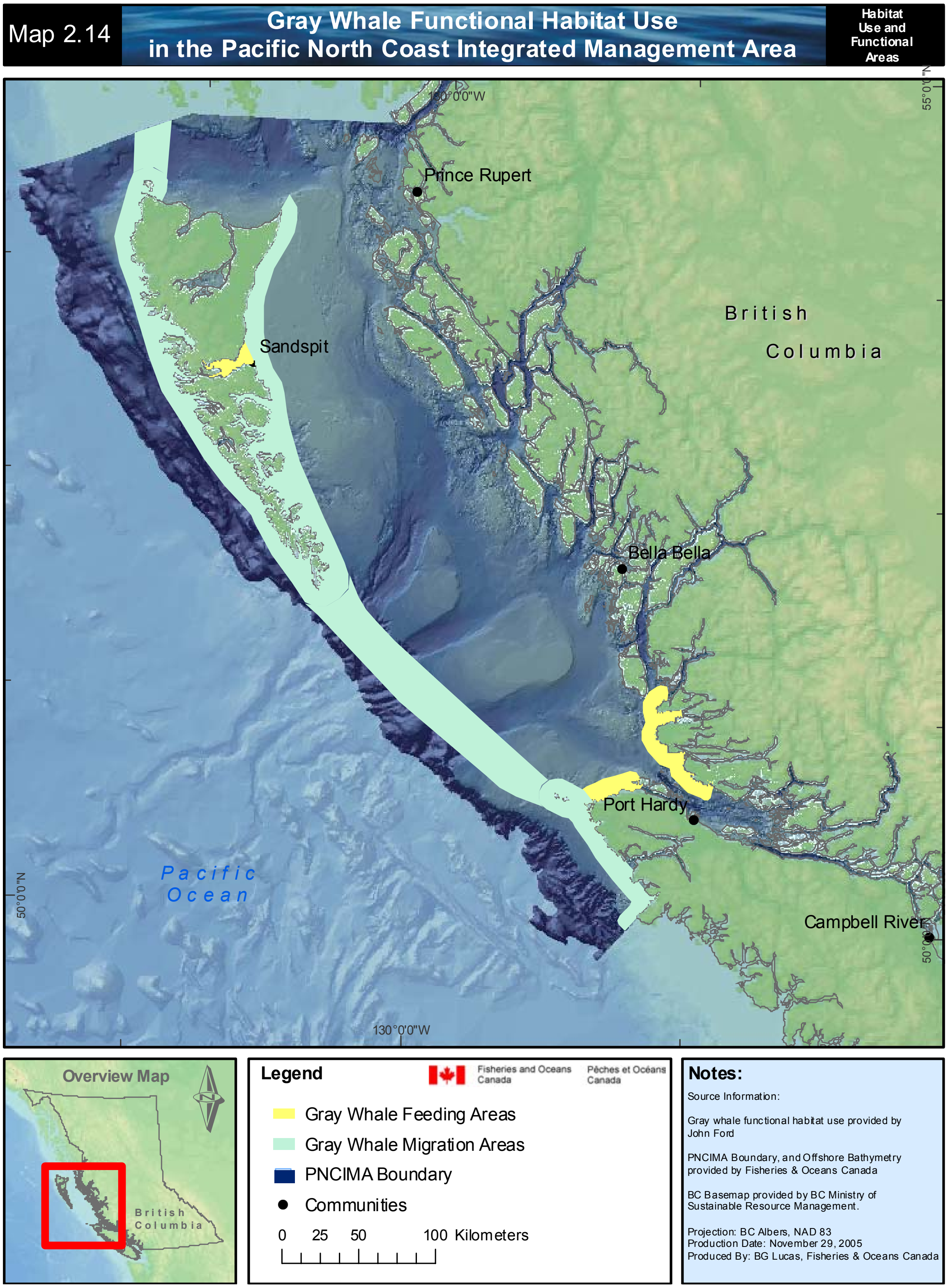
Eulachon functional habitat use provided by Doug Hay and Tom Therriault

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: December 5, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.13 Eulachon functional habitat use in PNCIMA.



Source Information:

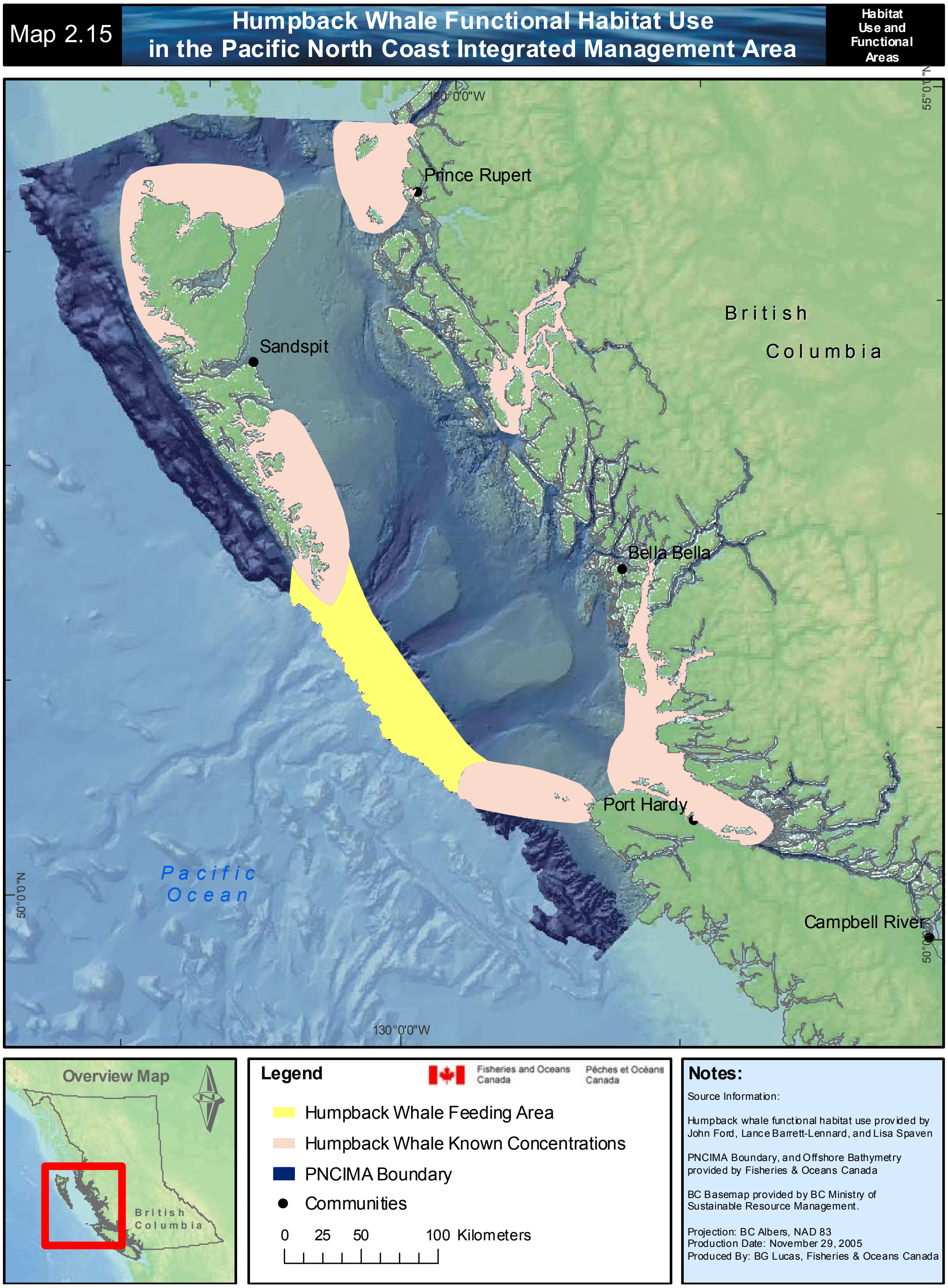
Gray whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 29, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.14 Gray whale functional habitat use in PNCIMA.



Source Information:

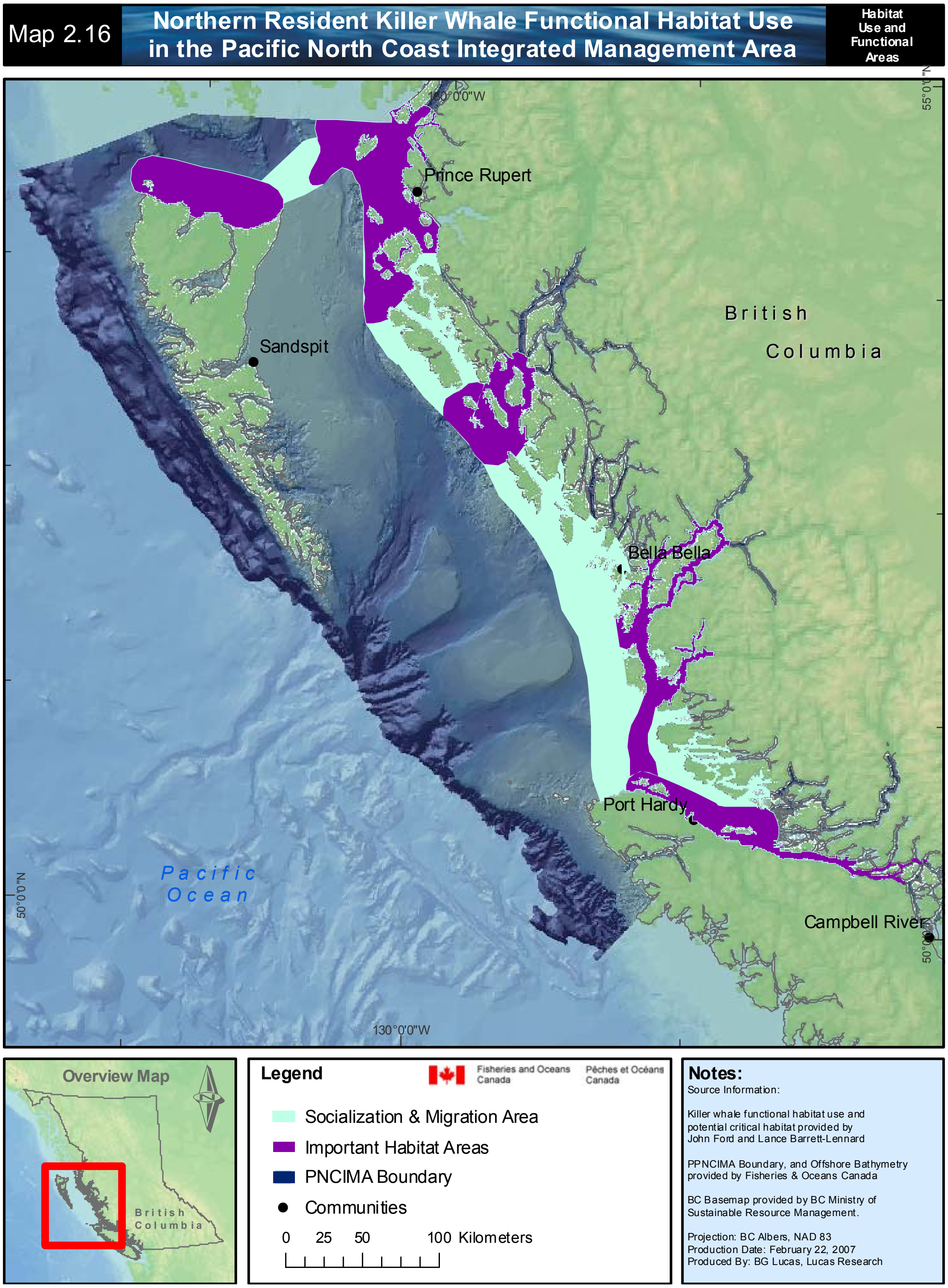
Humpback whale functional habitat use provided by John Ford, Lance Barrett-Lennard, and Lisa Spaven

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 29, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.15 Humpback whale functional habitat use in PNCIMA.



Notes:
Source Information:

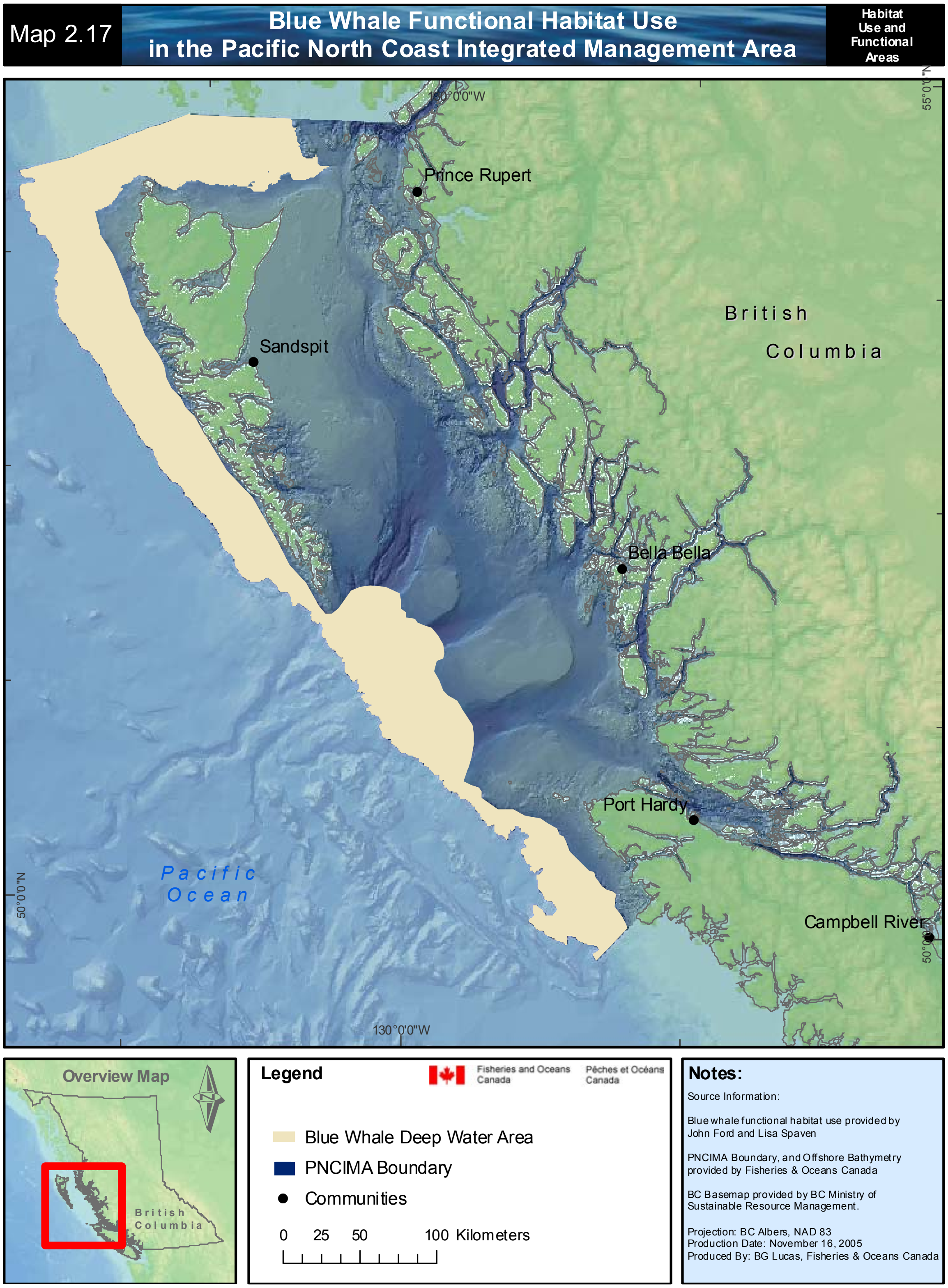
Killer whale functional habitat use and potential critical habitat provided by John Ford and Lance Barrett-Lennard

PPNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

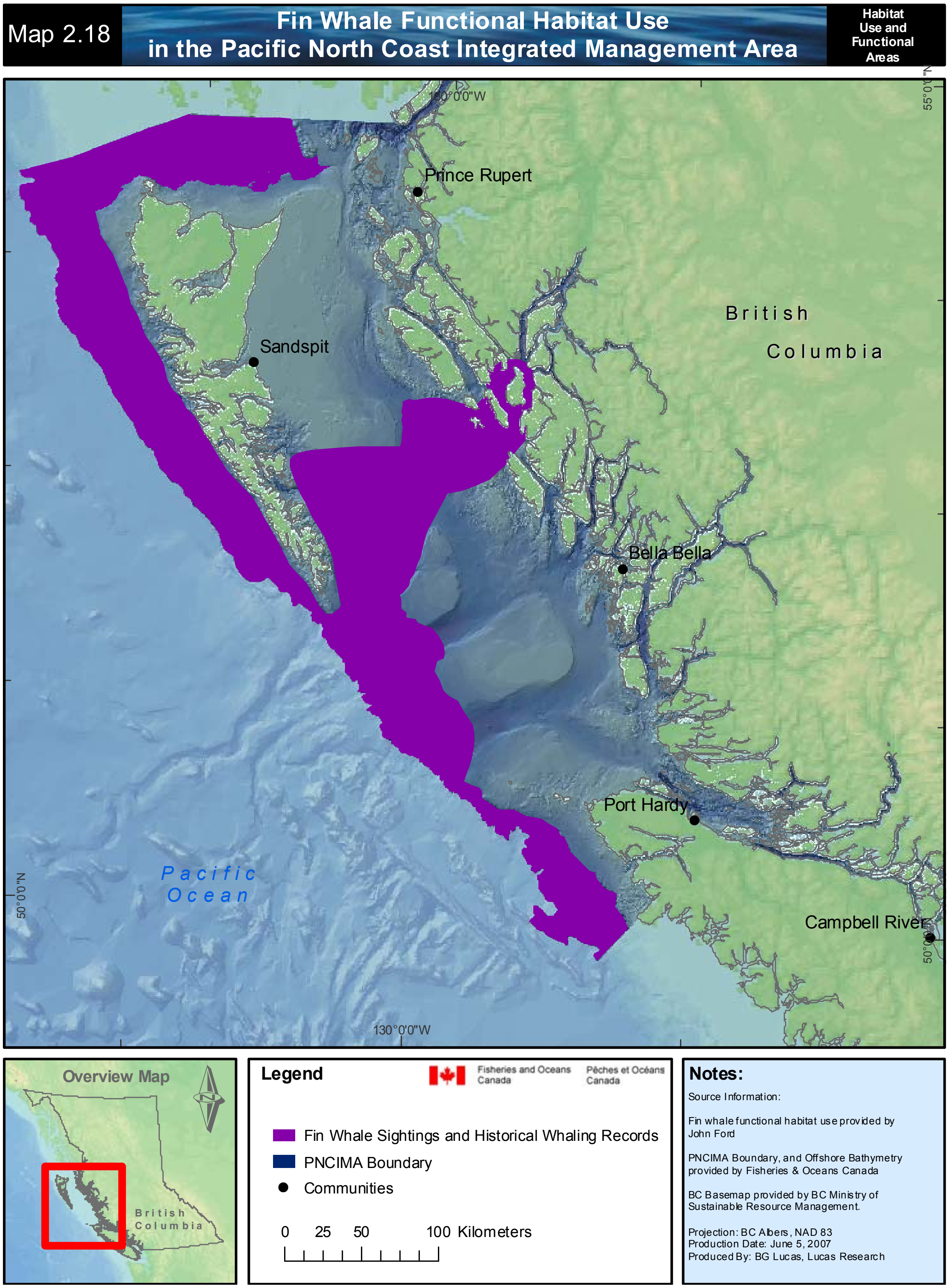
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

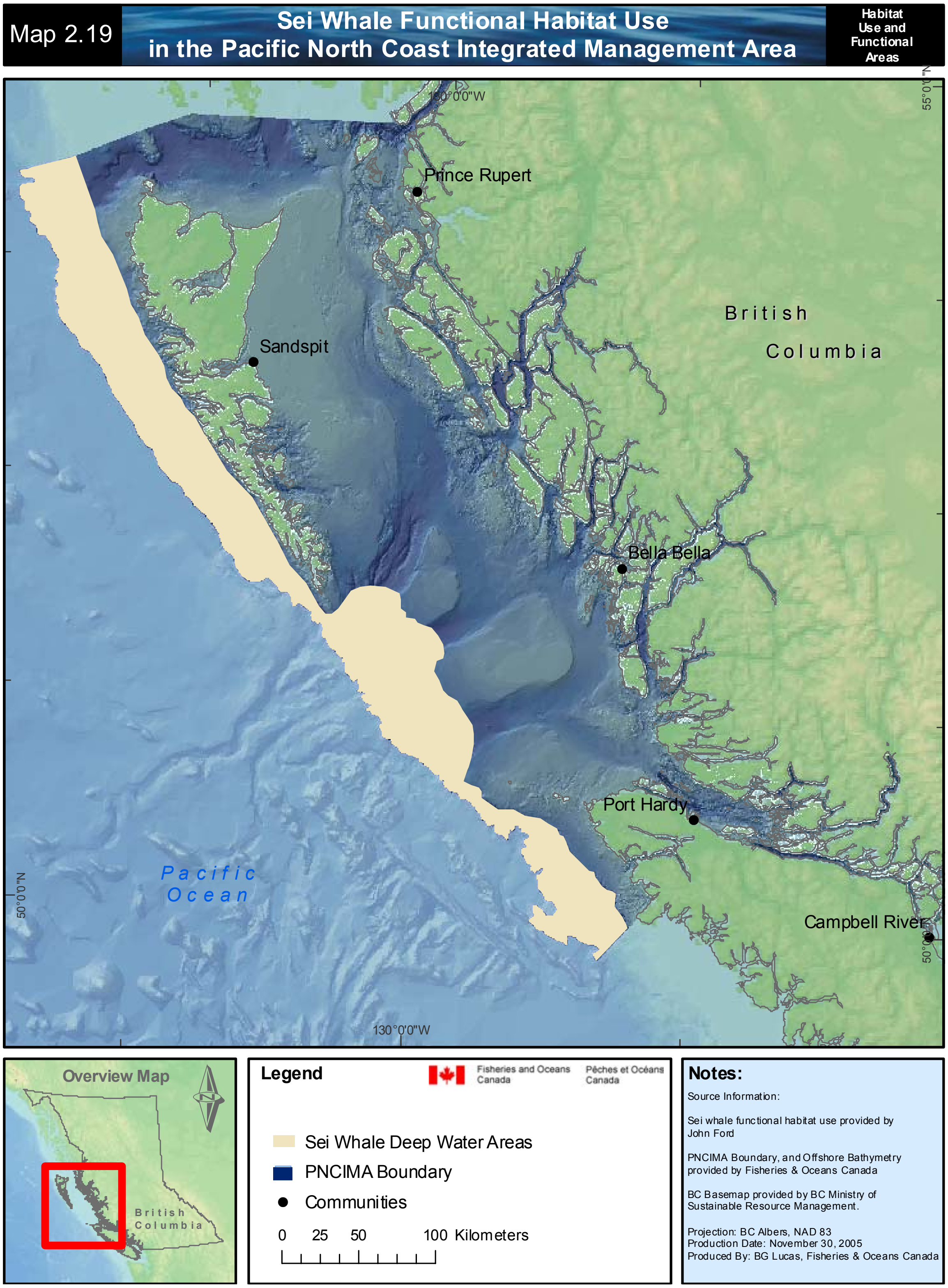
Map 2.16 Northern resident killer whale functional habitat use in PNCIMA.



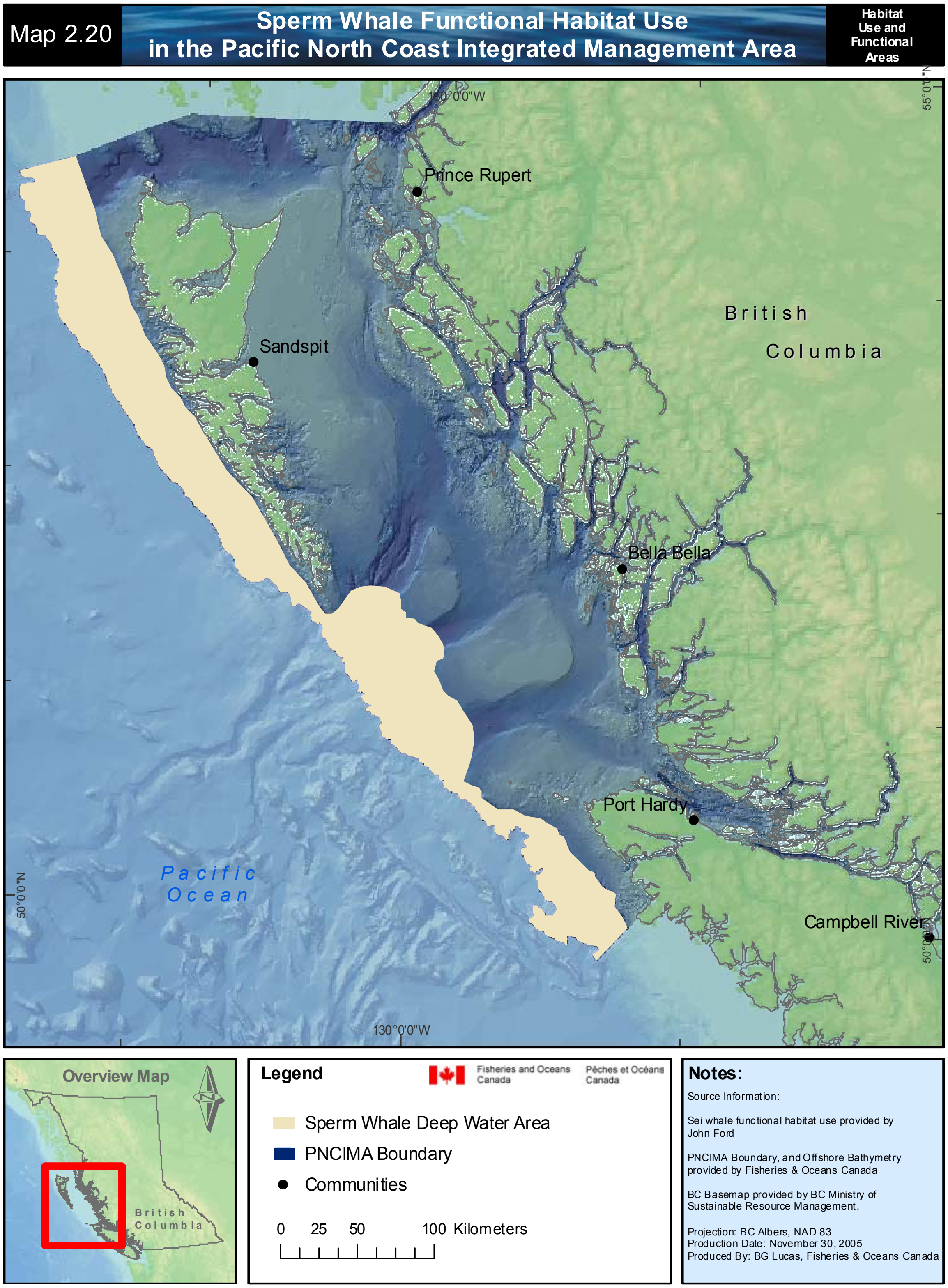
Map 2.17 Blue whale functional habitat use in PNCIMA.



Map 2.18 Fin whale functional habitat use in PNCIMA.



Map 2.19 Sei whale functional habitat use in PNCIMA.



Source Information:

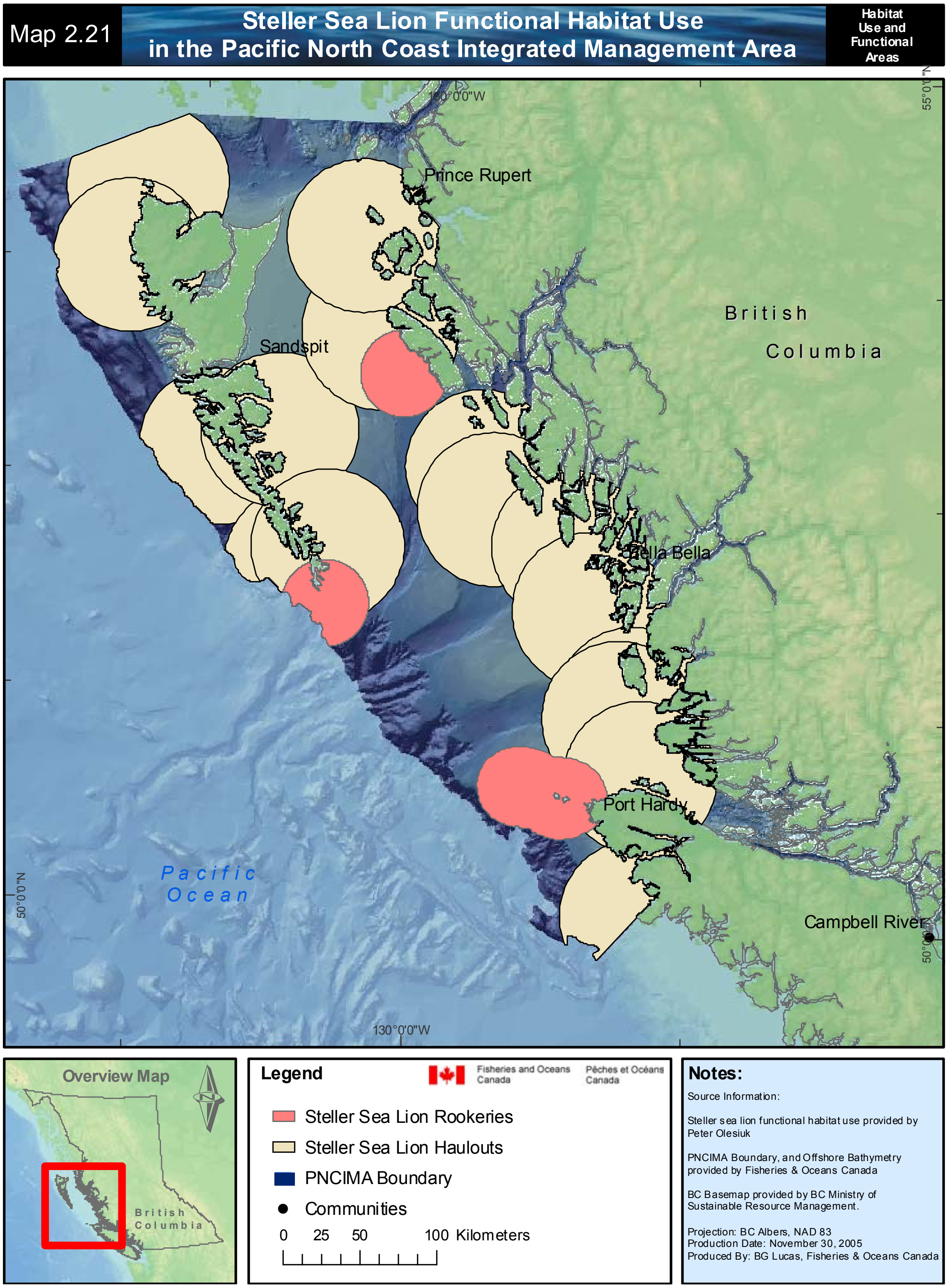
Sei whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.20 Sperm whale functional habitat use in PNCIMA.



Notes:

Source Information:

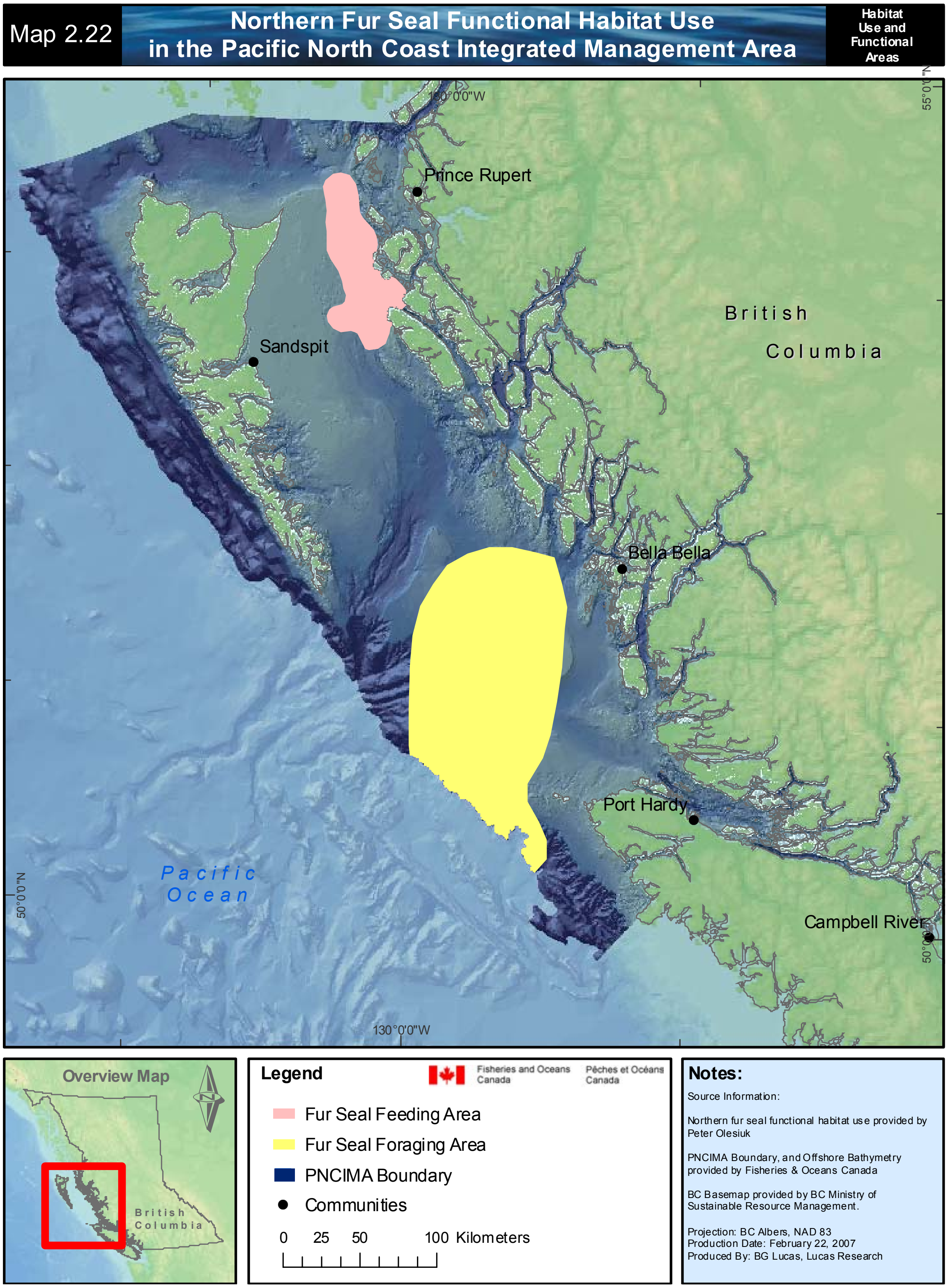
Steller sea lion functional habitat use provided by Peter Olesiuk

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.21 Steller sea lion functional habitat use in PNCIMA.


Map 2.22 Northern Fur Seal Functional Habitat Use in the Pacific North Coast Integrated Management Area

Habitat Use and Functional Areas

Notes:

Source Information:

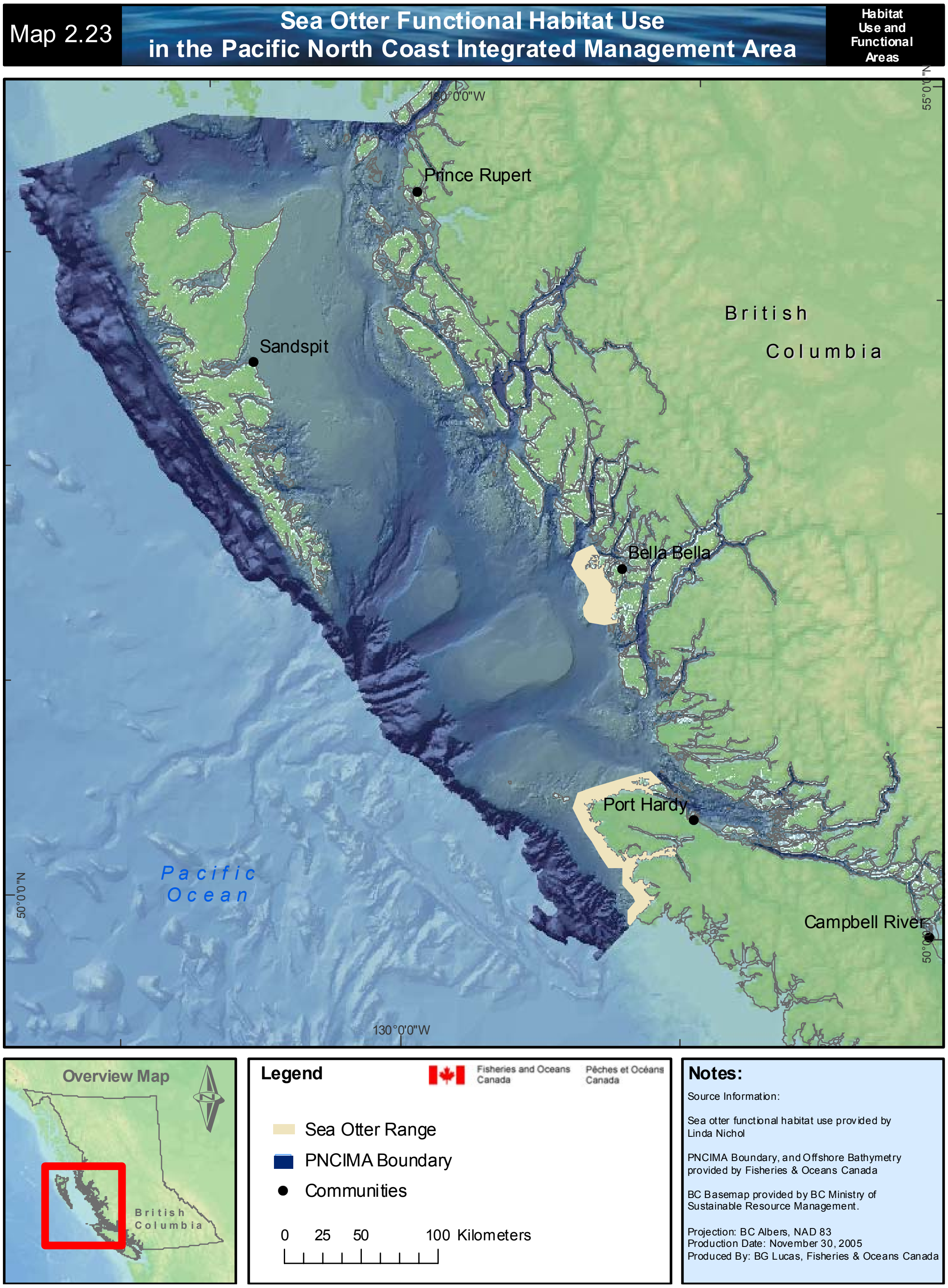
Northern fur seal functional habitat use provided by Peter Olesiuk

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.22 Northern fur seal functional habitat use in PNCIMA.



Source Information:

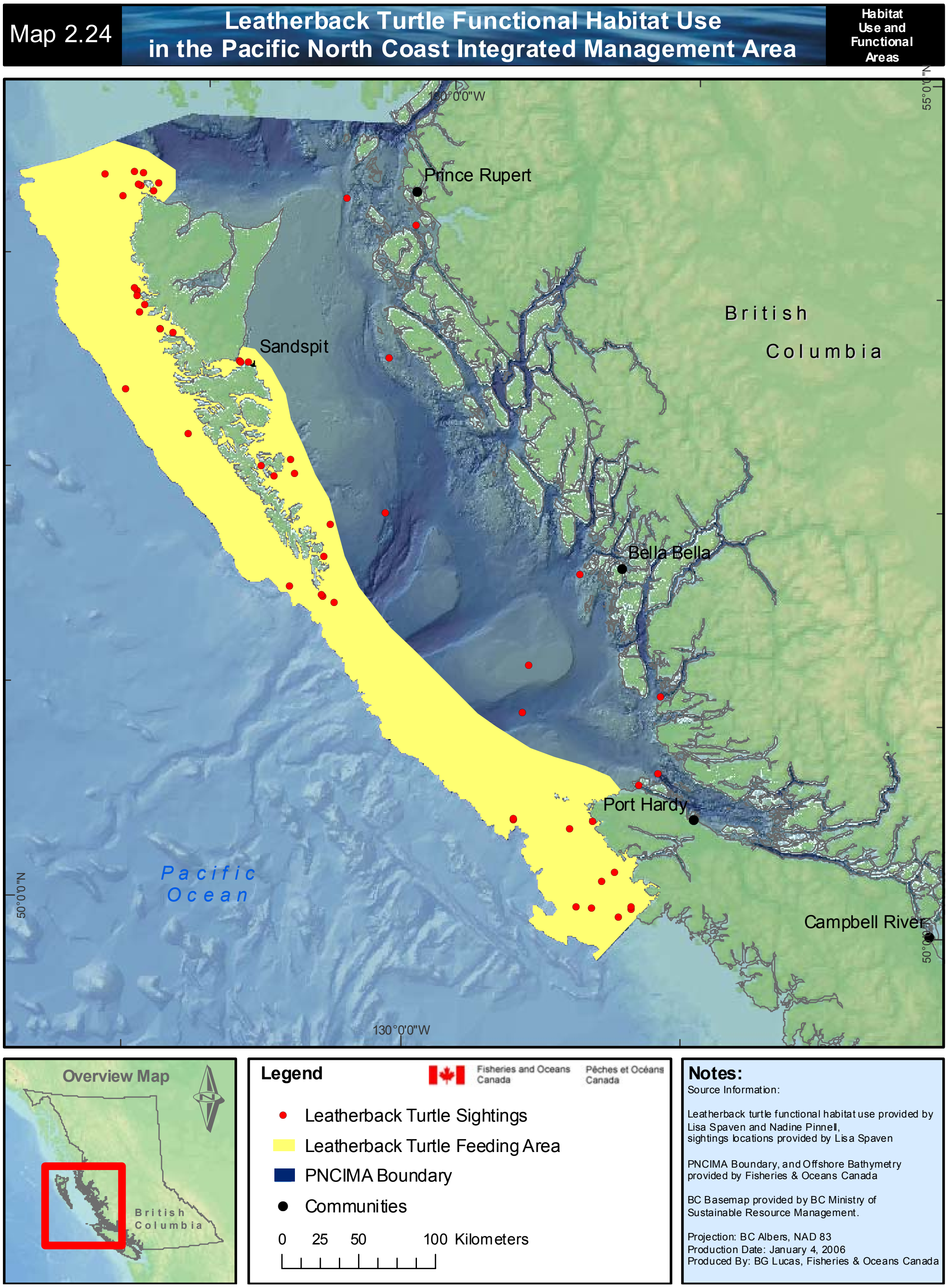
Sea otter functional habitat use provided by Linda Nichol

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.23 Sea otter functional habitat use in PNCIMA.



Map 2.24 Leatherback turtle functional habitat use in PNCIMA.

GLOSSARY

Accreted – Accretion is a process in which parts of the Earth's crust are solidified into larger bodies of rock.

Agglomerative clustering – Start by treating each object as a separate cluster, then group them into bigger and bigger clusters.

Anthropogenic – Human-caused.

Benthivores – An animal which feeds on animals that live on the sea floor.

Convergent – Processes by which water and particles in the water are aggregated.

Coriolis force – An apparent force exerted on moving parcels of water due to the rotation of the Earth; e.g. net movement of water is to the right of the wind direction in the Northern Hemisphere.

Demersal – On or associated with the sea floor.

Dendrogram – A tree-form diagram that is a graphic depiction of hierarchical relationships between sequences or organisms.

Detritus – Dead particulate organic material.

Diel – A daily cycle. Diel variation usually occurs once for every 24 hr period.

Downwelling – Sinking of higher density water, uaully driven by surface winds from a particular direction.

Ekman downwelling – Downwelling of surface water driven by the wind.

Epifauna – Animals that live on the surface of the sea floor.

Fecund – Species that have a high reproductive output based on when and how often they reproduce.

Fluvial – Related to flowing water; fluvial erosion refers to erosion by moving water, such as rivers.

Gametogensis – The formation of male and female gametes (egg and sperm) by meiosis.

Gonad – Reproductive organ.

Ichthyoplankton – Finfish and invertebrates which live by floating in the water; usually refers to the larval stages of finfish and invertebrates which can move against ocean currents as adults.

Inexorable – Relentless, inevitable.

Littoral – The coastal, near-shore, areas of an ocean or sea.

Macrophyte –Large aquatic plants.

Megalopa – Late larval stage.

Metamorphosis – Change in form during development.

Monotonic increase – Consistently increasing.

Moulting – To shed outer shell or exoskeleton.

Non-intermittent spawners – Individuals release all their eggs at one time.

Ontogenetic variability (in diet) – Variability relatied to the origin and development of individual organisms.

Piscivore – An animal which feeds on fish.

Planktivore – An animal which feeds primarily on plankton; plankton is the collective group of tiny plants and animals that float or drift near the surface of a body of water; plankton is very low on the aquatic food chain and therefore a vital element in that ecosystem.

Planktonic – Drifting small organisms that inhabit the water column of the ocean.

Sexual dimorphism – A distinct difference in appearance between males and females of the same species.

Terranes – A section of the earth's crust that has collided with and and become attached to a different part of the Earth's crust, as in a continental margin**.**

Upwelling winds – Winds that drive upwelling of denser and cooler water towards the ocean surface.

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Ecosystem Overview:
Pacific North Coast Integrated Management Area (PNCIMA)

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Canadian Technical Report of Fisheries and Aquatic Sciences

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2007

ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

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ABSTRACT

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

This report provides an overview of physical and biological ecosystems in the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is one of several Large Ocean Management Areas created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada. PNCIMA includes the Pacific coast of British Columbia from the Canada-Alaska border in the north to Brooks Peninsula on NW Vancouver Island and Quadra Island and Bute Inlet in the south; from the outer limit of the continental slope in the west to the coastal watersheds in the east.

PNCIMA is characterized by steep and rugged coastal mountains, abundant offshore islands, a coastline dominated by rocky shores with few sand and gravel beaches, valleys and fjords that extend to the ocean floor, and a glacially scoured continental shelf with cross cutting troughs. The Pacific Ocean moderates the climate, resulting in warm wet winters and cool summers. PNCIMA is located in a transition zone between two areas, one dominated by Alaska Coastal Current downwelling (north), and the other by California Current upwelling (south). PNCIMA's semi-enclosed basin, varied bottom topography, and freshwater input set it apart from other areas of the North American west coast. The troughs and steep edges influence, and likely enhance, plankton and fish production. Strong tidal mixing in the narrow passes and channels enhances productivity around the periphery.

The overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components in the food web, as long as other species occur within the same functional group. However, trophic pathways to individual species may be more constrained; it is unknown which species may be critically sensitive to the reduction or elimination of other species. Existing data suggests that the trophic structure is largely controlled by "bottom-up" forcing.

The ecosystem receives a large biomass of migratory species: stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that enter PNCIMA when conditions are unusually warm. Migrants provide an input of energy and food, but also can export energy from the system, as in Pacific salmon's transfer of energy and nutrients from marine to terrestrial coastal ecosystems.

Habitat use for many large and/or commercial marine species found within PNCIMA is summarized, including significant nearshore and biologically productive pelagic habitats. Eleven appendices detail our current state of knowledge for the geology, meteorology and climate, physical and chemical oceanography, plankton, marine plants, invertebrates, groundfish, pelagic fishes, Pacific salmon, marine mammals and turtles, and sea birds in PNCIMA.

RÉSUMÉ

Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

Le présent rapport donne un aperçu des écosystèmes biologiques et physiques de la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP). La ZGICNP est une zone étendue de gestion océanique parmi plusieurs créées afin que le ministère des Pêches et des Océans (MPO) puisse assurer la gestion écosystémique des activités humaines dans les zones marines. La ZGICNP est délimitée au nord par la frontière entre la Colombie-Britannique et l'Alaska, au sud par la péninsule Brooks (Nord-Ouest de l'île de Vancouver), l'île Quadra et l'inlet Bute, à l'ouest par la limite extérieure du talus continental et à l'est par les bassins hydrographiques côtiers.

La ZGICNP est caractérisée par des montagnes côtières abruptes et escarpées, un grand nombre d'îles extracôtières, une ligne de côte dominée par des rivages rocheux et quelques plages de sable et de gravier, des vallées et des fjords qui se prolongent sur le fond océanique, et une plate-forme continentale affouillée par les glaciers et présentant des dépressions transversales. L'océan Pacifique a un effet modérateur sur le climat et est responsable, de ce fait, des hivers chauds et humides et des étés frais de la côte Ouest. La ZGICNP est située dans une zone de transition entre une zone caractérisée principalement par la plongée du courant côtier de l'Alaska (au nord) et une zone caractérisée par la remontée du courant de Californie (au sud). La ZGICNP se distingue des autres zones de la côte ouest de l'Amérique du Nord par son bassin partiellement fermé, son fond à topographie variée et son apport en eau douce. Ses dépressions et ses bordures abruptes améliorent probablement la production de poissons et de plancton. Un mélange tidal important dans les passages et chenaux étroits entraîne une hausse de la productivité en périphérie.

La structure trophique globale de la région de la ZGICNP semble être relativement stable en cas de réduction ou d'élimination de composantes individuelles du réseau trophique, en autant que le ou les groupes fonctionnels touchés soient constitués d'autres espèces. Cependant, les voies trophiques menant à des espèces individuelles sont peut-être plus restreintes; les espèces qui pourraient être très vulnérables à la réduction ou à l'élimination d'autres espèces sont inconnues. Les données existantes suggèrent que la structure trophique est largement régulée par un mécanisme de forçage ascendant.

L'écosystème accueille une biomasse élevée d'espèces migratrices : il constitue la destination de certaines espèces, telles des baleines; il sert d'escale, notamment pour le saumon du Pacifique et des oiseaux marins migrateurs; il sert d'habitat pour des espèces, telles le zooplancton et des poissons pélagiques, qui y migrent lorsque les conditions sont plus chaudes que la normale. Les migrateurs importent et exportent de l'énergie et des ressources alimentaires de l'écosystème, comme dans le cas du saumon du Pacifique qui transfert de l'énergie et des éléments nutritifs des écosystèmes marins aux écosystèmes côtiers terrestres.

Le présent document comprend un sommaire de l'utilisation des habitats de la ZGICNP par de nombreuses espèces marines commerciales ou de grande taille, notamment des habitats pélagiques importants à productivité biologique élevée et situés près des côtes. Onze annexes présentent en détail nos connaissances actuelles relatives à la géologie, à la météorologie et au climat, à l'océanographie chimique et physique, au plancton, aux plantes marines, aux invertébrés, au poisson de fond, aux poissons pélagiques, au saumon, aux mammifères marins, aux tortues et aux oiseaux marins dans la ZGICNP.

PREFACE

This Ecosystem Overview is one of a several reports on the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA is a Large Ocean Management Area (LOMA) created for ecosystem based management of human use in marine areas by Fisheries and Oceans Canada (DFO). This Ecosystem Overview covers the ecosystem status and trends for geological, oceanographic and biological systems in the LOMA. Other reports may include marine use analyses, ecologically and biologically sensitive areas, ecologically sensitive species, depleted species, degraded areas, ecosystem assessments, conclusions and recommendations.

Parts of this volume were based on an earlier report (Johannessen *et al.* 2005), which was drafted to compile background information for regional management of the north coast of British Columbia for DFO, and later expanded to include the central coast management area.

INTRODUCTION

PROJECT DEFINITION

Context and purpose

Canada's *Oceans Act* states that "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment." Implementation of integrated management planning is central to the new governance and ecosystem based management approach of the Oceans Action Plan (OAP). The OAP identified five priority Large Ocean Management Areas (LOMAs) across Canada for coordination of Integrated Management (IM) efforts. The Pacific North Coast Integrated Management Area (PNCIMA) is one; the others are the Eastern Scotian Shelf, Beaufort Sea, Gulf of St. Lawrence, and Placentia Bay/Grand Banks. Ecosystem Overview and Assessment Reports (EOARs) are one of the tools being used to develop ecosystem objectives for these LOMAs. Other reports being developed under the OAP include a Marine Use Analysis and a Socio-Economic Overview and Assessment Report.

The purpose of the PNCIMA Ecosystem Overview is to provide an overview of our current state of knowledge of the ecosystem(s) in PNCIMA. This Ecosystem Overview provides a knowledge base upon which impact assessments can be completed and recommendations provided for integrated management and sustainable use of the area (DFO Oceans Directorate 2005). As an overview, it provides a summary of the most relevant information and directs readers to publications with more comprehensive information. It is a science-based technical document, intended for use in ecosystem planning, and in preparation of later volumes of the EOAR.

The PNCIMA Ecosystem Overview was guided by a series of common EOAR principles: ecosystem focus, brevity and highlights, state of knowledge, scale integration of nested systems, ecologically significant boundaries, collaborative and team project, flexibility to regional constraints, multiple volumes, information management, and plain language (DFO Oceans Directorate 2005). It was produced with the best available information and state of knowledge.

Boundaries of the study area

PNCIMA's boundaries were determined primarily on ecological characteristics, and encompass approximately 88,000 sq km. It extends from the outer limit of the foot of the continental slope in the west, to the coastal watersheds in the east. The Canada-US border for Alaska is the northern boundary. The Brooks Peninsula on NW Vancouver Island and Quadra Island are encompassed in the southern boundary.

Report structure

This Ecosystem Overview is comprised of two summary chapters and 11 appendices. The first chapter is a description of what we know about how the ecosystem functions, the linkages, and interactions. It integrates the information detailed in the appendices and highlights key information gaps. Chapter 1 was reviewed and refined at a workshop in March 2006 held at the Institute of Oceans Sciences, in Sidney, BC.

The second chapter summarizes what is known about the use of habitat in PNCIMA by marine organisms for important life history functions, such as feeding, breeding, and migrating. The habitat map folio illustrates geographical areas for specific species or groups where those areas are large enough to be visible on a LOMA scale.

The appendices are excellent primers on their topics. They each provide important background details to understanding how and why PNCIMA ecosystems are structured and function the way they do. They also provide references to current literature for in-depth information on pertinent subjects.

CHAPTER 1: ECOSYSTEM DESCRIPTION

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1.0 INTRODUCTION

This chapter integrates the information presented in the appendices, and provides the broad overview and synthesis of this material to understand "how the marine ecosystem(s) of the central and north BC coast (the Pacific North Coast Integrated Management Area; PNCIMA; Figure 1.0) works." It attempts to understand the structure and function of the system, and where there may be critical "control points" in space, time, or organisation (*e.g.,* trophic connections). An important additional objective is to identify critical unknowns and key information gaps to our understanding of how the ecosystem works.

This analysis includes nearshore and open water systems of the PNCIMA region. It does not include detailed consideration of inlet and fjord waters, largely because there are insufficient data from these areas. It also does not consider terrestrial systems nor detailed connections between terrestrial and marine environments.

We build our understanding of these marine ecosystems using four principal themes: (a) spatial patterns and processes; (b) food web interactions; (c) migratory species; and (d) temporal variability. We conclude with a summary and short discussion of key data gaps and uncertainties.

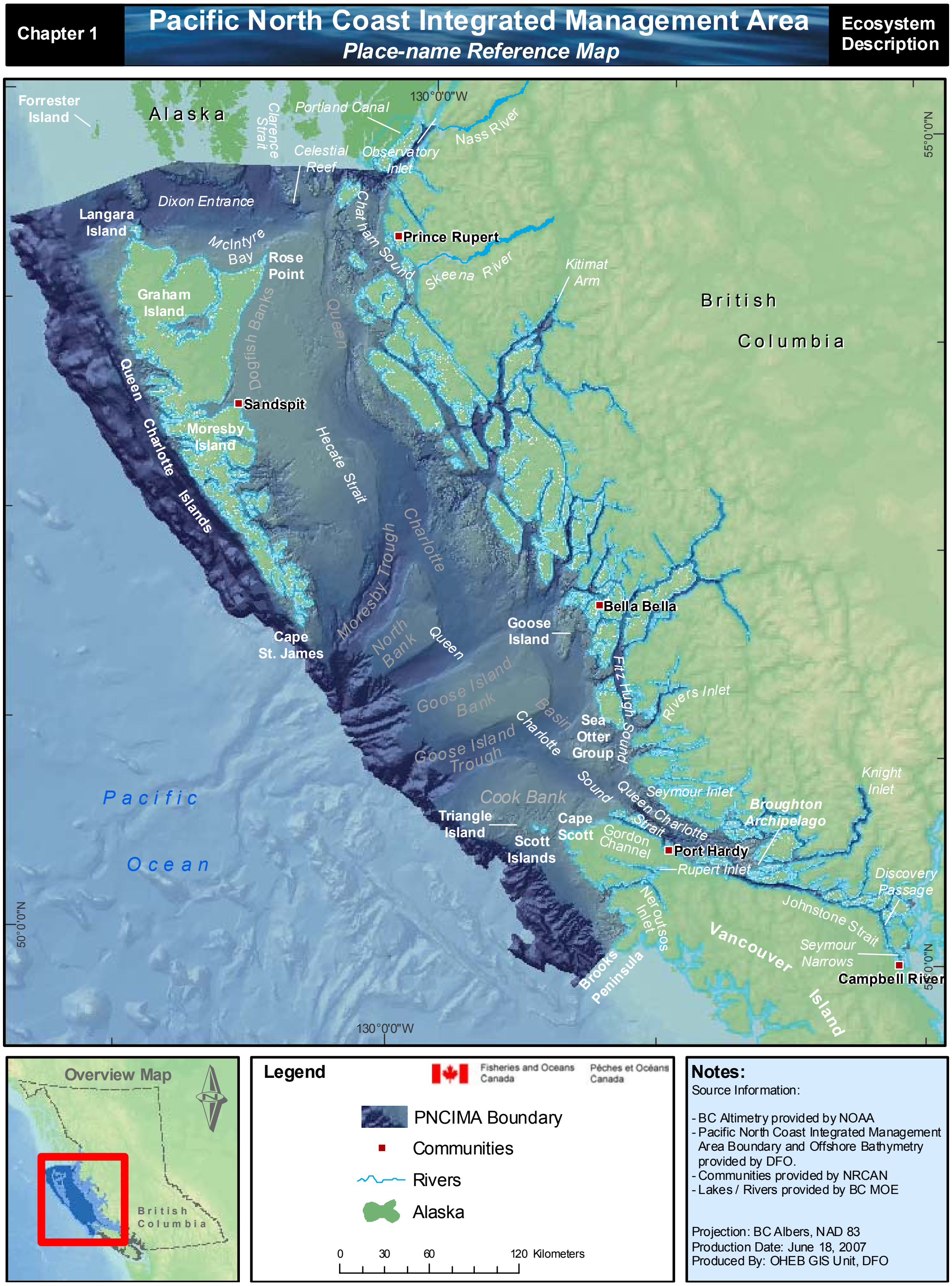


Figure 1.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 1.

1.1 GEOLOGICAL SETTING

The geology of the PNCIMA region steers and determines much of its physical and biological processes. The Pacific Coast today is the result of geological processes stretching back hundreds of millions of years. Over the largest time scale, the dominant process involved is plate tectonics, by which terranes from other parts of the world were accreted onto North America. Most of the bedrock of British Columbia was added to North America in this way. The slow but inexorable forces involved in this process also caused the tectonic uplift and buckling of the crust resulting in the mountain ranges of BC. Subsequent erosion of these mountains developed the sediment filled basins between these ranges.

The tectonic forces that have formed BC continue today and BC's offshore has a complex combination of plate boundaries including a subduction zone, spreading ridges, and transform faults. This results in a variety of earthquake environments that are capable of everything from frequent low magnitude earthquakes to giant megathrust earthquakes that can achieve magnitudes greater than 9 and have occurred roughly once every 300 years.

Over the last few million years, finer details have been chiselled into the tectonically developed bedrock features by the repeated advance and retreat of glaciers over the land. As subsequent glaciations largely erase the effects of the previous ones, most of the glacial features seen today are a result of the last glacial advance (between 10 and 30 thousand years ago). Many of the terrestrial glacial features have in turn been modified by fluvial erosion and deposition during postglacial time (the last 10,000 years), while the marine features have been subject to tides, currents, and littoral processes. Sedimentary input to the continental shelf has been very low since glacial retreat because the deep basins of the coastal fjords allow the settling of river-borne sediments. This results in a 'sediment starved' shelf where the older glacial deposits are constantly re-worked and produces a coastline dominated by rocky shores with few sand and gravel beaches.

The physical features of the coast also affect the freshwater input to the marine area. The PNCIMA area contains a variety of watershed forms resulting in different hydrologic profiles, though spring and summer meltwater runoff dominate the mainland watersheds which provide most of the freshwater input. This input and its timing are critical to phytoplankton blooms which form the base of the marine food chain. Global warming is already seen to be affecting the timing and volume of freshwater input in this area.

The PNCIMA area is also host to potentially significant petroleum-based resources. The Queen Charlotte Basin is one of four sedimentary basins found beneath Canada's Pacific continental shelf. Exploration from the 1960s to the 1980s suggests that this basin may hold significant reserves of oil and gas. Natural gas hydrates have also been found on southern portions of BC's continental slope. This potentially significant source of natural gas may also exist on the slope within the PNCIMA area. See Appendix A for more information on the geology of PNCIMA.

1.2 METEOROLOGY AND CLIMATE

British Colombia's coastal climate and weather conditions are a direct result of its position between the northeast Pacific Ocean and the Coast Mountains. Winds are dominated by the Aleutian Low Pressure system in winter and the North Pacific High in summer. This means that winter storms absorb great amounts of moisture as they track eastward toward the British Columbia coast. Much of this moisture falls as precipitation when it hits the Coast Mountains, making BC's coast the wettest place in Canada. The positions of the air pressure systems often cause winter storms to hit the central and north coast of BC more frequently than the southern coast. This results in the highest precipitation totals occurring within PNCIMA.

The ocean also moderates temperatures, with the winter storm winds transporting heat across the central Pacific and the milder northwest summer winds bringing relatively cooler air masses onto the coast. These air pressure systems and their winds also drive ocean circulation, which controls the source, and thus temperature, of water off the BC coast, which in turn affects coastal air temperatures.

Variations in climatic conditions strongly affect ecosystems. Most obvious is the seasonal variation that controls such things as the spring phytoplankton bloom, timing of peak stream flow, ocean wave intensity and ocean current strength and direction. However, the variation between years and decades for a given season is of great significance as these conditions can strongly affect the timing of ecosystem functions, which can be critical to the success of various biota. El Niño events, for example, transport warm waters and their biological communities northward to the BC coast, creating competition between indigenous and invasive organisms. There is an increasing focus in research on understanding how climate variability affects the ecosystem and whether that variability can be predicted.

PNCIMA is located in a transition zone between a northerly area dominated by the Alaska Current system and a southern area dominated by the California Current. The location of this transition zone varies depending on the relative dominance of these two systems. Shifts in this location are marked by periodic appearance of northern and southern species. See Appendix B for more information on the meteorology and climate of PNCIMA.

1.3 OCEANOGRAPHIC SETTING

PNCIMA forms the portion of BC coastal waters north of Campbell River and Brooks Peninsula and includes all salt and brackish waters in BC north of these two points as well as freshwater streams draining into these seas (Figure 1.0). In physical oceanographic terms, these waters form a transitional region north of the northern end of the California Current domain, and south of the southern end of the Alaska Current domain. Brooks Peninsula, on northwest Vancouver Island, is generally considered to be the dividing point between Alaska Coastal Current and California Current domains. Whereas the California Current is characterized by moderate to strong upwelling winds in summer, the Alaska Coastal Current is characterized by relaxation of winter downwelling in spring and summer rather than by upwelling winds. Where upwelling winds do occur in summer, generally in PNCIMA and SE Alaska, they are generally weak and persist only for a few months.

PNCIMA, in common with SE Alaska to the north, experiences extremely strong storms in autumn and winter with accompanying winds from the southeast and accumulations of metres of precipitation over autumn and winter (Figure 1.1). Coastal currents are forced by these winds to flow to the northwest alongshore, and can be considered the southern end of the Alaska Coastal Current. In parts of the three main basins on the shelf, Queen Charlotte Sound, Hecate Strait and Dixon Entrance, the currents are forced by the bathymetry to flow westward, or even upwind, but the overall surface flow is alongshore. The outer coast is wind and wave swept, and some inside regions, such as Dogfish Banks, experience sediment transport and shoreline erosion due to wind-forced waves. Inside channels and inlets are much more protected from waves and winds, and along many of these channels the trees extend right down to the high-tide line. Tidal currents range from the world’s strongest to almost nil, with varying impact on the biota.

Inflow of major rivers is mainly into Chatham Sound and Observatory Inlet in the north, and into Fitz Hugh Sound on the central coast. Fresh waters flowing into Queen Charlotte Strait are considerably mixed with salt water by the time they reach this strait. Freshwater input from shorter rivers and directly onto the three main basins is considerable, and has to be accounted for in any balance of freshwater input. Tidal and wind-forced mixing of fresh water with sea water is hugely variable and determines many of the high primary production regions in PNCIMA, as noted later. See Appendix C for more information on the oceanography of PNCIMA.

These physical processes determine the ecosystem structure. Each of these physical inputs changes in nature and strength throughout PNCIMA, so that the ecosystem itself differs throughout this area. Despite these areal shifts, we present below a brief summary of the general features common to much of PNCIMA, with individual areas discussed later.

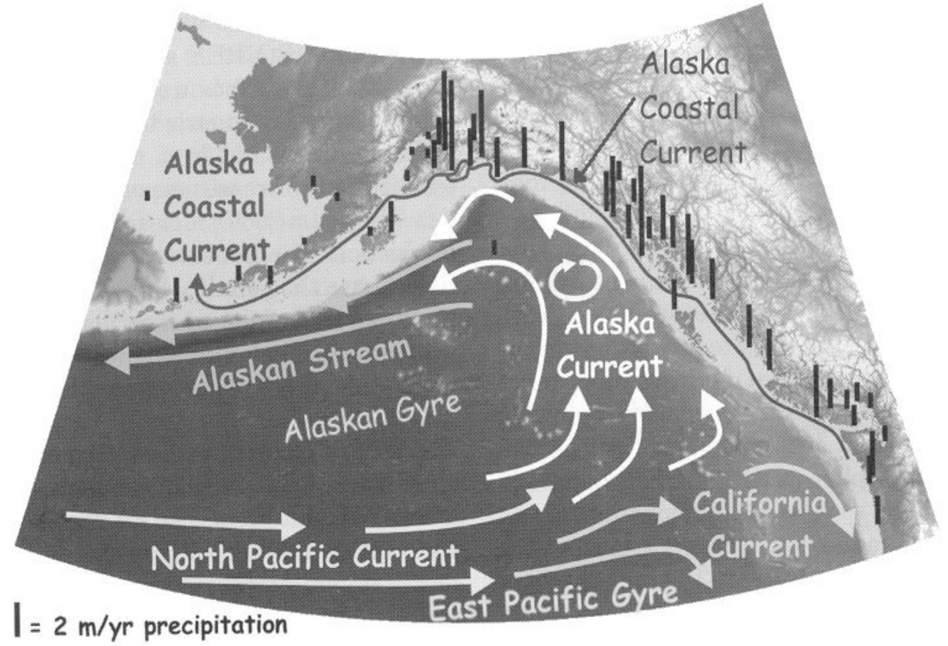


Figure 1.1 Surface circulation fields in the Gulf of Alaska (arrows) and average annual precipitation totals from coastal stations and the central gulf (black vertical bars) (adapted from Mundy and Olsson 2005 after; Baumgartner and Reichel 1975).

What regulates the biological productivity of this marine region?

The PNCIMA region is productive of plankton, fish and invertebrates. Ware and Thomson (2005) examined the primary productivity (growth rate of phytoplankton per year) of coastal NE Pacific and BC marine ecosystems, and concluded that resident fish yield was significantly correlated with the amount of primary production that was retained in these areas by physical processes. Using satellite observations of surface chlorophyll *a* concentrations for BC waters (Figure 1.2) from 1998 to 2005 as a proxy for the rate of primary production, and observations of zooplankton biomass and the total catch ("yield") of resident fish, they calculated that a significant linear relationship existed between mean average chlorophyll *a* concentration (in mg m^{-3}) and average annual resident fish yield (in metric tons km^{-2}):

$$\text{Long-term Fish Yield} = 0.08 + 0.437*[\text{chl.}a] \qquad (r^2 = 0.76, P = 0.015) \qquad (1)$$

This equation suggests that a sustained doubling of the annual average chlorophyll *a* concentration would lead to an approximate doubling of the annual yield (catch) of resident fish species. Resident fish species were defined to exclude species such as Pacific hake, Pacific sardine, and pink, chum, sockeye, and coho salmon, which are believed to reside or pass through the PNCIMA marine ecosystem for only short periods of their life.

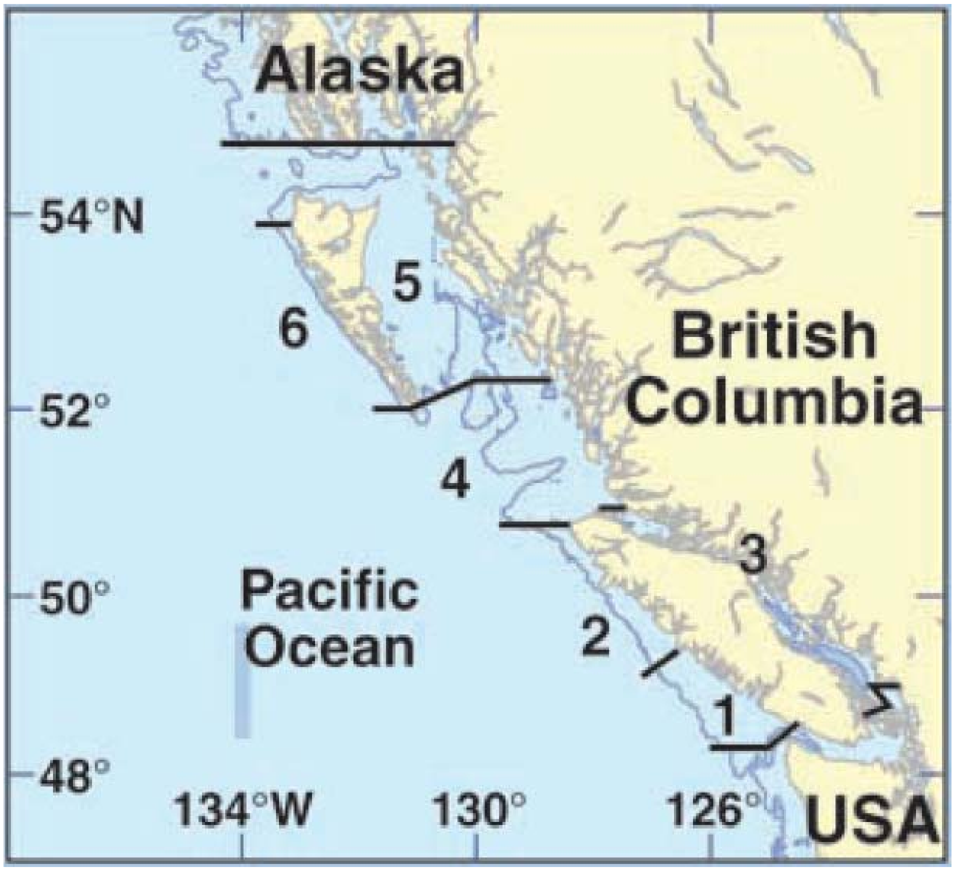


Figure 1.2 Regions of the BC coast examined by Ware and Thomson (2005) for comparisons of primary production and resulting catches of resident fish. 1: southern Vancouver Island shelf; 2: northern Vancouver Island shelf; 3: Strait of Georgia; 4: Queen Charlotte Sound; 5: Hecate Strait; 6: west coast Queen Charlotte Islands (from Ware and Thomson 2005).

For the coastal waters of BC, the relationship of chlorophyll to zooplankton (in mg dry weight m^{-3}) was not linear, whereas that between zooplankton and the long-term catch of resident fish was linear (Figure 1.3):

$$\text{Zooplankton} = 46.57 * [\text{chl.}a]\ 0.488 \qquad (r^2 = 0.85) \qquad (2)$$

$$\text{Long-term fish yield} = 0.055 * \text{Zooplankton} - 1.98 \qquad (r^2 = 0.79) \qquad (3)$$

This suggests that the amount of zooplankton in BC waters, and the subsequent amount of fish, can be estimated (on a long-term annual basis) from the amount of phytoplankton that is produced each year.

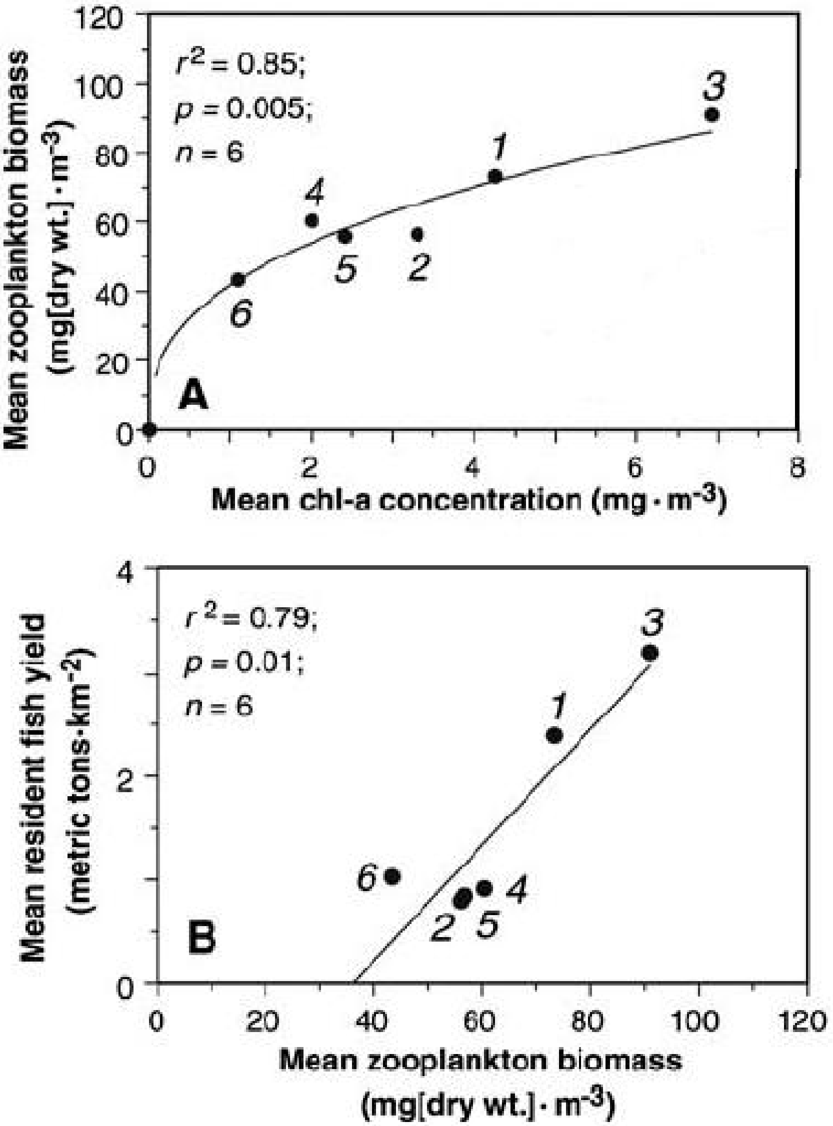


Figure 1.3 Relationships of chlorophyll *a* biomass to zooplankton biomass (top) and between mean zooplankton biomass and mean yield (catches) of resident fish populations (bottom) for the six regions of the British Columbia coast (see Figure 1.2) identified by Ware and Thomson (2005).

When compared among eight geographic regions from southern California to Kodiak, Alaska (Figure 1.4), Ware and Thomson (2005) found that the "Charlotte" region (equivalent to the PNCIMA shelf region) ranked sixth in terms of mean annual chlorophyll *a* biomass per unit surface area (with the region west of Vancouver Island ranking first). However, this "Charlotte" region ranked third in terms of its long-term annual fish yield per unit surface area, after the Vancouver Island and Columbia regions (Table 1.0). Ware and Thomson (2005) suggested that the higher fish yield per unit of chlorophyll in this "Charlotte" region is because more of this chlorophyll is retained on the continental shelf as a result of reduced upwelling compared with regions further south due to the presence of the Queen Charlotte Islands that form a barrier to movement of water into the deep ocean.

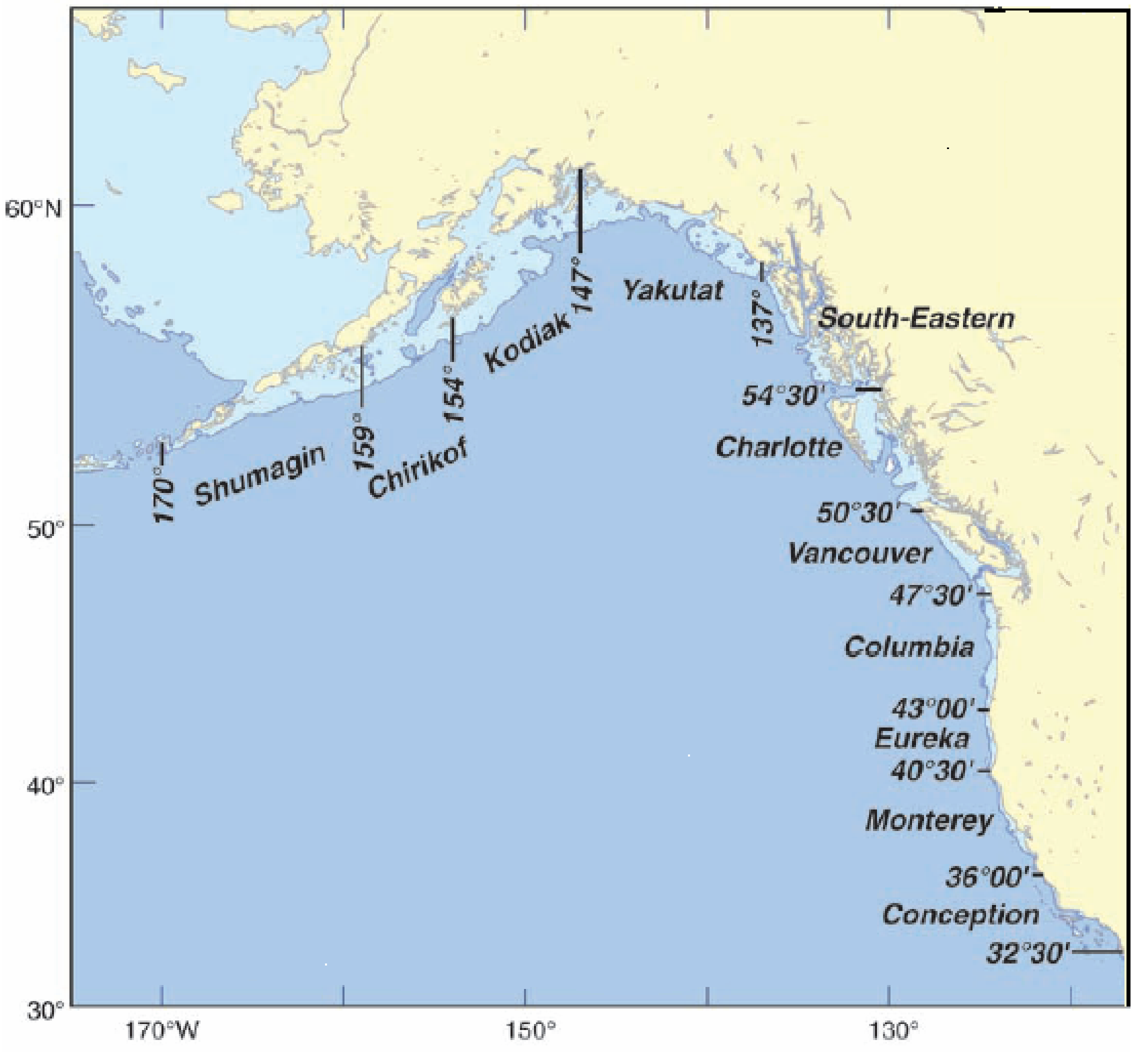


Figure 1.4 Regions of the coastal NE Pacific considered by Ware and Thomson (2005) for relationships between chlorophyll *a* biomass and long-term annual fishery yield of resident fish stocks (from Ware and Thomson 2005).

Table 1.0 Mean annual chlorophyll *a* concentrations (with temporal coefficients of variation for the period 1998-2003 in parentheses) and long-term annual fishery yields of resident species for various coastal regions of the NE Pacific (see Figure 1.2 and Figure 1.4)(from Ware and Thomson 2005).

Region	**Surface area (km^2)**	**Chl-*a* ($mg\ m^{-3}$)**	**Resident fish yield ($t\ km^{-2}$)**
Conception	60,046	1.38 (0.57)	0.06
Monterey	41,613	2.29 (0.54)	0.45
Eureka	18,692	2.20 (0.86)	0.66
Columbia	36,573	3.24 (0.68)	0.88
Vancouver	34,688	5.15 (0.66)	1.97
Charlotte	82,769	2.16 (0.69)	0.79
Southeast Alaska	43,342	2.79 (0.80)	0.60
Yakutat	76,430	1.57 (0.63)	0.27
British Columbia			
S. Vancouver Island (1)	11,312	4.25 (0.70)	2.39
N. Vancouver Island (2)	10,099	3.30 (0.71)	0.85
Strait of Georgia (3)	8,803	6.92 (0.57)	3.19
Q.C. Sound (4)	31, 408	2.00 (0.71)	0.92
Hecate Strait (5)	44,158	2.41 (0.68)	0.80
West coast Q.C. Islands (6)	7,203	1.10 (0.69)	1.03

When analysed at the finer spatial scale of six BC coastal regions (Figure 1.2), Ware and Thomson (2005) found that on a per unit surface area basis the three northern regions (Queen Charlotte Sound, Hecate Strait, west coast Queen Charlotte Islands) had below the average ($3.34 \pm 2.08\ mg\ m^{-3}$) chlorophyll *a* mean annual biomass for these six regions, and below the average ($1.53 \pm 1.01\ t\ km^{-2}$) long-term fish yield (Table 1.0). Within BC, therefore, ocean productivity is higher in southern BC than in the north, although the data are skewed by the very high chlorophyll *a* concentrations and fish yields on the southwestern continental shelf of Vancouver Island and in the Strait of Georgia.

Overall, these analyses of Ware and Thomson (2005) suggest that the PNCIMA region of the BC coast has moderate annual phytoplankton biomass, but high long-term fishery yields of resident fish populations, compared to other regions from southern California to Alaska. These analyses also indicate that, at least on large spatial scales, zooplankton biomass and higher fishery yields of commercial resident fish populations are directly related to the amount of mean annual primary production and resulting chlorophyll *a* biomass. Therefore, the (partial) answer to the question “What regulates the biological productivity of this region” is phytoplankton production and retention, so that any sustained process or event which changes phytoplankton production substantially will eventually have measurable effects on fish production in these systems. The obvious next question, however, is “What regulates phytoplankton production in this region?”

1.4 SPATIAL AND SEASONAL PATTERNS

We have selected eight sub-regions of PNCIMA based on physical and phytoplankton-related processes that are common to each of these sub-regions. Relevant to this discussion are three figures from Appendix D: Plankton (Figure 1.5). These images show the spatial and seasonal variability of phytoplankton concentrations at ocean surface, as inferred from spectral colour data collected by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor on the American Orbcom satellite. Individual regions in these images are discussed below as they relate to the physical forces of PNCIMA: winds, waves, tides, fresh water, heating and bathymetry.

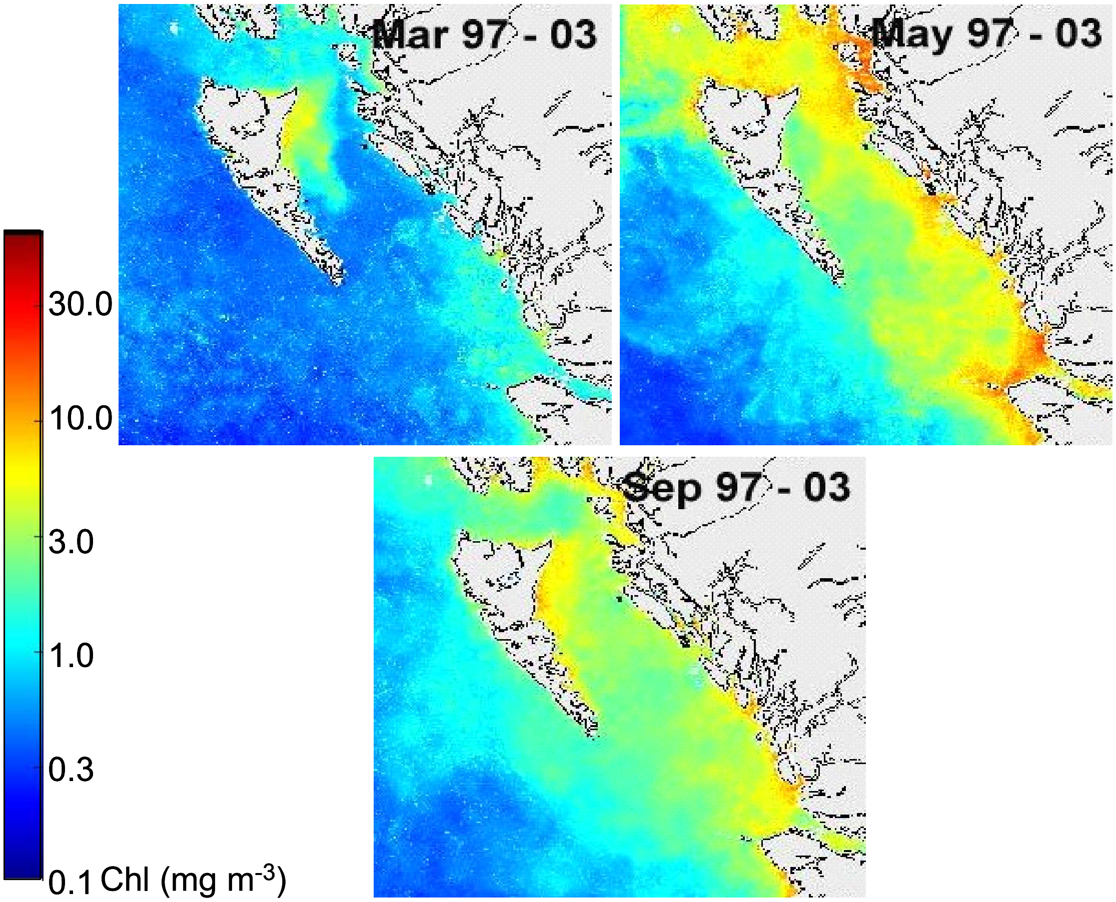


Figure 1.5 Aggregated monthly averaged satellite-derived chlorophyll data from 1997 to 2003 for March, May and September. Data reveal ocean-surface phytoplankton hotspots, and the fact that the shelf is quite productive (>1 mg m^{-3}) from March through to September (A. Peña, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2006).

An interesting seasonal cycle of phytoplankton concentrations in surface waters was detected by the SeaWiFS satellite. Spring phytoplankton bloom first arrives at NE Hecate Strait in March (as described later), then in eastern Hecate Strait and Queen

Charlotte Sound in May, with low plankton concentrations along western Hecate Strait in May. This May pattern partially reverses in September, when the western side of Hecate Strait holds higher concentrations of phytoplankton that the eastern side. We speculate these high spring levels are associated with relaxation of winter downwelling and mixing of outflowing fresh waters with high-nutrient sub-surface waters. By September, outflow of fresh water is at a seasonal minimum, and both downwelling relaxation and upwelling have turned off, dropping productivity along the eastern shore. However, shallow bottom depths along the west side of Hecate Strait might allow the early autumn storms to mix high-nutrient bottom waters to the surface.

The eight sub-regions are:

(a) Campbell River to Port Hardy,
(b) Queen Charlotte Strait to Brooks Peninsula,
(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance,
(d) Cape St. James,
(e) Western Hecate Strait,
(f) Dixon Entrance,
(g) West Coast Queen Charlotte Islands,
(h) Inlets.

(a) Campbell River to Port Hardy

This region comprises the channels of Seymour Narrows, Discovery Passage, Johnstone Strait and the eastern end of Queen Charlotte Strait, as illustrated in Figure 1.0. Tidal mixing gives these channels their unique status. These waters experience extreme tidal mixing, with Seymour Narrows likely holding the world record for most tidal mixing and dissipation in a single narrow channel. Waters are well mixed top to bottom in several hundred metres depth in many portions of these straits, yet these channels support an estuarine circulation. In Johnstone Strait this estuarine circulation is evident in the mean velocity and water properties structure. There is a mean seaward (westward) upper layer flow of about 0.2 $m\ s^{-1}$, strongest on the mainland side due to the Coriolis force, while the mean lower layer flow is landward (eastward) at about 0.1 $m\ s^{-1}$, strongest on the Vancouver Island side (Thomson 1981). As noted above in Section 1.0, these channels and the inlets receive relatively little attention in our report due to lack of ecological data.

They support excellent sports fishing for salmon, especially near Campbell River. This fishing is perhaps due to the containment of salmon in the narrow channels on their return to spawn. Many to most juvenile salmon from the Fraser River transit these channels on their outbound migration.

Because these channels are so well mixed, the primary productivity is expected to be relatively low. Phytoplankton in very turbulent waters spend too little time at surface to support strong blooms. This relatively low productivity is expected to permit the waters that are nutrient enriched by tidal mixing to exit this region into Queen Charlotte Strait with relatively high nutrient concentrations at surface.

Some recent studies have focussed on the Broughton Archipelago, where sea lice impact on pink salmon has been an issue that has stimulated significant research into the relative contribution of natural and fish farm sources of sea lice. These efforts and recommendations for future research are noted by Pennell and Ackerman (2006). This topic should provide a cautionary note on the difficulty in managing natural and aquaculture stocks of fish in the same region. After several years of research the scientific community has not reached consensus on the impact of sea lice from fish farms on the wild stocks of pink salmon (Pennell and Ackerman 2006). We refer readers to the ongoing research efforts in the Broughton Archipelago rather than attempt to provide another summary here.

(b) Queen Charlotte Strait to Brooks Peninsula

These waters follow the northern shore of Vancouver Island, starting at the eastern end of Queen Charlotte Strait, through Gordon Channel, Cook Bank, Scott Islands, and finally along the west coast of Vancouver Island south to Brooks Peninsula (Figure 1.0). This region is marked by relatively high phytoplankton concentrations in May and September, as revealed by SeaWiFS imagery in Figure 1.5, which can be attributed to a combination of winds, tides, and nutrient input from inlets and channels. The individual physical features are:

- well mixed outflow in a thick surface layer from Johnstone Strait and Broughton Strait,
- fresher outflow in a shallow surface layer from Fitz Hugh Sound and Smith Sound,
- strong SE winds in winter and weaker NW winds in summer,
- tidal mixing at and near the Sea Otter Group of islands, as well as near the reefs and small islands between the Sea Otter Group and the mainland,
- tidal mixing over Cook Bank and near the Scott Islands,
- offshore-directed cold plumes from the Scott Islands and Brooks Peninsula in summer.

Compared to other PNCIMA regions, this highly productive region has lower retention of surface waters and their biota due to the westward flows over Cook Bank past Scott Islands in spring and summer when winds blow from the north.

Figure 1.6 presents satellite images of surface water temperature of this region in spring and summer.

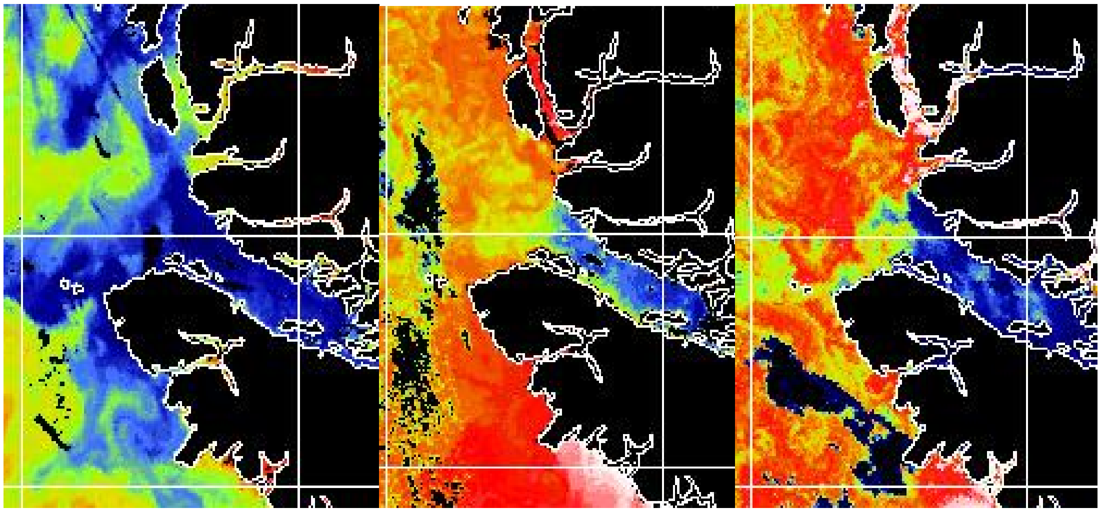

(a) 19 May 2002 (b) 23 July 1994 (c) 21 September 1993

Figure 1.6 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Centre image is from the same day presented in Figure 1.7.

These three images of Figure 1.6 each show cooler water in Queen Charlotte Strait, likely due to cold outflow from channels to the SE. Nutrient measurements in summer reveal these waters of Queen Charlotte Strait to be rich in nitrate, with levels over 10 μM being among the highest observed in PNCIMA (Appendix C, Figure C.23). Comparison of nitrate and temperature images shows the highest nutrients in the coldest waters, supporting the concept that deep cold waters brought to the surface have highest nitrate levels. By contrast, the outflow from Fitz Hugh Sound and Smith Inlet is often warmer than surrounding waters, perhaps due to the presence of sediments to absorb sunlight, and to the shallow depth of this surface freshwater plume. Chlorophyll images of Figure 1.5 suggest highest concentration of phytoplankton in May are in the portion of the outflow from Fitz Hugh Sound closest to the cold waters from Queen Charlotte Strait. We can speculate these are where these two water masses mix, providing maximum surface nutrients and thinnest surface layers, both leading to high phytoplankton growth rates. The strong tidal flows and tidal mixing near the Scott Islands likely provide additional input of nutrients to surface waters to support the seabird colonies on the Scott Islands.

In summer we often observe westward flowing plumes of coastal (cool) waters into the Pacific, from regions at and between Brooks Peninsula and the Scott Islands. These are expected to have been set up by NW winds piling up water along the north shore of Vancouver Island. Current meters set on Cook Bank in the 1980s showed accelerating westward flow when winds blew from the NW, and accelerating eastward flow with winds from the SE, providing support for the causes of these plumes. Surface drifters deployed in spring and summer in Queen Charlotte Sound in the 1990s drifted to the south and southwest during the prevailing winds from the northwest. Many of these drifters departed Queen Charlotte Sound to the southwest, or grounded on Vancouver Island (Crawford *et al.* 1999). However, not one of the drifters that departed Queen Charlotte Sound grounded on Vancouver Island south of Brooks Peninsula, or even came close to shore here. This behaviour suggests little transport of free-floating life south from PNCIMA to shores south of PNCIMA along the west coast of Vancouver Island.

(c) Eastern Queen Charlotte Sound, Hecate Strait and Dixon Entrance

Storm winds of winter push flow alongshore at all depths along this region, and contain much of the fresh water up against the eastern islands (Figure 1.0). Return flow to the south is found at depth along the western sides of Hecate Strait, and is considered to be the source waters for Haida Eddies that form off SW Moresby Island in winter.

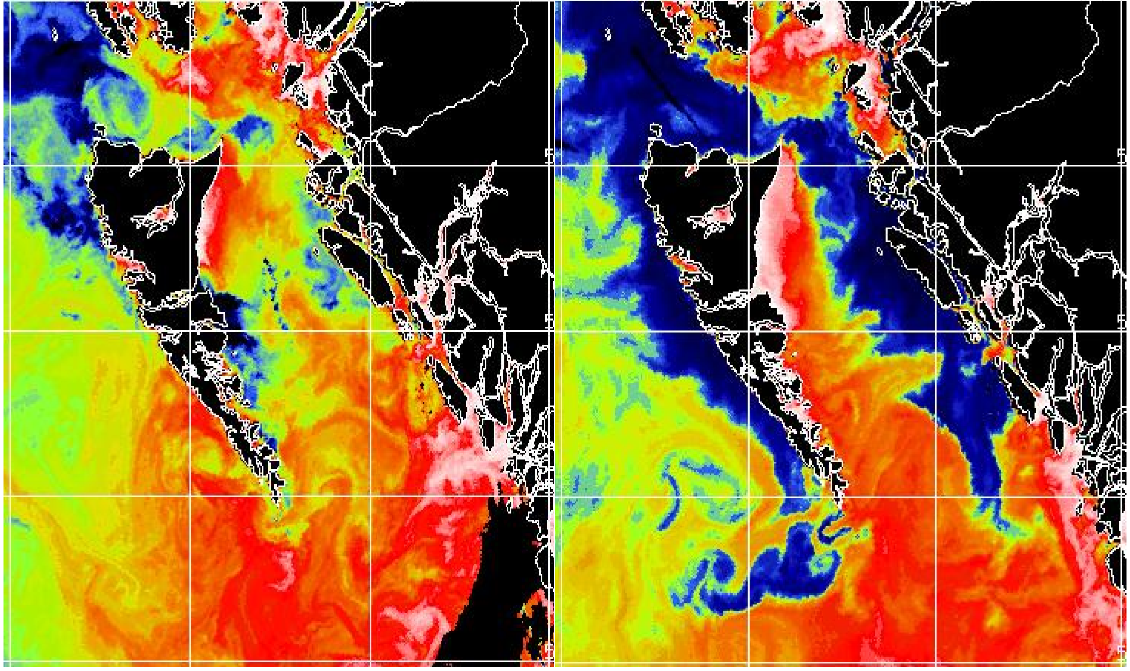
Bottom waters of the troughs of this system are warmest in winter, and may account for the winter spawning of many species of fish: Pacific cod for example. However, other factors such as food availability in spring can also be important. It is speculated that an eddy forms over North Bank in winter, and this eddy allows many of the ichthyoplankton of Pacific cod and other species to remain in Hecate Strait-Queen Charlotte Sound through the winter. This eddy would redirect to the north a portion of the return southward flow along the west side of Hecate Strait. Winter winds mix nutrient-rich water up from the bottom or near bottom, and when combined with Ekman downwelling, account for ample nutrient supply to all depths here in winter.

The high phytoplankton concentrations, noted above to lie between Fitz Hugh Sound and Cook Bank in May, are matched only by the high levels in Chatham Sound. These two regions receive the strongest outflow of fresh waters in spring, so we expect this outflow is linked to high chlorophyll concentrations. The Skeena River plume in Chatham Sound might mix with nutrient-rich waters below to produce the shallow, nutrient-rich surface layer needed for phytoplankton growth.

The Chatham Sound region of highest phytoplankton concentrations in May actually extends into northern Hecate Strait. This region receives Skeena Plume waters after they mix with deeper waters in Brown Passage and Edye Pass. Such mixing might provide the nutrient-rich, shallow surface layer to stimulate productivity. However, many other processes could enrich these waters, and we do not wish to speculate further.

The central coast between Fitz Hugh and Chatham sounds (Figure 1.0) receives lesser flows of freshet waters, and the May chlorophyll images of Figure 1.5 reveal lower concentrations of phytoplankton in surface waters than in Chatham Sound and near Fitz Hugh Sound. Deeper colder water progressively penetrates into Queen Charlotte Sound and Hecate Strait troughs in spring through late summer, attributed first to relaxation of winter downwelling, then to some extent in mid-summer to upwelling winds blowing from the north along these straits. These deep waters are nutrient-rich, providing food for all bottom life including sponge reefs.

Along this eastern side of the region during spring and summer, higher surface concentrations of chlorophyll are maintained by an estuarine-like circulation effect driven by freshwater runoff from the coastal mountains and inlets (F. Whitney, DFO, Institute of Ocean Sciences, Sidney, BC, pers. comm., 2006). In this process, the summer relaxation of the winter downwelling winds and/or weak summer upwelling brings the deep nutrient-rich waters close to the surface where it is available for phytoplankton growth by entrainment into the brackish surface flows over the saltier water. Energy for entrainment can be provided by tides or winds. These colder waters are clearly present in Figures 1.7b and 1.7c.



(a) 26 May 1993

(b) 23 July 1994

(c) 4 September 1993

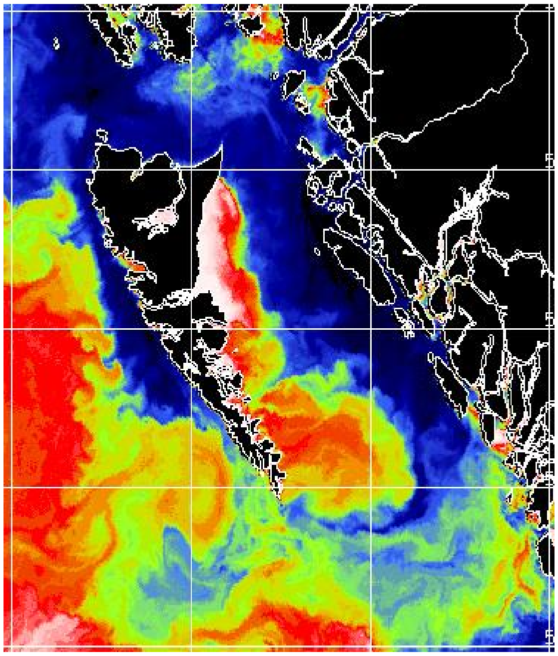


Figure 1.7 Sea surface temperature (SST) images of observations by AVHRR sensor on NOAA satellites. White denotes warmest SST, followed toward cooler waters by red, orange, yellow, green, blue, dark blue. Colour scale is adjusted to present best colour contrast on each day, and differs between images. Land and clouds are black; shoreline is white; airplane contrails appear as dark blue streaks. Image (b) is from the same day presented in Figure 1.6, with slightly different colour scale.

Phytoplankton concentrations along this central eastern coast decrease through summer, despite the occurrence of strongest upwelling winds in July. Therefore it is not a combination of upwelling winds and freshet that account for the high phytoplankton concentrations in May in surface waters of this eastern coast. More likely it is the rich nutrients stirred to surface in winter that trigger this spring bloom, as occurs elsewhere in mid-latitude oceans. In this case, the rich phytoplankton concentrations seen by satellite in Chatham and outside Fitz Hugh sounds are attributed mainly to the shallow surface layer in the fresh water plumes.

(d) Cape St. James

Waters near Cape St. James deserve their own category. Flow at this cape exerts huge impact on primary and secondary productivity of surrounding waters, yet this impact is not observed in SeaWiFS imagery. Several factors are at play here:

- deep waters with very strong tidal mixing,
- persistent outflow from Hecate Strait past this cape,
- formation of Haida Eddies by winter outflow past this cape,
- close proximity of deep inflow to Hecate Strait.

Studies in the 1990s revealed strong and persistent outflow of surface water from southern Hecate Strait into the Pacific Ocean. This flow is confirmed to within 15 km of Cape St. James. Therefore any flow from Hecate Strait to the open Pacific Ocean passes close by this region. Once there, it mixes thoroughly with surrounding oceanic waters, forming cold surface plumes visible in satellite imagery for up to 120 km away from the cape. These plumes occasionally re-circulate at surface into Queen Charlotte Sound, as noted in drifter tracks (Crawford *et al.* 1995) and also in satellite imagery in Figure 1.7a (inflow appears as a relatively warm plume headed to the NE). This recirculation might be even stronger in sub-surface flows. The deep channel of Moresby Trough is close to this cape, so inflowing waters will likely entrain some of the waters mixed at the cape. Finally, the strong winter outflow from Haida Eddies can hold as much as the entire water volume of Queen Charlotte Sound and Hecate Strait combined. Fisheries and Oceans Canada (DFO) studies in the oceanic NE Pacific have found coastal species of zooplankton and nutrients in these eddies, as well as much of the winter supply of heat and fresh waters entering these two basins. Clearly Haida Eddies transport coastal waters and their properties out to 1000 km or more from this cape.

Given this high mixing rate, the lack of high chlorophyll concentrations observed by SeaWiFS need some explanation. We speculate on relevant factors here. Despite the strong mixing at this cape, there is no supply of fresh water to keep this mixed water at the surface, so much of the mixed water will sink below the euphotic zone. This lack of chlorophyll here underlines the need for fresh water in estuaries and coastal regions to support high productivity in mixed waters. Secondly, nutrient-rich water mixed to the surface here will advect away from the cape with two days and enter another domain. So phytoplankton spend too little time in this region and near the surface for primary productivity to develop.

(e) Western Hecate Strait

This is another unique region of PNCIMA. In an area of deep rocky fjords the shallow banks of this region offer unique ecology. For example, a rich supply of sediments is provided to NW Dogfish Banks by the eroding adjacent shores of eastern Graham Island. This shoreline erodes more rapidly than any other in Canada. Interestingly, second highest tides of BC are found here (tides at the head of Portland Canal are highest), and strongest wave-generated ocean mixing. Indeed, the combination of tidal mixing and wave-forced mixing keeps portions of this bank well mixed at almost all times. Lack of deeper cool water in summer, and deeper warmer water in winter assures this region is coldest in winter and warmest in summer of all PNCIMA regions on the continental shelf.

Biologically, this region is usually linked to McIntyre Bay in SE Dixon Entrance, due to the high concentrations of Dungeness crab in these two regions. McIntyre Bay is accreting, perhaps as the recipient of Dogfish Banks sediments or possibly locally derived sediments. We speculate that the presence of Dungeness crab are more likely due to the broad shallow banks than to any other factor. Their abundances go up and down over the years, with little predictability.

SeaWiFS imagery of Figure 1.5 shows that Dogfish Banks and the nearby regions of McIntyre Bay are the first to experience plankton blooms in spring, with strong growth in March. Although this season also experiences high sediment loads in surface waters here, the satellites are able to detect the unique spectral levels of plankton in reflected daylight, and these signatures indicate high levels of chlorophyll here.

This early development of chlorophyll biomass is predictable from knowledge of nutrient dynamics and the potential depth of vertical mixing. Higher chlorophyll concentrations over Dogfish Banks in northwest Hecate Strait occur because the depth of vertical mixing is limited by the shallow depths of the bottom, whereas in deeper areas winds are able to mix the water column, and its constituent phytoplankton cells, below the critical depth for phytoplankton blooms to occur (Perry and Dilke 1986). By May, the nutrients on the shallow bank are exhausted and phytoplankton concentrations decline. In addition, there appears to be little exchange of waters between Dogfish Banks and deeper regions to enable import of nutrients (Crawford *et al.* 1998). Deep areas have a greater store of nutrients, and in many cases import nutrients and are able to maintain higher phytoplankton concentrations later into the spring, especially along the frontal regions in this area (Perry *et al.* 1983).

Waters along the southwest side of Hecate Strait are deeper than on Dogfish Banks and only in September do the SeaWiFS images reveal more than average concentrations of phytoplankton. Lack of plankton in May might be due to lack of freshwater plumes to form shallow, nutrient-rich surface layers, since little runoff flows from the Charlottes compared to other shores.

(f) Dixon Entrance

In a region of north-south channels this strait clearly offers a unique aspect to PNCIMA. It is the deepest of the three basins, and its deep central axis extends into Clarence Strait and US waters to the north. Deep flows here are directed eastward year-round. But its most unique feature is the Rose Spit Eddy north of Rose Point at the NE corner of Graham Island. This feature was noted in early water property surveys of the region (Crean 1967), and also in the Hecate hydraulic model built in the 1960s at Pacific Biological Station (PBS) in Nanaimo. Several oceanic studies of the 1980s and 1990s observed this eddy in tracks of near-surface drifters and in dynamic height anomalies in both summer and winter. Finally, satellite images of sea surface temperature offer evidence for its existence. These numerous studies are offered as evidence, because theoretical and numerical studies offer only weak evidence for its presence. In physical oceanographic terms, this strait is sufficiently wide that the estuarine flow here will be out on the north side and in on the south side, both at surface, rather than out on the surface and in at subsurface depths as found in more narrow channels. With the Skeena River and Nass River plumes flowing usually to the north of Chatham Sound, and these outward and inward estuarine flows on the north and south sides of Dixon Entrance respectively, only a southward flow in the west is needed to complete the eddy. Forcing for such a flow is provided by NE winds in summer.

The eddy leaks considerable water, with outflow directed to the NW past Forrester Island or to the SW past Langara Island. Generally only one or the other of these routes is taken at any one time, with some evidence of influence of the wind on choice of routes (Crawford and Greisman 1987).

A second interesting feature is the strong internal semi-diurnal (twice-daily) tidal currents in Dixon Entrance, up to 60 cm s^{-1}, and much stronger than expected for the range of tides present. Internal tides are due to up-and-down motion of sub-surface waters in this basin, and are expected to be set up along the narrow ridge that runs through Celestial Reef in eastern Dixon Entrance.

(g) West Coast Queen Charlotte Islands

Here we have yet another unique region of PNCIMA, also unique to the North American West Coast. The continental shelf west of Moresby Island is the narrowest of British Columbia, with the least freshwater input. The shelf west of Graham Island is somewhat wider, with somewhat more freshwater input. Both coasts experience extreme pounding by winter waves. So it is not surprising that fisheries here are mainly for deep-water species along the continental slope. The remoteness of this region and numerous small islands allow seabird colonies to thrive.

(h) Inlets

As noted earlier, this overview does not include detailed consideration of inlet and fjord waters, largely because there is insufficient data in these areas and each inlet requires its own study. The inlets in PNCIMA are numerous, and require more attention for environmental assessment. Many inlets (Knight, Rupert, Neroutsos, Observatory, Seymour, and Rivers inlets, Alice and Kitimat arms, and Fitz Hugh Sound) have been studied for assessment of specific industries or fisheries issues.

These inlets are deep with slow tidal currents, and considerable freshwater input. As a result, the outflow plumes of fresh water are shallow, often 1-5 metres deep, and often form shallow outflows into Hecate Strait, Queen Charlotte Sound and Dixon Entrance, as well as the outer coast. Knight Inlet in the south has been the subject of many detailed studies of tidal flow and mixing at its sill, and this information is available for application to other inlets. However, mixing and biological processes in each fjord depend on the depth, shape and position of the sills, as well as prevailing wind directions, complex geography of the inlet, and freshwater input. Each inlet can be considered unique.

A case of interest is the abrupt decline of Rivers Inlet salmon populations in the late 1990s. Although there have been numerous studies of this region since then, the factors influencing this run are not well known. McKinnell *et al.* (2001) provided evidence that the collapse of some stocks within PNCIMA was due unknown events that influenced marine survival (see Appendix I: Salmon). This example, together with the continuing conflict over sea lice and fish farms in Broughton Archipelago, should warn us of the difficulties in assigning anthropogenic and natural causes of ecosystem change in PNCIMA before, during and even after human impact on this area.

1.4.1 Linkages to Zooplankton and Fish

Zooplankton are known to aggregate on bathymetric edges likely as a result of convergent processes but also partially in response to higher phytoplankton concentrations. There have been few direct observations of zooplankton distributions in PNCIMA, certainly in comparison to southwest Vancouver Island. However, as inferred from distribution patterns observed elsewhere and a limited amount of field data, euphausiid concentrations should be highest on the continental slope and along the margins of the deep troughs in Queen Charlotte Sound (see Appendix D: Plankton).

Within PNCIMA, groundfish are most abundant in Goose Island Trough, near Cape St. James, and at the southeast end of Dixon Entrance. Other significant aggregations are seen along bathymetric edges around Goose Island and Middle banks (North Bank) as well as the northern edge of Moresby Trough (Figure 1.8). This distribution pattern is supported by results of groundfish bottom trawl surveys (A. Sinclair, unpublished data). The DFO trawl survey program has recently been expanded to include Queen Charlotte Sound and to provide greater coverage of Dixon Entrance and Hecate Strait. While the dataset is much less extensive than that from the commercial fishery, the surveys provide information from areas not normally fished.

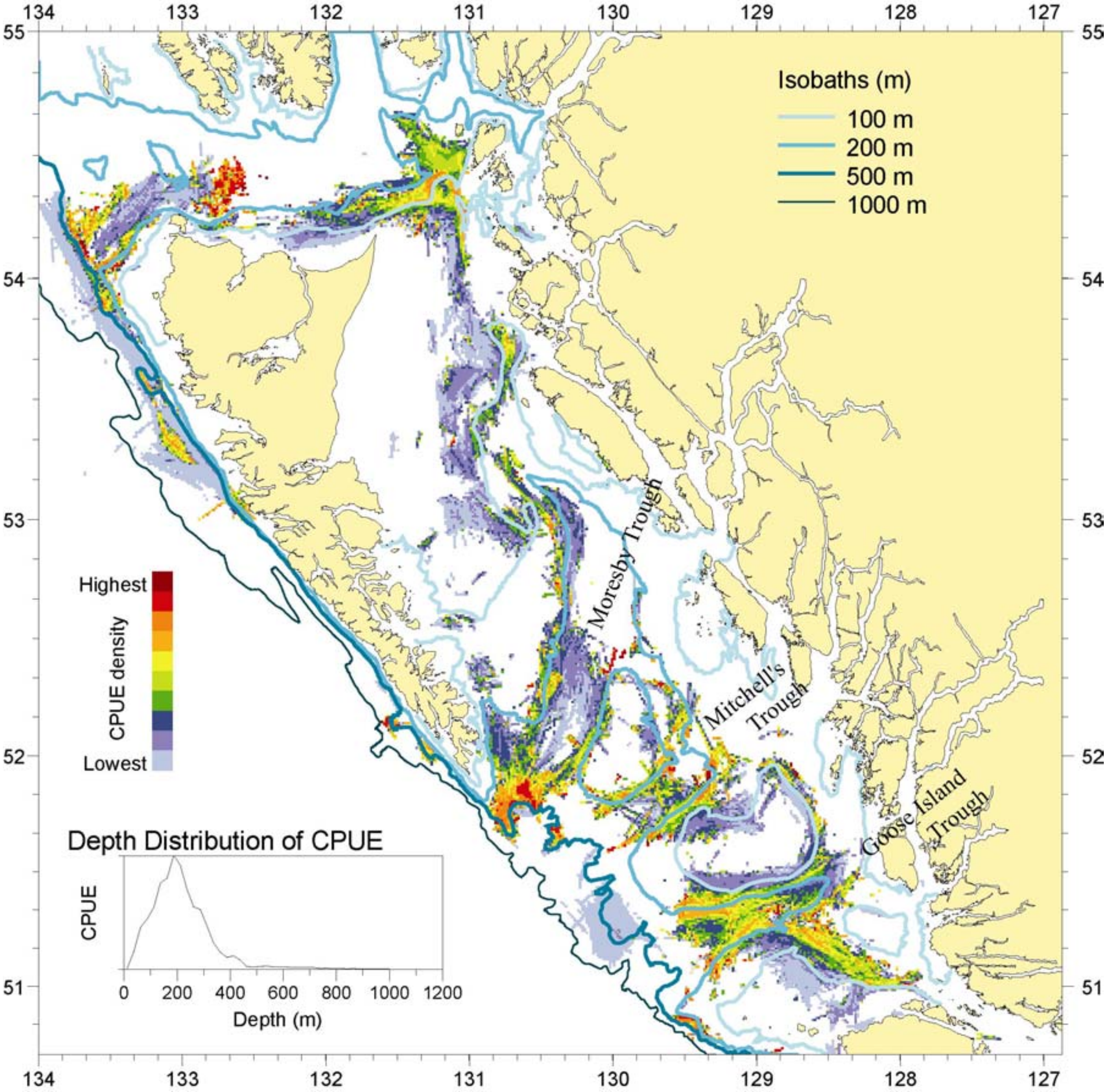


Figure 1.8 Spatial distribution of groundfish catch per unit effort (CPUE) in the bottom trawl fishery in PNCIMA, 1996-2004. It was assumed that CPUE is an index of relative biomass. The data were plotted using a 1 km^2 grid. The grids were colour coded by decile of the cumulative distribution, with the highest density coloured red and the lowest light blue. The line graph shows the depth distribution of CPUE (from Sinclair *et al.* 2005).

The main concentrations in Goose Island Trough and southeast Dixon Entrance are adjacent to the areas of highest phytoplankton concentrations. The combinations of estuarine flows in these two areas and the existence of bi-directional flows provide the mechanisms for enrichment from primary production, concentration of food supply, and retention of particles in these areas to explain the high abundance of fish there. In contrast, the central and southern portions of Hecate Strait at depths less than 100 m have lower fish biomass, are further away from an abundant source of primary production, and have relatively uniform bathymetry with fewer bathymetric edges to support large concentrations of euphausiids.

The Cape St. James area is the convergence of several flows that could concentrate food supply. As long as a feeding fish can maintain its position against the currents in this area, it will receive a much higher contact rate with food particles than in many other areas in PNCIMA.

There is much less information on the distribution of pelagic species. Pacific herring and Pacific sand lance are known to be abundant in PNCIMA. The distribution of herring spawning grounds are well known (see Chapter 2, section 2.5.1, Map 2.12, and Appendix H: Pelagic Fishes, Section 2.0), however their distribution during the feeding period of their life cycle is poorly understood. Both species are caught in bottom trawl surveys, but are poorly represented relative to their abundance in nature and relative to groundfish species for which the surveys were designed. Catches of both species are higher in Hecate Strait than in Queen Charlotte Sound. This is likely because the depths in Hecate Strait include more seafloor of the appropriate depth for these species. Within Hecate Strait, these pelagic species appear to be more abundant in the northern area than to the south. Thus, within Hecate Strait at least, the distribution of pelagic species is similar to that of groundfish.

The overlap in euphausiid and fish distributions is unlikely to be coincidental, but rather a clear trophic linkage. Both are influenced by bathymetry, which influences circulation, which is driven by tides and wind, and enhanced by the estuarine circulation.

1.4.2 Species Richness

The recent expansion of synoptic groundfish bottom trawl surveys in PNCIMA provides a new source of information on species richness in the area. The mean numbers of fish species taken per survey tow in the period 2003-2005 are plotted in Figure 1.9. The highest species richness values were seen adjacent to the southern central coast area and through Goose Island trough. These areas have a large range of habitat types including rugged reefs, highly variable bathymetry, exposed bedrock, as well as patches of smoother mud, sand, and gravel. The lowest species richness values occurred over the shallow banks (Goose Island, Middle, Dogfish) as well as in McIntyre Bay north of Graham Island. These areas have a more homogeneous habitat type dominated by outwash sand and gravel.

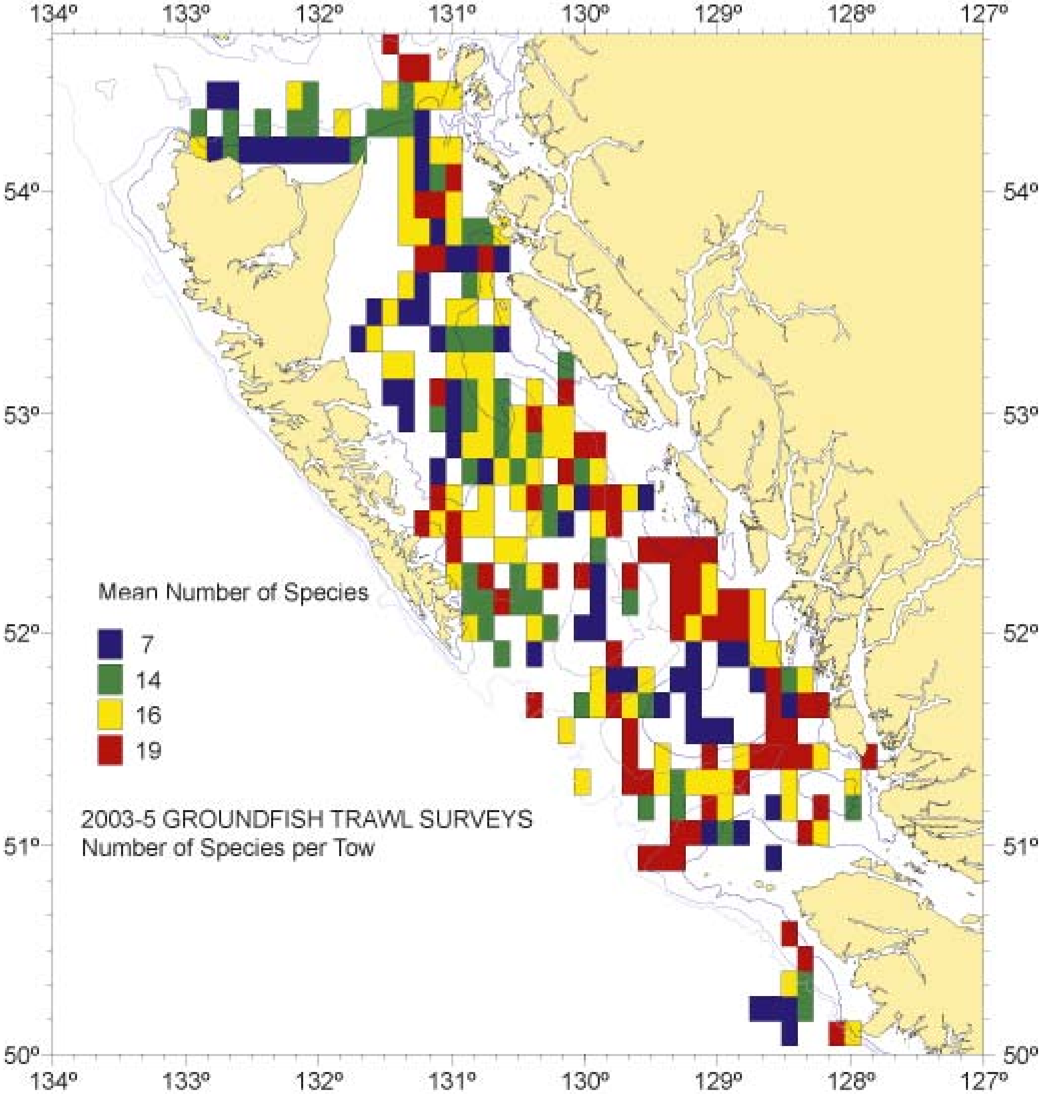


Figure 1.9 Spatial distribution of fish species richness (mean number of species per tow) sampled by bottom trawl surveys in PNCIMA 2003-2005. The grid cells were coloured according to the quantiles of the overall distribution. Cells with the highest richness are red, the lowest richness are blue.

1.4.3 Species Distributions

Sinclair *et al*. (2005) examined associations between surficial geology and the distribution of 21 groundfish species caught in bottom trawl fisheries in PNCIMA. Three main groups emerged. The first included shallow water species distributed over sand and gravel habitat that is exposed to considerable disturbance and reworking from tidal and storm energy. The species were rock sole, big skate, English sole, spotted ratfish, Pacific halibut, lingcod, Pacific cod, and petrale sole. This habitat type is likely to be less susceptible to anthropogenic disturbance. These species tended to have relatively short life spans and had the fastest growth rates. A second group occupied deeper waters and a soft silt and mud bottom type that was less exposed to disturbance from natural causes. The species were longnose skate, arrowtooth flounder, spiny dogfish, rex sole, sablefish, and Dover sole. Given the finer sediments and less exposure to natural disturbance, this habitat may be more susceptible to anthropogenic disturbance than the former. These species had intermediate life spans and growth rates. The third group was in deep water over firm glaciomarine mud and glacial till habitats. All species in this group were from the genus *Sebastes* (including boccacio, yellowtail, silvergray, rougheye, redbanded, yellowmouth rockfish and Pacific Ocean perch) and were the slowest growing and longest lived group. A fourth group could be added to this list of species/geological associations, the inshore rockfish species which includes copper rockfish, quillback rockfish, and yelloweye rockfish. These species are taken in hook-and-line fisheries in shallow coastal reef areas. These habitats are often covered with thick epifauna and macrophyte communities that provide a buffer from natural forces such as waves and storms. However, the epifauna and macrophytes are highly susceptible to anthropogenic removal. As with the other *Sebastes* species, these have long life spans and slow growth rates. An interesting fifth component is the Dungeness crab which is found in abundance in the shallowest area of northern Hecate Strait and McIntyre Bay where the sand bottom is constantly being reworked by tides and storms. This species has a shortest life history and fastest growth rate of all the species listed here, surviving for only five to six years.

The general pattern here is for species with greater scope for growth, *i.e.,* high growth rates and short life spans, to occupy habitats that are more resilient to disturbance.

1.5 TROPHIC CONNECTIONS

Three general food web systems can be defined for the PNCIMA region: phytoplankton-based systems; nearshore (macrophyte)-based systems; and detritus-based systems. Strictly speaking the latter (detritus-based) systems are also derived from phytoplankton or macrophyte production, but enough marine organisms feed directly or indirectly on detritus to warrant its own food web, at least in the context discussed here. Almost nothing is known about the microbial loop in this region, although studies have been conducted to the south off Vancouver Island and in the Strait of Georgia. Elsewhere and on theoretical grounds it has been suggested that the microbial loop can divert an important fraction of primary productivity away from higher trophic levels. If some of this microbial production does make its way to higher trophic levels, it does so by increasing the number of trophic links, which decreases the efficiency of the transfer of energy, thereby decreasing the overall production of these higher trophic levels (Ware 2000).

Information on plankton and detritus-based food webs in the PNCIMA region is largely based on direct observations of stomach contents (mostly from groundfish and some pelagic species) and on model studies using ECOPATH (Christensen and Walters 2004). There are several significant unknowns in both of these approaches to food-web analyses. Direct observations are effort-intensive, and tend to be conducted for only a short period of time on selected surveys. They rarely provide extensive coverage of species throughout the entire region or in all seasons. Model studies using ECOPATH require values for many parameters for all groups in the model; these are based on observations as much as possible, but adequate data for most species are lacking. Estimates from similar taxonomic groups and from elsewhere are used to provide possible values, and simulation studies are usually conducted to evaluate system sensitivity to key parameters. In addition, marine ecosystems are unusual (compared with terrestrial ecosystems) in that most species go through very large changes in body size, shape, and habitats between egg, larval, and adult stages. Larval and adult stages of the same species could easily be considered as different species, with predators and prey changing roles as they grow. Such complex life history changes are rarely included in food web models or stomach content analyses, but may be important at stabilising or de-stabilising marine ecosystems.

The ECOPATH modelling approach is described by Christensen and Walters (2004). In the model constructed for northern BC (broadly equivalent to the PNCIMA region), 53 functional groups were defined. These groups range, with varying degrees of resolution, from phytoplankton, detritus and macrophytes to copepods and euphausiids, to small and large crabs, to forage fishes, to juvenile and adult stages of pelagic and demersal fishes, to seabirds and whales (Ainsworth *et al.* 2002). These analyses illustrate the clear separation between those groups that feed within a phytoplankton-based food web, and those groups that feed within a primarily detritus-based food web.

Using observations of stomach contents of demersal fishes collected during surveys in 1985 and 1987, Pearsall and Fargo (2007) identified three main types of feeding: benthivores, planktivores, and piscivores. They further identified five main feeding strategies: euphausiid feeders, shrimp feeders, benthic (macro- and meiobenthos) feeders, macrobenthic feeders, and piscivores. They found that benthic feeders showed more stability among locations and seasons in their diets than did piscivores. Ontogenetic variability in diet was also more apparent for the piscivores, with juveniles often feeding to a larger extent on macrobenthic organisms than the adults. Appendices to this report (*e.g.*, marine plants, invertebrates) also present schematic food web diagrams illustrating linkages among various groups of species.

Nearshore systems are defined as those for which organic carbon is largely derived from terrestrial sources and/or macrophytes. These regions are limited by depth, in particular to depths shallow enough for the euphotic zone to support the growth of macrophytes (typically to about 35 m in these coastal regions; Sloan and Bartier 2000). The most important macrophytes in the PNCIMA region are kelps and eelgrasses. Estimates of the productivity of giant kelp (*Macrocystis* sp.) in California found that photosynthesis was greatest near the sea surface, was reduced to 5-10% of this surface value at 4 m depth, and was reduced to 0.5-2% of surface values at 8 m depth (Mann 1982 p.59). Estimates of the daily net production of giant kelp beds in California have found sustained growth rates of 1-4% of biomass per day (Mann 1982 p.59); the production to biomass (P/B) ratio estimated by Ainsworth *et al.* (2002) for macrophytes in northern BC was 5.3 yr^{-1} (the P/B ratio estimated for phytoplankton was 179 yr^{-1}, *i.e.*, over 30 times the growth of macrophytes). However, relative to the area over which phytoplankton are distributed, a rough estimate suggests that phytoplankton contribute substantially (5,000-10,000 times) more primary productivity to the PNCIMA region than do macrophytes.

Macrophyte and terrestrial organic carbon serve as critical food sources for the nearshore food-web. They directly support echinoderm and gastropod mollusc invertebrates such as sea urchins and abalone, which in turn are fed upon by fish and sea otters (where they occur). Macrophytes are also critically important as habitat structure-forming organisms, *i.e.,* kelp and eelgrass beds. These provide surface habitat for crustaceans (such as kelp crabs) and for particular life stages of commercial finfish such as herring eggs. They also create an environment for many species of invertebrates and finfish to live within by providing cover and shelter, in particular for juvenile fishes like herring and salmon. They act to increase the supply of drifting phytoplankton and algae by slowing local currents and generating turbulence.

A schematic example of these plankton, detritus, and macrophyte-based food webs for the PNCIMA region is illustrated in Figure 1.10.

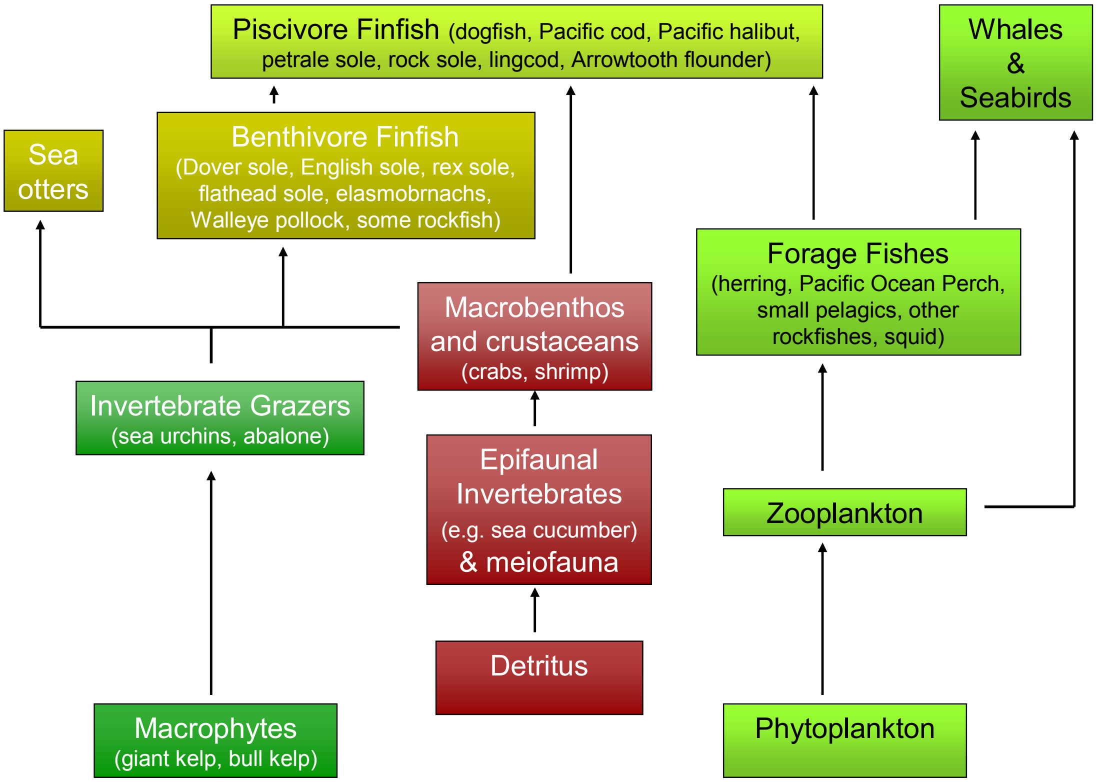


Figure 1.10 Schematic food webs for the PNCIMA region.

Ainsworth (2006) used the ECOPATH model of the PNCIMA region to explore the system's responses to environmental forcing over the past several decades. He created a "primary production forcing anomaly" pattern at the base of the (ECOPATH) food web that "matched" the temporal dynamics of the system. This pattern was negatively correlated with sea surface temperature (Spearman rank correlation coefficient, $r_s = -0.57$), and indicated reduced primary production from 1975 to 2000 compared with the period from 1950 to 1975. These simulations suggest that primary production and herring recruitment anomalies (another variable for which data could be compared with model outputs) were correlated with environmental time series such as sea surface temperature, the Pacific Decadal Oscillation (PDO) and other regional climate indices, and are therefore linked to the large-scale climate dynamics of the North Pacific. Ainsworth (2006) also concluded that in the northern BC marine ecosystem, lower trophic level dynamics are dominated by bottom-up controls (*i.e.,* climate effects on plankton productivity) whereas higher trophic levels also included top-down (*i.e.*, predator, and fishing) interactions. He concluded that strong predator controls (influences) do not cascade down to the lowest trophic levels of this ecosystem.

The number of linkages in these food web models and diet studies suggests that several important prey items exist within the web, in particular herring, other forage fishes, and large zooplankton such as euphausiids. There is no indication of an overall "wasp-waist" food web structure (*e.g.*, Cury *et al.* 2000), in which energy flows are funnelled through one or a few key species in the middle of the trophic web. The lack of such a feature suggests a more stable trophic structure than might occur in wasp-waist systems such as upwelling areas, and a trophic structure that should be more resilient to natural and human disturbances. However, individual species may have preferences for one or a few key prey items which dominate their diets, either because of spatial or temporal overlaps, behavioural characteristics of predator and prey, and critical biochemical or energy contents. If these prey items are severely reduced in abundance, disappear entirely, or somehow shift their distributions or behaviours so as to become unavailable to these predators, the predator populations may be severely affected. This suggests that, whereas the food web in the PNCIMA region overall may not display a "wasp-waist" structure, such a structure may exist for certain species. For example, the diets of killer whales in this region was composed of salmon (96.7%), the bulk of which (72.2%) were chinook (Ford and Ellis 2005). Such a structure may also exist for large whales such as humpback and blue whales in the PNCIMA region, which feed largely on euphausiids. Identifying which species might be affected in this way, and which prey species might play "wasp-waist" roles, could be done using food web models such as ECOPATH.

1.6 MIGRATORY SPECIES

Section 1.3 discusses the productivity of "resident" species of the PNCIMA region, *i.e.,* those species which spend all of their life within the central and north BC marine ecosystems. Like much of the coastal and continental shelf regions of the northern NE Pacific, however, the PNCIMA region produces a large number of fish which leave the region as juveniles and return as adults, such as Pacific salmon. The region also receives a considerable number of species which migrate to or through it from elsewhere. Such migratory species include marine birds, fish, and marine mammals such as pinnipeds and whales.

The PNCIMA region is on the migratory route for many species of birds which summer in the Arctic. They use the offshore, nearshore, and inter-tidal resources of the PNCIMA region to fuel their migrations to and from their Arctic feeding grounds. Juvenile salmon (and adult salmon during their return migrations) also use the resources of this region during their migrations north along the North American coast. Observations since the late 1990s have found that juvenile pink, chum, and sockeye salmon are quite abundant in the PNCIMA region from June to November (Figure 1.11), likely representing continual migrations of fish from sources to the south (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2006). Marine mammals such as pinnipeds (*e.g.,* Stellar sea lion) and Mysticete whales (*e.g.,* humpback, fin, and blue whales) migrate into the PNCIMA region in certain seasons to feed on abundant zooplankton (especially euphausiids) and forage fish (*e.g.,* herring).

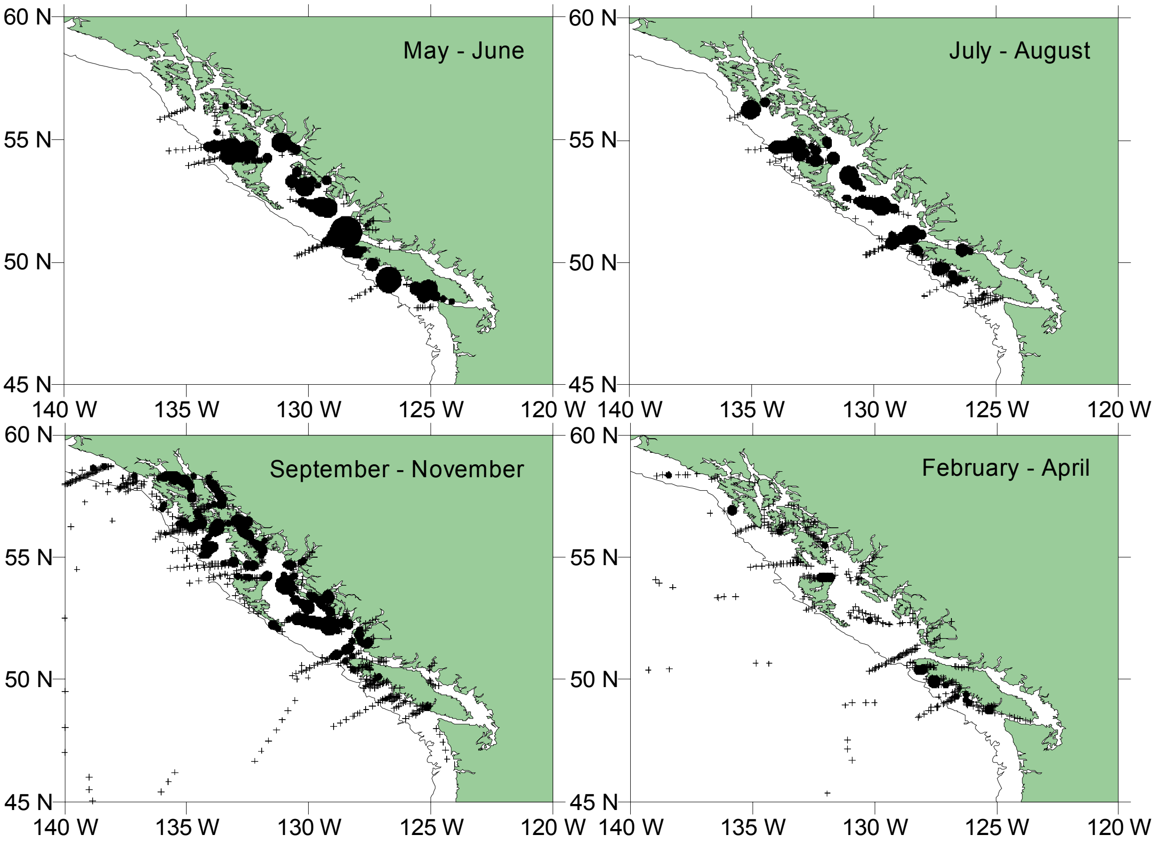


Figure 1.11 Seasonal distribution of juvenile sockeye salmon (*Oncorhynchus nerka*) in the PNCIMA region from surveys conducted since 1998 (M. Trudel, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Migrations of marine fish into the PNCIMA region occur in a different fashion to the migrations of marine birds and mammals. With the exception of Pacific hake, whose life history has evolved to include summer migrations from California to BC waters to feed on euphausiids, most other species migrate into the PNCIMA region in association with changes in environmental conditions – in particular when conditions become unusually warm. Such migrations are most obvious during El Niño conditions (*e.g.*, Wing *et al.* 2000) but can also occur during other warm periods (*e.g.,* DFO 2005). Most of these species are pelagic fish or invertebrates such as Pacific sardine, northern anchovy, and ocean sunfish. The timing and duration of their appearance in PNCIMA waters also tends to be less regular than for seasonal migratory species such as birds, mammals and Pacific hake, but they tend to be most evident during summer of warm years.

These species represent three different groups and strategies for the use of the PNCIMA region by "non-resident" species. These strategies are:

- *stop-over* migrants, such as marine birds migrating to the Arctic and salmon originating from rivers to the south which migrate through the PNCIMA region on their way north as juvenile and south as adults;
- *destination* migrants, such as whales, Stellar sea lions, and Pacific hake which migrate into the PNCIMA region from elsewhere to feed, usually during spring and summer; and
- *environmental* migrants, such as warm water zooplankton and pelagic fish and invertebrates which extend their ranges and distributions northwards with warm conditions and retract southwards with cool conditions.

It is evident that the extent and dynamics of use of the PNCIMA region will be different for species in each of these categories, and will depend on the factors driving the migrations.

The net impact of such migratory species on the PNCIMA region is unclear. For example, do these migratory species represent an import and net gain of energy into the PNCIMA region from other regions, and is this net import critical to the functioning and sustainability of the PNCIMA ecosystems? Or, do these migratory species represent a net loss of energy from PNCIMA to other regions, so that the PNCIMA region has an important role in supporting external ecosystems? Such questions represent significant unknowns as to how the PNCIMA marine ecosystems are connected with other adjacent and distant marine ecosystems.

A reasonable starting hypothesis is to suggest that migratory species represent a net loss of energy from PNCIMA and an export to other ecosystems. Most obvious are *stop-over* migrants which use the PNCIMA region to feed and refuel during their long-distance migrations but which do not reside long enough within the PNCIMA system to become significant prey for resident species. Large *destination* migrants may represent a similar loss of energy from PNCIMA as there are few resident predators on these species in the PNCIMA region.

There is, however, a fourth category of migrating species which do play a very significant role in importing energy and nutrients largely derived outside of PNCIMA into the region. These are the Pacific salmon that originate from the lakes and rivers within the terrestrial boundaries of PNCIMA, migrate through the coastal and shelf ecosystems to the open NE Pacific, and return to their natal streams as adults to die (Figure 1.12). As a result of this migration they import significant quantities of "marine-derived" nutrients, (*i.e.,* nutrients that were obtained while feeding and growing in the open ocean) to the terrestrial ecosystems of coastal central and northern BC. With the excessive rainfall in this region these coastal terrestrial ecosystems tend to be nutrient poor; nutrients derived from salmon migrations provide an important ocean-terrestrial link that re-supplies these essential nutrients to terrestrial systems.

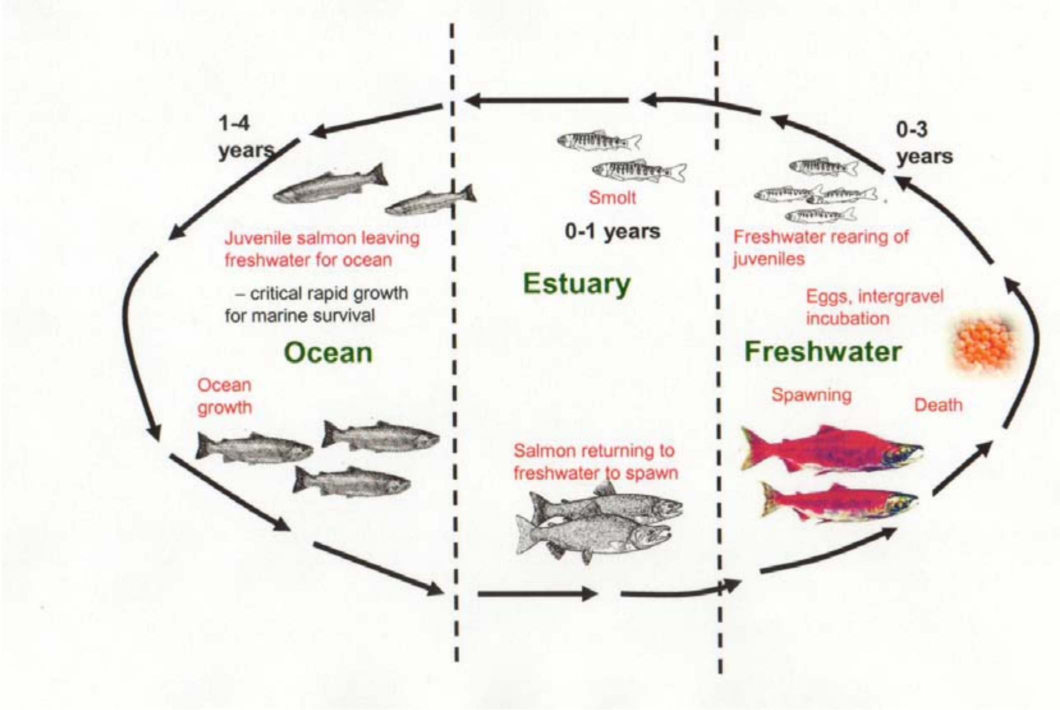


Figure 1.12 Typical life-cycle of Pacific salmon showing the ocean-terrestrial connection and the export of marine-derived nutrients to terrestrial ecosystems (from Johannes *et al.* 2003).

1.7 TEMPORAL PATTERNS OF PRODUCTION

Temporal patterns of the production and biomass of lower trophic level organisms such as phyto- and zooplankton for a generic location in the open waters of the Hecate Strait – Queen Charlotte Sound region have been modeled by Ware and McQueen (2006c). They developed a simulation model that tracks the flow of biomass from phytoplankton through to copepods, euphausiids, and other zooplankton. The model is forced by water temperature, hours of sunlight, wind mixing, and upwelling (using upwelling-favourable winds as a proxy); note that they excluded from their model any winds that were not upwelling-favourable, as they believed these generally are not conducive for the production of phytoplankton. Freshwater flows and their effects on the vertical stability of the water column were not included. The model simulates daily phytoplankton production from 1 March to 30 November of each year. The model is fully described in Ware and McQueen (2006b).

Using input data from the past 4 decades, the model estimates that primary production averaged about 223 g C m^{-2} yr^{-1}, which would make this region less productive than the Strait of Georgia but much more productive than the oceanic Gulf of Alaska. Primary production was low during the 1960s in their simulation, increased through the 1970s to the early 1990s, and then declined slightly in the mid-1990s (Figure 1.13). The strongest driver of these decadal-scale patterns was the average upwelling wind speed during the production season ($r^2 = 0.58$; Figure 1.13), which was increasing during the 1970s and 1980s, although the moderate value of the regression coefficient indicates that many other factors, such as sunlight, wind mixing and zooplankton grazing, also play important roles in regulating primary production. The principal production season in this region runs from March to November.

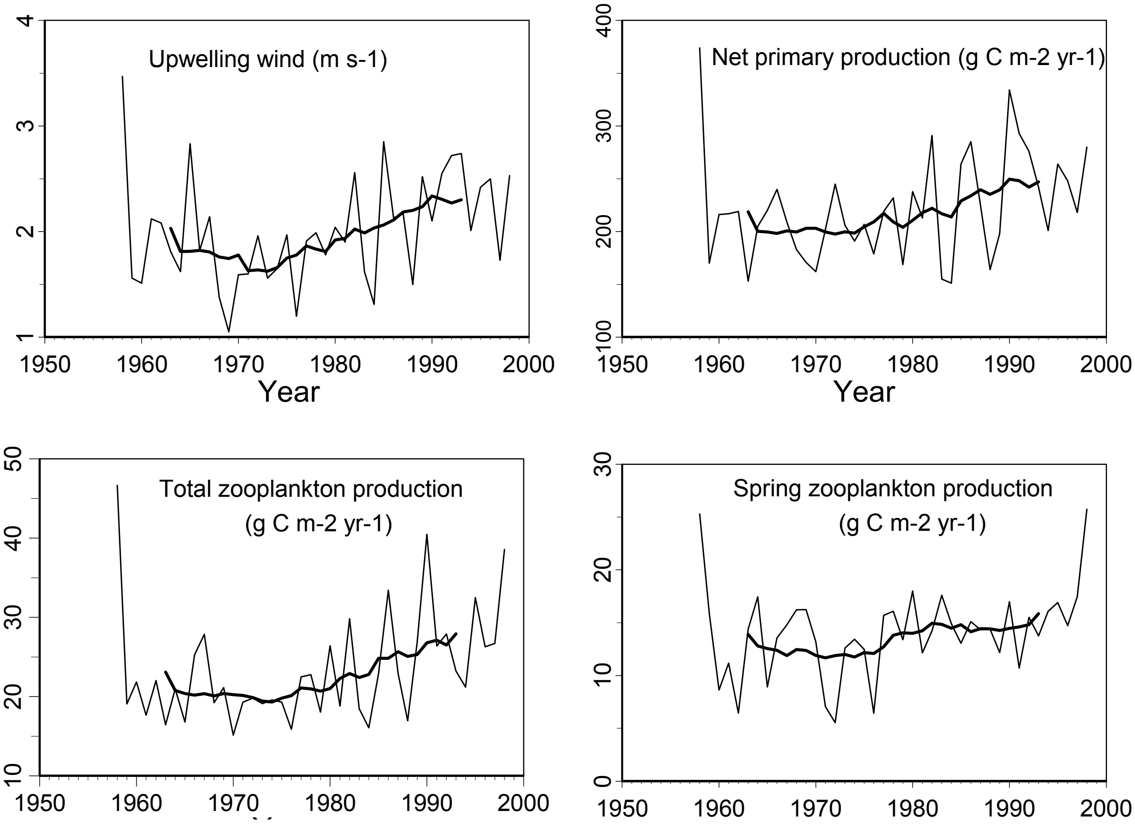


Figure 1.13 Annual (March to November) average upwelling-favourable wind speed, modelled net primary production, total zooplankton production, and spring zooplankton production, 1958-1998, from the Hecate Strait lower trophic level model of Ware and McQueen (2006c). Heavy line is a decadal-scale (11 year) moving average.

Upwelling-favourable winds are expected to bring more nutrients into near-surface waters along the east side of Hecate Strait and the west coast of the Queen Charlotte Islands in summer. However, it is important to remember that the Ware and McQueen (2006c) study identified upwelling winds only by the direction of the wind, not by the ocean processes associated with this wind. The strength of upwelling is not well known, and other processes associated with NW winds might have equal or greater impact on primary production in some regions. For example, Coriolis force directs surface currents to the right of the wind in the Northern Hemisphere. Studies of winds and surface drifters in the three major basins (Dixon Entrance, Hecate Strait and Queen Charlotte Sound) found the surface flow was on average about 35° to the right of the wind (Crawford *et al.* 1996; 1999). Thus NW winds would push waters away from an eastern shore. This water could be replaced by deeper waters (upwelling) or the surface flow could be mainly surface outflow from inlets such as Fitz Hugh Sound and Chatham Sound. Either process would push nutrient-rich waters into the regions we note later as more highly productive.

As expected, total zooplankton production and spring zooplankton production also followed similar decadal patterns, although the decadal trend is not as pronounced (except at the end of the 1990s) in the spring zooplankton time series. Annual total zooplankton production was reasonably well correlated with the net primary production ($r^2 = 0.76$). Zooplankton converted primary production into zooplankton biomass with an efficiency of about 10%. The model suggests a significant ($r^2 = 0.42$) positive relationship of this zooplankton ecological efficiency with the sea surface temperature (SST), such that the ecological efficiency was less than 9% for SST less than 11 °C, and was greater than or equal to 12% for SST greater than 12 °C. Ware and McQueen suggest this implies that zooplankton become more efficient grazers at warmer temperatures, and occurs in the model because grazing rates of zooplankton increase exponentially with temperature. In contrast to total zooplankton production, the spring zooplankton production was most well correlated ($r^2 = 0.63$) with the average SST, and only very weakly correlated ($r^2 = 0.09$) with the annual net primary production, suggesting that late winter-spring conditions and phytoplankton production may have a greater influence on spring zooplankton than annual conditions.

Ware and McQueen (2006a) compared their model output (updated to 2002) with observed data for the period since 1998. They found the correlation between chlorophyll *a* concentrations derived from the model and chlorophyll *a* concentrations that were observed from the SeaWiFS satellite to be $r^2 = 0.37$. Comparisons of the model outputs with observed annual anomalies in the nestling growth rates of Cassin's Auklet chicks on Triangle Island off the northwest tip of Vancouver Island were most highly correlated with the date of the spring phytoplankton bloom ($r^2 = 0.86$) and with the modeled copepod production rates. These results are broadly consistent with observations of the responses of seabird populations to ocean climate changes at the northwestern tip of Vancouver Island (Bertram *et al.* 2005; Hedd *et al.* 2006). Correlations between model estimates of spring zooplankton, copepod and euphausiid production and the growth rates of Pacific herring populations in Hecate Strait and Queen Charlotte Sound were about $r^2 = 0.37$.

The NASA SeaWiFS Ocean Biology Processing Group has made available satellite ocean colour data obtained since 1997, resolved to monthly time scales and 9-km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml)[1]. For the PNCIMA region, the mean monthly and annual mean (January to November) chlorophyll *a* concentrations are shown in Figure 1.14. They indicate relative constancy of the mean annual chlorophyll concentration from 1998-2005, except for 2002 which had very high chlorophyll during spring. The data also indicate that peak spring (April-May) chlorophyll concentrations are significantly (t-test, P=0.018) higher from 2002-2005 (mean = 2.8 mg m^{-3}) compared with 1998-2001 (mean = 1.8 mg m^{-3}).

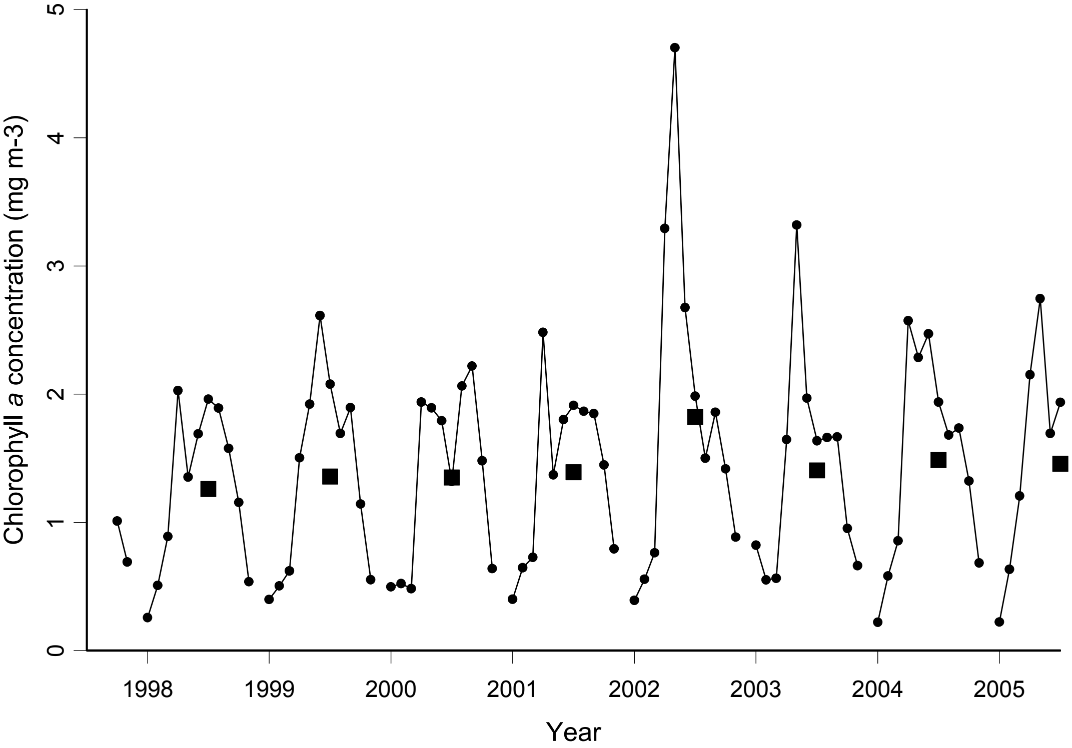


Figure 1.14 Monthly mean chlorophyll *a* biomass (mg m^{-3}) for the PNCIMA region as measured by the SeaWiFS satellite sensor at 9 km spatial resolution (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml). Note no data are available for December of any year. Large squares represent the annual average chlorophyll *a* biomass calculated from monthly averages from January to November of each year.

The long-term catches of "resident" finfish (which excludes Pacific hake, sardine, and pink, chum, sockeye, and coho salmon), as used by Ware and Thomson (2005), from 1920-2004 show the very high catches of pelagic species (herring) during the 1960s, followed by their decline, the closure of the herring reduction fishery, and the

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[1] The images and data used in this study were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

introduction of most groundfish fisheries since the 1970s (Figure 1.15). These patterns should be comparable with the time series of plankton as produced by the model of Ware and McQueen; however, the catch series is too highly regulated by management actions and such a comparison inferring direct control of annual variations in fish yields by annual plankton production would be meaningless.

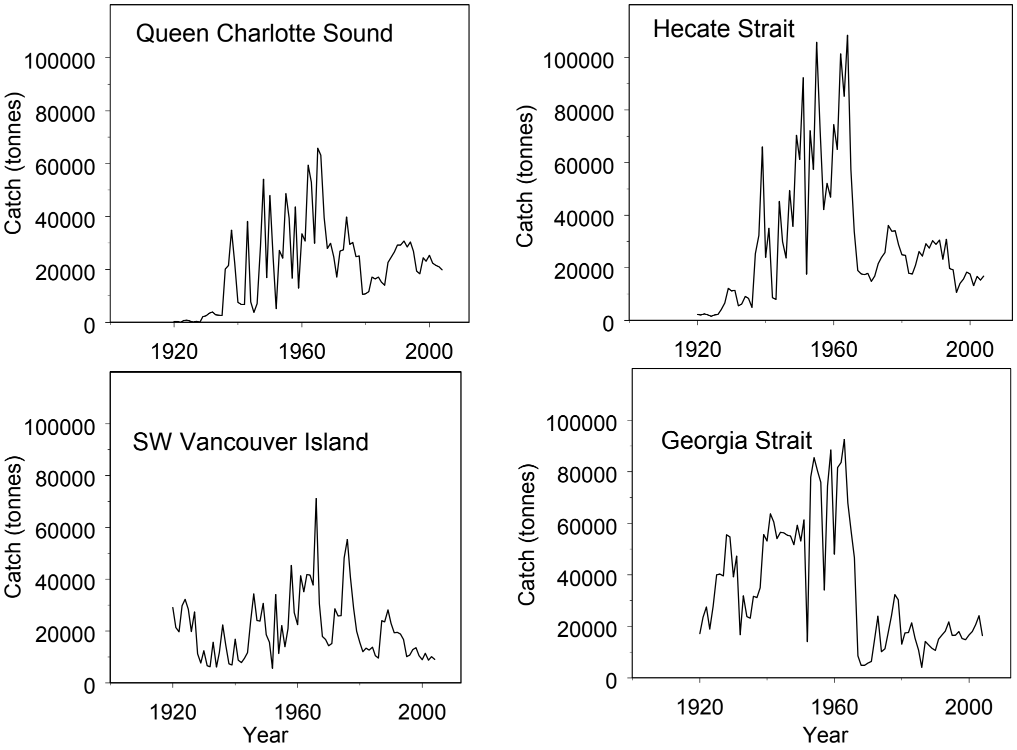

Figure 1.15 Annual catches of "resident" fish (all finfish species excluding Pacific hake, Pacific sardine, pink, chum, sockeye and coho salmon) from 1920-2004 in two southern regions and two PNCIMA regions of the BC coast.

The longest series of fishery independent indices of groundfish species biomass in PNCIMA are available from the Hecate Strait Assemblage Survey which began in 1984 and was carried out approximately every two years until 2003. Twenty-one individual species time series were selected for comparative analysis. Cluster analysis was used to group time series with similar temporal trends. Four clusters emerged (Figure 1.16). One group comprising 7 species (arrowtooth flounder, Pacific sanddab, Dover sole, slender sole, flathead sole, spotter ratfish, and rex sole) showed an increasing trend over the entire time series with an approximate four-fold increase in biomass (Figure 1.17). Two other groups showed an initial period of increase, followed by a decline to the late 1990s, and an increase in the early 2000s. These 2 groups accounted for 12 species. The final group that included Pacific cod and spiny dogfish, showed a downward trend throughout the time series.

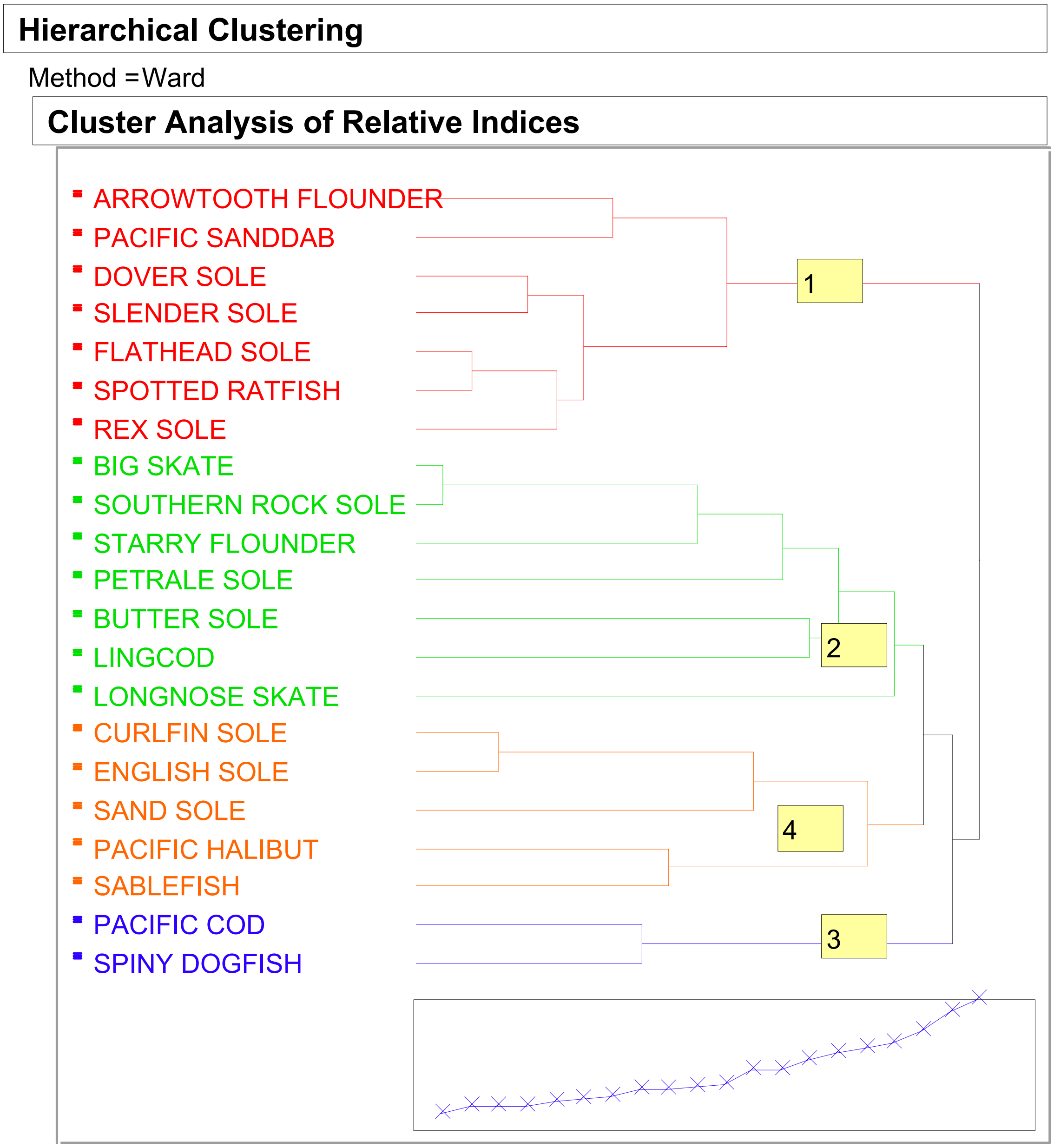

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Figure 1.16 Dendrogram from a cluster analysis of relative biomass indices for 21 groundfish species taken in the Hecate Strait Assemblage Survey, 1984-2003. The line graph in the bottom right indicates the dissimilarity at each cluster join. The species time series were standardized to the individual series means. Agglomerative clustering was used with Ward's method. Four clusters were identified.

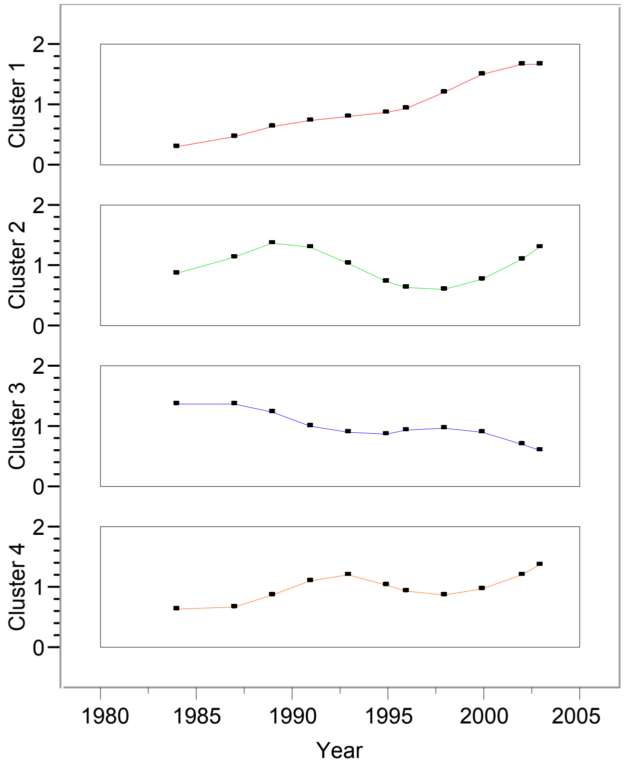

Figure 1.17 Smoothed time series of relative biomass of 4 species clusters identified in a cluster analysis of the Hecate Strait assemblage survey results, 1984-2003.

There is some correspondence between these trends in biomass with trends in primary and secondary production in PNCIMA, modulated to a certain extent by fishing. The Ware and McQueen (2006c) model predicts a generally increasing trend in primary and secondary production in PNCIMA over the time period of this survey. This supports the monotonic increase in biomass of the first cluster. The species in cluster 1, with the exception of Dover sole, are of limited commercial value and are mainly bycatch in the groundfish fisheries in the area. The species in the second and fourth clusters, on the other hand, are more important commercially. The intermediate decline in biomass in these time series corresponds to a period of intense fishing effort by bottom trawlers in Hecate Strait (Figure 1.18). The increases in biomass in the most recent years in these time series correspond to a reduction in fishing effort and a continuing increase in primary and secondary production.

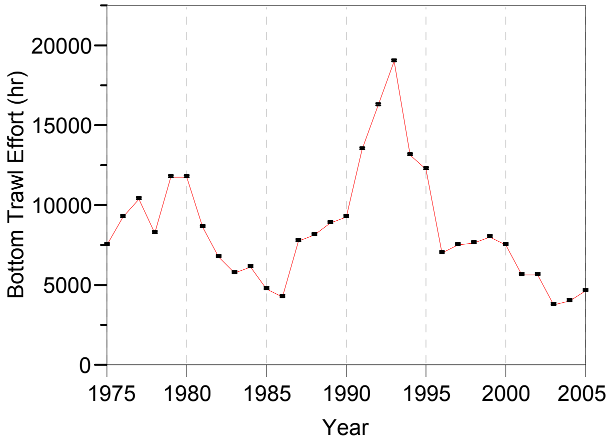

Figure 1.18 Nominal fishing effort (hours) by bottom trawlers in Hecate Strait (PFMC Areas 5CD) at depths less than 150 m, 1975-2005.

The trend in Pacific cod biomass is quite different from the trends described above. Pacific cod recruitment is inversely correlated with pressure-adjusted sea levels at Prince Rupert in their natal winter. This sea level is proxy for flow through the strait and the advection of eggs out of Hecate Strait following spawning. A recruitment mechanism related to advection/retention of eggs and larvae has been proposed (Tyler and Crawford 1991) and confirmed with more recent data (Sinclair and Crawford 2005). These analyses found greater statistical support for the advection/retention mechanism than for growth during juvenile stages. Advection characteristics in the area were not favourable to good cod recruitment in the 1990s. This was exacerbated by intensive fishing for the species. It may be that Pacific cod responds to a different recruitment mechanism than the majority of groundfish species in PNCIMA.

There has been an increasing trend in abundance of many marine mammal populations in PNCIMA. This includes several baleen whale species, many of which visit PNCIMA during their feeding seasons. Sea lion and seal populations are on the increase, as are the reintroduced sea otters. The exception would be the resident killer whale populations which are still at very low abundance in PNCIMA. Those species that have been increasing had all previously been the subject of intense removals by humans, either for commercial reasons or were culled. However, these removals ceased several decades ago. It is difficult to tell whether their recent increases in abundance are a response to increased production in the area or a response to reduced harvest. But, these animals feed at several different trophic levels and their increases in abundance may have some effect on the trophic balance in PNCIMA.

1.8 SUMMARY

The geological environment forms the underlying habitat of the area and significantly affects the physical functioning of PNCIMA.

- The steep and rugged coastal mountains affect climate, rainfall and watershed function.
- The valleys and fjords that cut into these mountains and extend to the adjacent seafloor result in the dominance of estuarine circulation in the nearshore environment and create a sediment-starved shelf.
- The abundant mainland islands create many kilometres of protected and semi-protected coastline and waterways.
- The Queen Charlotte Islands act as a retentive barrier to outflow of water from PNCIMA.
- The glacially scoured continental shelf with its cross cutting troughs form several bathymetric edges and affect currents and circulation in the area.
- The dominant, glacially derived sediments are likely to be a controlling factor in benthic habitats.
- The Queen Charlotte Basin beneath the continental shelf has the potential to contain significant oil and gas reserves.

The proximity of the Pacific Ocean moderates BC's coastal climate, producing relatively warm winters and cool summers compared to the interior of British Columbia.

- Two large scale pressure systems over the northeast Pacific control much of the PNCIMA weather and climate. The Aleutian Low tends to dominate in winter. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC and Alaskan coasts. The North Pacific High dominates in summer and tends to deflect storms northward during this time. These pressure systems and their associated winds also drive the main ocean circulation patterns of the northeast Pacific.
- PNCIMA is located in a transition zone between a northerly area dominated by the Alaskan current system and a southern area dominated by the California current system.

The combined influences of a semi-enclosed basin, varied bottom topography, and fresh water input set PNCIMA apart from other areas of the North American west coast.

- Most of PNCIMA is relatively enclosed geographically, with the Queen Charlotte Islands enclosing most of its northern portion, resulting in little advection of water to the deep ocean in summer. As a result, plankton are more likely to be retained in these basins, not lost to the ecosystem. This contrasts with upwelling regions to the south off California, or regions of SE Alaska where shelf waters are swept offshore in summer.
- Most of the advection out of PNCIMA that does occur is in winter from Dixon Entrance, and at Cape St. James into Haida Eddies. It may be that nutrient-rich oceanic waters replace the advected water in time for the spring blooms.
- High phytoplankton abundance is often associated with areas of high freshwater input. However, the lack of strong tidal mixing of river outflow into deep water near fishing banks sets PNCIMA apart. In PNCIMA, we find less river flow discharging into poorly mixed waters, and although some regions such as Chatham Sound and Fitz Hugh-Smith Sound outflows support plankton production, they do not have sustained, strong productivity. Interestingly, the northeast sector of Hecate Strait supports high fish biomass. This is adjacent to channels where Skeena River water goes through deep well-mixed channels on its way to Hecate Strait, so this mixing might be a factor.
- The steep edges of Dixon Entrance and the three troughs that transect Queen Charlotte Sound and Hecate Strait focus convergent processes that are likely to enhance zooplankton and subsequent fish production.
- There is strong seasonal variability that exceeds interannual variability.
- The area is less affected (in general) by large-scale industrial activities; fishing is the major human forcing to which this system is exposed.
- Retention: In northern to central Hecate Strait, the outflow in spring and summer is likely low. Regions such as Chatham Sound and eastern Dixon Entrance also experience relatively little outflow of plankton, due to estuarine recirculation in Chatham Sound and the Rose Spit Eddy in eastern Dixon Entrance.

As a working model, northern BC waters can be examined using the “triad” approach of Bakun (1996), which suggests that productive marine ecosystems require an optimal combination of three processes: enrichment (of nutrients), concentration (of nutrients and plankton to levels which promote feeding), and retention (of nutrients and food long enough for predators to utilise the resource). In the PNCIMA region:

- *enrichment* is achieved by upwelling (or a weakening of downwelling winds), by the estuarine flow characteristics of freshwater runoff from the coastal inlets, and tidal and wind mixing – all of which act to bring nutrients closer to the surface where they can be accessed by phytoplankton (and macrophytes in the nearshore region);

- *retention* is achieved by the general topography and relatively weak upwelling of the region, in particular the Queen Charlotte Islands, which block extensive advection of water and its constituents into the deep ocean; and
- *concentration*, which is achieved by bathymetric and hydrographic features and their interactions with the circulation.

This model implies that any process, natural or human, that interrupts any of the three aspects of this triad will impede and possibly reduce the productive capacity and resilience of this ecosystem. For example, the productivity of the system as a whole is influenced by the extent of upwelling favourable winds; should these winds change as a result of natural climate changes (as has happened in the past) then they will have an impact on the productivity of the entire ecosystem. The spatial pattern of plankton productivity will be affected by changes in the hydrological regime; if freshwater runoff changes in timing or amount it can be expected to impact the degree of nutrient entrainment into the upper layers by estuarine processes and the locations at which these processes occur. An example is continuing decrease in glacier size with climate warming. High melt rates at present provide more flow in spring and summer than we can expect in the future once these glaciers have disappeared.

From the analyses currently available, the overall trophic structure of the PNCIMA region appears to be relatively robust to reduction or elimination of single components of the food web, as long as other species occur within the same functional group. Overall, the food web does not appear to display a “wasp-waist” structure, in which energy flows predominately through one or a few species at intermediate trophic positions. However, trophic pathways to individual species may be more constrained (*e.g.,* krill to whales); it is unknown which species may be critically sensitive to the reduction or elimination of which other species.

The ecosystem does receive a large biomass of migratory species: of stop-over migrants, such as Pacific salmon and marine migratory birds; destination migrants such as whales; and environmental migrants such as pelagic zooplankton and fish that invade PNCIMA when conditions are unusually warm. These species provide an input of energy and food, but also result in an export of energy from the system. Calculations of the net effect have not been conducted that we are aware of. However, it is likely that there will be a net loss of energy from the system since many of the migratory species (*e.g.,* salmon, birds) pass through the region relatively rapidly and do not stay long enough to be significant prey for resident species. Pacific salmon play a significant role in transferring nutrients from marine to terrestrial coastal ecosystems in the PNCIMA region.

There appears to be a spatially dependent trophic linkage from phytoplankton to fish in PNCIMA. This is consistent with what Ware and Thomson (2005) describe for the North American Pacific coast as well as for the entire BC coast. In PNCIMA, phytoplankton biomass is highest at the southeast end of Dixon Entrance where the freshwater input of the Skeena River is highest, and in the entrance to Queen Charlotte Sound in the south where the high-nutrient inflow from Queen Charlotte Strait mixes with fresher runoff from Fitz Hugh and Smith sounds. These same areas also support the high biomasses of groundfish and pelagic fish.

There is evidence from the model of Ware and McQueen (2006c) that the trend in phytoplankton production in PNCIMA has been upward since the late 1970s. The results from the Hecate Strait Assemblage bottom trawl survey suggest a simultaneous increase in biomass of several groundfish stocks. This upward trend is most clear for a group of lightly exploited species. The trends for other more heavily exploited species was interrupted by a pulse of high fishing in Hecate Strait in the early 1990s. This correspondence supports a largely bottom-up control on groundfish production when fishing is not a factor. An exception may be Pacific cod, which appears to be more strongly influenced by advection of eggs and larvae.

1.9 UNCERTAINTIES AND KNOWLEDGE GAPS

We have tried, in the preceding pages, to pull together a very rudimentary portrait of how PNCIMA works. Some of the linkages we have described are embarrassingly simplistic, and many are very likely to be completely wrong. Hopefully this will prompt others to show where we are wrong and why.

Clearly there are many, many things we do not understand about how PNCIMA works. It would be futile to try and summarize the depth of our lack of understanding. What follows are some points we gleaned from the other sections of this report, what was brought to our attention during discussions with others, and what we thought were important issues to focus on in the near future. This list, by no means whatsoever, should supersede any other list of uncertainties and knowledge gaps that has been developed through other processes.

Terrestrial bedrock geology is quite well understood at the PNCIMA area scale in BC and the level of detail is constantly improving. Submarine bedrock geology is less well constrained. Current knowledge of seafloor sediments and substrate material is patchy and limited by the need to extrapolate between widely spaced sampling points. The advent of multibeam sonar technology is providing extremely accurate information but will take many years to complete a shelf-wide map. The variability in the transport, deposition and erosion of submarine sediments is also poorly constrained but our understanding is likely to improve with technological advances.

While the exact timing of large earthquakes can not be predicted, current techniques allow a high degree of certainty that the subduction zone off of the west coast of Vancouver Island is currently locked and will likely produce an earthquake around magnitude 8 within the next few hundred years or so. The transform fault off the Queen Charlotte Islands is known to produce the occasional magnitude 8 earthquake, but the frequency of this is not well known.

Climate prediction on all time scales is difficult. The complexity of ocean-atmosphere systems and their interaction also prevents sufficient understanding for accurate predictions, although new observational programs are improving climate models through the collection of near real time oceanographic data. Thus, although it is known that climatic conditions are critical to ecosystem function, and that they vary significantly on various time scales, predictive capabilities need to be improved.

Modelling of climate and coupled climate-ocean conditions is limited by computing capacity (most of these efforts require supercomputers), by the complexity of the climate itself, and by a lack of monitoring data, especially over and within the Pacific Ocean. Advances in this area will improve climate prediction capabilities.

A recent analysis was made of BC's climate observation capacity. The 'Review of the Adequacy of Climate Related Observation Networks' (M. Miles and Associates 2003), found that, according to World Meteorological Organization standards, BC is severely lacking in climate and stream gauging, sediment discharge stations, and climate station density and is somewhat lacking in monitoring of evaporation, hydrometric networks and snow course density monitoring. Deficiencies are most common in areas that are remote, high elevation, or have small watersheds. This would describe most of the PNCIMA area. These deficiencies are specifically discussed in terms of the ability to verify and support climate modelling efforts.

Virtually all that is reported here on phytoplankton distribution and bloom timing was taken from satellite imagery that has several drawbacks. These images cover only the surface ocean. As such, they cannot detect deep chlorophyll layers and may underestimate production in well mixed areas where phytoplankton are drawn away from the surface. The images also measure standing stock and may underestimate production in areas where grazing is high. There is a definite lack of field observations of primary production in PNCIMA that should be addressed.

Zooplankton are poorly sampled in PNCIMA. While we have inferred a spatial and temporal linkage between phytoplankton and fish, it must pass through zooplankton. We have little information on when and where zooplankton and ichthyoplankton feed. This is needed to confirm our inferred linkage and to better understand the pathways through which energy flows through these different trophic levels.

Most of the information presented here on fish distribution pertains to adults and is dominated by commercially important species. Comparatively little is known about the distribution of juveniles of these same species, and less yet on larval distributions and spawning locations of these species. However, the available information indicates important ontogenetic differences in life history and distribution.

Information on food web linkages and who eats whom is severely lacking, having been collected only for groundfish species in limited seasons during two years in the 1980s.

We have said little in this report on the ecology of the west coast of the Queen Charlotte Islands. This is because very little is known about this region. The shelf is very narrow with the slope descending rapidly to well over 1000 m along much of this edge. This coast is isolated, poorly charted, and with few refuges from the often severe weather. For that reason, it is probably the least disturbed coastline in PNCIMA. It is tempting to conclude that production in this area is relatively low, however little information is available.

1.10 ACKNOWLEDGEMENTS

We wish to thank the authors of the other sections of this PNCIMA ecosystem overview and others who participated in our workshop held at the Institute of Ocean Sciences on March 9-10, 2006 for sharing their ideas and impressions of the PNCIMA ecosystem. We also thank Barbara Lucas for her editorial comments.

CHAPTER 2: HABITAT USE AND FUNCTIONAL AREAS IN THE PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA

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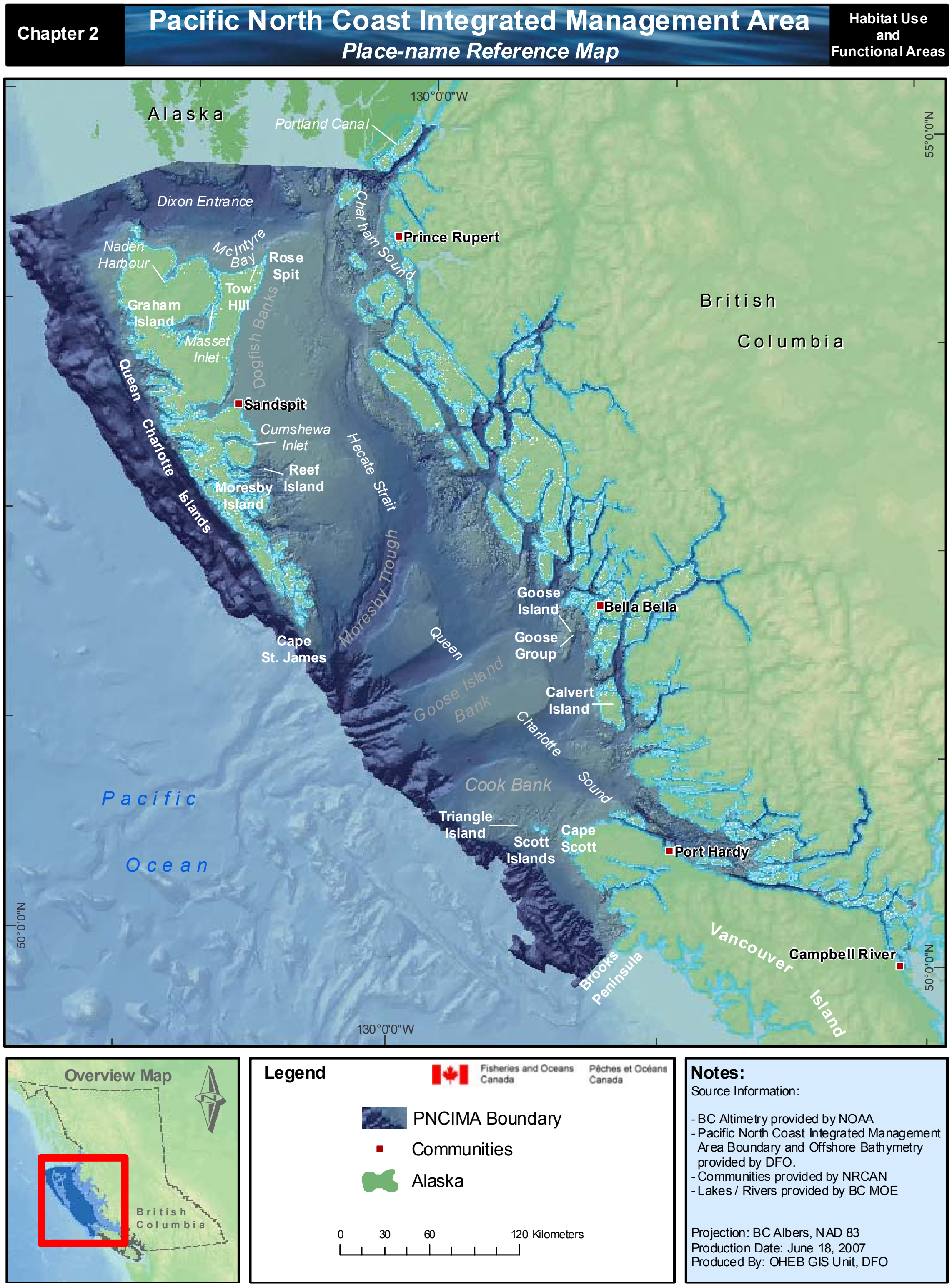
2.0 INTRODUCTION

This chapter provides a geographical presentation of habitat use for many of the large and/or commercial species in the Pacific North Coast Integrated Management Area (PNCIMA; Figure 2.0). It also summarizes the highlights of habitat use detailed in the appendices to this report - Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA).

In general, little is known about the functional habitat use for most life history stages for marine species in British Columbia (BC). Where it is known, maps show migration routes, spawning areas, rearing areas, foraging areas, and other important habitat areas.

Some of the maps used in this chapter were initially developed in the early stages of the process to identify Ecological and Biologically Sensitive Area (EBSAs) for PNCIMA. Clarke and Jamieson (2006) used a modified Delphic approach with species specialists to identify important areas based on criteria for uniqueness, aggregation, fitness consequences, naturalness, and resilience (Fisheries and Oceans Canada 2005). Functional habitat uses identified during the EBSA process have been indicated in the maps in this chapter, along with any additional habitat information available.

For some species, such as benthic invertebrates, their adult habitat is indicative of most benthic life stages because they move little as adults. The majority of our knowledge of marine species comes from fishery assessments of commercially-harvested species, resulting in bias towards them in fished areas and against non-commercial species and unfished areas.



Notes:

Source Information:

- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE

Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure 2.0 PNCIMA region showing locations and features of BC waters mentioned in Chapter 2.

2.1 PLANKTON

Plankton are commonly grouped into three categories: phytoplankton, zooplankton, and bacterioplankton. Phytoplankton supply their own food, through photosynthesis, and thereby provide most of the food energy that supports the rest of the marine food web (see Appendix D: Plankton). Bacterioplankton break down particulate detritus, releasing dissolved nutrients. Both these groups are grazed by zooplankton, which include single celled organisms and the larval and juvenile stages of many benthic and pelagic species. Larval and juvenile zooplankton are discussed in detail in the appendices to this Ecosystem Overview for PNCIMA.

Plankton concentrations vary spatially and temporally, as does the species composition. PNCIMA appears to have moderately high phytoplankton biomass over most of the continental shelf from spring through fall, with very high levels at the entrance to some inlets and fjords. Euphausiid zooplankton, a key prey for some fish and birds, are associated with the three steep-sided troughs in Queen Charlotte Sound. A combination of nutrient enrichment, localized concentrations (*e.g.,* along bathymetric edges), and retention of critical life stages can provide biologically productive pelagic habitats (Bakun 1996).

Plankton are affected by the climatic conditions detailed in Appendix B: Meteorology and Climate and are subjected to the currents detailed in Appendix C: Physical and Chemical Oceanography.

2.2 MARINE PLANTS

Benthic marine plants include two important habitat-forming macrophyte groups, kelp and eelgrass. Temperate kelp beds are one of the most productive ecosystems in the world (Mann 1982). Kelp beds are important spawning and nursery areas for fish and invertebrates, and contribute a significant amount of fixed carbon to the nearshore ecosystem (Duggins *et al.* 1989). Selected kelp beds in PNCIMA were surveyed by the BC Ministry of Agriculture, Fisheries and Food between 1976 and 1996 (BC MAFF 1996). Surveys were conducted using fixed wing aircraft and field trips to the kelp beds to verify species and densities. Biomass estimates for those beds were reported by Lindstrom (1998) and are included in Appendix E: Marine Plants. Kelp beds were extensive in surveyed areas (Map 2.0), but required digital enhancement to increase their visibility on a Large Ocean Management Area (LOMA) scale. Detailed digital maps are available for each area from the Habitat Branch of Fisheries and Oceans Canada.

Eelgrass, *Zostera marina* and *Z. japonica*, form extensive meadows in soft sediments in the lower intertidal and shallow subtidal, mostly in protected waters, such as heads of inlets. These beds provide important habitat and sometimes food for waterfowl, crab, herring and juvenile salmon (BC MSRM 2002). They also stabilize sediments and contribute to nutrient cycling in both direct and indirect ways (Phillips and Menez 1988;

Dunster 2003). An eelgrass bed mapping atlas is available online (Community Mapping Network 2006), but the beds are too small to show on a LOMA scale. Additional eelgrass maps that may be of interest are detailed in Appendix E: Marine Plants.

The Coast Information Team (CIT 2003) identified saltmarsh vegetation, eelgrass beds and kelp beds as the major nearshore habitats because of their high biological productivity and sensitivity to human impacts and because "these categories are recognized ecologically, are protected by policy, and are the best surrogates at this scale to represent a range of habitats" (CIT 2003).

Estuaries are also highly productive habitats where terrestrial, freshwater, and marine ecosystems meet. Although they account for less than 3% of the BC shoreline, they are used by 80% of all coastal wildlife (NRTEE 2005). In BC, 442 large estuaries have been identified from existing mapping products (Pacific Estuary Conservation Program 2004). Of these, MacKenzie *et al.* (2000) has surveyed twenty eight central and north coast estuaries. Their objectives were to acquire site specific information about estuarine ecosystems based on plant community types, to describe the range of estuary types, including biological and geomorphogical information, to create a site classification, and to identify estuaries with particularly high habitat value or rare ecosystems.

2.3 INVERTEBRATES

Invertebrates inhabit the full range of marine environments, intertidal to great depths, benthic to pelagic, mud to rock, and even upon other species. A detailed description of invertebrates species is available in Appendix F: Invertebrates.

Many marine invertebrates are sedentary or move little in their environment, except during larval stages. Some, such as corals and reef forming sponges, form habitat for other species. Coral and sponges may provide essential habitat for some benthic organisms, including many juvenile and some adult fish species (especially rockfish). Important concentrations of coral and sponge have been identified (Ardron 2005), along with occurrences of coral in PNCIMA (Map 2.1) (Etnoyer and Morgan 2003; Jamieson *et al.* in press). Siliceous hexactinellid sponges form reefs in deep waters in Queen Charlotte Sound (Conway 1999).

Commercial molluscs include clams, scallops, abalone, squid and octopus. Clams are found intertidally and subtidally throughout PNCIMA (Table 2.0) on a scale too small for mapping. Their habitat use is summarized in Table 2.1. Geoduck occur throughout the coast in unconsolidated substrates (C. Hand, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Commercial crustaceans include euphausiids, shrimp and prawns, and crabs. Shrimp spawn in late autumn to early winter. Females carry their eggs on their abdomen until the eggs hatch in early spring. The timing of hatching varies by species and by area. It is important to protect breeding females long enough for them to release the eggs (Fisheries and Oceans Canada 2006; Dunham and Boutillier 2001). Larvae are pelagic for approximately three months before they settle. The limited migration activity of adult prawns results in the existence of hundreds of separate stocks. However, meta-populations that share larvae may exist for prawns and shrimp because their lengthy pelagic larval stage may allow dispersal and exchange between populations (Booth 2000; Stocker *et al. eds*. 2001). Nearshore juveniles that occur predominately in channels and near estuaries may be particularly sensitive to habitat alterations (Johannessen *et al.* 2005).

Crab larvae are pelagic, while the adults are benthic. Crabs are soft-shelled when moulting, and then are particularly susceptible to predation and injury. Juveniles tend to moult more frequently per year, whereas adult crabs tend to moult annually; mating occurs when the females moult. Fertilized eggs remain attached to the female's abdomen for 4-5 months until they hatch, usually in late winter to early spring. During the egg incubation period, females often bury in the substrate to protect their eggs. Larvae are planktonic for approximately 4 months before reaching an active swimmer stage. Chances of survival are highest at settlement if the megalopa metamorphoses into a juvenile crab in water less than about 50 m depth. Juvenile crabs of less than 70 mm survive best in lower intertidal and shallow subtidal waters, where they sometimes overwinter. Because juveniles are concentrated in nearshore areas, including coastal estuaries, they are especially susceptible to human activities (Booth 2000).

High concentrations of Dungeness crabs are found in some areas of PNCIMA (Map 2.2). Larvae are found throughout the coast at particular times of year, in the spring around Vancouver Island and in the summer around the Queen Charlotte Islands (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). An ocean gyre off the north coast of the Queen Charlotte Islands retains larvae in productive areas off McIntyre Bay, Rose Spit and Tow Hill (G. Jamieson, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Naden Harbour, Masset Inlet, Portland Canal, and the Prince Rupert region are areas of high adult concentrations.

Two species of Tanner crab occur in PNCIMA, *Chionoecetes tanneri* and *C. bairdi*. *C. tanneri* are found in deep waters of the continental shelf break (Map 2.3). Surviving larvae are likely found only at depth (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). High concentrations of *C. tanneri* are found in the two circled areas in PNCIMA, and further south, off the west coast of Vancouver Island. *C. bairdi* are found in most mainland inlets at depths of 50-70 m, but they do occur as deep as 400 m (A. Phillips, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Table 2.0 Summary of clam habitat in British Columbia.

Common and Scientific Name	Distribution	Preferred Habitat	Growth Rate	Spawning Time	Food Sources	Notes
Butter Clam *Saxidomus gigantea*	Common in protected beaches in bays and estuaries throughout BC.	Lower 2/3 of intertidal zone to max. 15 m subtidal depth. Typically in beaches of porous sand, broken shell, gravel and mud. Burrow to max of 25 cm. Permanent burrows.	Slow growing. Legal size 38 mm, (5-6 yrs. Strait of Georgia;7-8 yrs. Alert Bay; 9^{+}yrs. north coast). Max. age, 20^{+}yrs. Max. size, 130 mm.	Sexually mature at 38 mm (~3 yrs). May in Strait of Georgia, later in north coastal areas.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	
Manila Clam *Venerupis philippinarum*	Currently range from Laredo Inlet in the central coast to California on protected beaches.	From 1 m intertidal zone to well above mid-intertidal level. Does NOT inhabit subtidal. Mixed substrates of gravel, sand or mud. Permanent burrows.	Harvestable at 38 mm, 3-4.5 yrs of age in the central coast. Sexually mature 2-3 yrs Max. size 75 mm, approx. 10 yrs. Max. age 16 yrs. in BC.	August in central coast. Mid June and Sept. in Strait of Georgia.	Suspension feeder, mainly phytoplankton, as well as, zooplankton and detritus.	Require surface temperatures of 14^{o}C or greater to permit gametogensis, spawning and larval development. Intentional introduced in north and central coasts but failed to produce sustainable populations. Natural recruitment in central coast probably from Quatsino Sound. Limited competition with native clams.
Native Littleneck Clam *Protothaca staminea*	Common in protected beaches in bays and estuaries along the coast, and near rocky outcrops on outer coastal areas.	Slightly above mid-intertidal to a max. subtidal depth of 12 m. Firm gravel beaches. Associated with Butter clams. Burrow 3-8 cm below surface, max. depth 15 cm. Permanent burrows.	Rapid growth to 5 yrs. of age, then decreases. Legal size, 38 mm (5-6 yrs. in the north coast, 3.5 yrs. south coast). Max. age, 14 yrs. Max. size, 70 mm (~10 yrs.).	Sexually mature at 2 yrs. (25 mm). Spawn April to October.	Suspension feeder, mainly phytoplankton, as well as zooplankton and detritus.	Growth varies from beach to beach and between tide levels on any given beach.

Table 2.0 Continued…

Common and Scientific Name	**Distribution**	**Preferred Habitat**	**Growth Rate**	**Spawning Time**	**Food Sources**	**Notes**
Razor Clam *Siliqua patula*	Surf-swept beaches from Aleutian Islands, AK to California. In BC, two major stocks Long Beach on WCVI and on beaches east of Masset on the northeast coast of Graham Island, QCI.	Mid-tide level to 20 m subtidal depth. Sandy, exposed beaches. Burrow just below surface max. 25 cm; can burrow to depth >60 cm in less than a minute. Do NOT form permanent burrows.	Variable, fastest at lower beach levels. Legal size 90 mm reached in 1-2 yrs. on WCVI 3-4 yrs. on QCI. Max age, 10 yr. Max size, 18 cm.	Sexually mature after 1 yr. (south) and 3 yr. (north). July and early Aug. on Queen Charlotte Islands. May and June on Long Beach, WCVI.	Filter feeder, mainly planktonic diatoms, but also zooplankton and detritus.	Currently found only on QCI in PNCIMA region.
Varnish Clam *Nuttallia obscurata*	Well established in Strait of Georgia and Barkley Sound. Most northern occurrence published to date is Cameleon Harbour in Johnstone Strait, but species is actively spreading.	High intertidal. Sand/gravel beaches, particularly loose sand.	Unknown but speculated to be similar to Manila clams. Max size, 69 mm. Max weight, 61 g.	Timing unknown.	Filter feeder, mainly plankton, but also organic detritus.	Associated with Manila and littleneck, softshell (*Mya arenaria*), and *Macoma* clams. Compete with Manila clams over high intertidal zones. Varish clams dominate high intertidal and Manilas mid intertidal.
Cockle *Clinocardium nuttallii*	Common throughout BC but not abundant in any one location.	Shallow burrow, often large adults are exposed. Prefers muddy substrates which are not common in BC (restricted estuaries, bays and channels.	Moderately fast Shell size of 60 mm ~ 3 yrs. of age. Max size , 120 mm.	Cockles are hermaphroditic, unlike the other species mentioned here.		
Soft-shelled clam *Mya arenaria*	Found throughout BC primarily in estuaries.	Soft substrate mud-sand. Mid to upper intertidal area.	Max size, 150 mm.			Commercially harvested of the east coast of North America.

(Fisheries and Oceans Canada 2000a; DFO 2001b; 1999c; 1999d; 2001c; 2001e; Stocker *et al. eds*. 2001; Jamieson and Francis 1986)

Table 2.1 Habitat use for selected invertebrate molluscs in PNCIMA.

IT = Intertidal, ST = Subtidal, BE = Benthic, PE = Pelagic, PL = Planktonic, SP = Sponge Reef, SG = Seagrass Beds, KE = Kelp Beds, ES = Estuaries, MU = Mud, SA = Sand, GR = Gravel, SH = Shell, RO = Rocky.

			Life History Function				
Group	**Common Name**	**Scientific Name**	**Migration**	**Spawning**	**Rearing Larvae**	**Rearing Juvenile**	**Foraging**
Bivalves	Geoduck	*Panopea abrupta*		IT, ST, BE, MU, SA, GR	PL	PL	IT, ST, BE, MU, SA, GR
	Horse Clams	*Tresus capax*		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
		Tresus nutallii		IT, ST, MU, SA, GR, SH	PL	PL	IT, ST, MU, SA, GR, SH
	Butter Clam	*Saxidomus gigantea*		IT, ST, ES, MU, SA, GR, SH	PL		IT, ST, ES, MU, SA, GR, SH
	Manila Clam	*Venerupis philippinarum*		IT, MU, SA, GR	PL		IT, MU, SA, GR
	Littleneck Clam	*Protothaca staminea*		IT, ST, ES, GR	PL		IT, ST, ES, GR
	Razor Clam	*Siliqua patula*		IT, ST, SA	PL		IT, ST, SA
	Varnish Clam	*Nuttallia obscurata*		IT, SA, GR	PL		IT, SA, GR
	Cockle	*Clinocardium nuttallii*		MU	PL		MU
	Soft-shelled Clam	*Mya arenaria*		IT, ES, MU, SA	PL		IT, ES, MU, SA
	Pink Scallop	*Chlamys rubida*		IT, ST, MU, SA, GR, RO	PL		IT, ST, MU, SA, GR, RO
	Spiny Scallop	*Chlamys hastata*		IT, ST, GR, RO		PL	IT, ST, GR, RO
Gastropods	Northern Abalone	*Haliotis kamtschatkana*		IT, ST, KE, RO	PL	IT, ST, KE, RO	IT, ST, KE, RO
Cephalopods	Opal Squid	*Loligo opalescens*	IT, ST	IT, ST, MU, SA, GR, SH, RO		IT, ST	IT, ST
	Neon Flying Squid	*Ommastrephes bartrami*	PE	PE	PE	PE	PE
	Giant Pacific Octopus	*Octopus dofleini*		BE	PL	BE, SE, MU, SA. GR, SH, RO	BE, SE, MU, SA. GR, SH, RO

Commercial echinoderms include sea cucumbers and sea urchins, which occur benthically throughout British Columbia's coastal waters. Sea cucumbers inhabit a range of habitats, including eelgrass beds, mussel beds, and sheltered rocky substrates. Sea urchins are commonly found along rocky shores with various habitat preferences; kelp beds, moderately strong surf, and open waters. Sea urchin depths range from the low tide line to 1157 m (Stocker *et al. eds*. 2001; DFO 2001d; 2001a; Fisheries and Oceans Canada 2002b; Parker 2002; Perry *et al.* 2001; 2002; Perry and Waddell 1999; Rogers and Neifer 2002; Workman 1999).

Breeding season in sea urchins appears to be triggered by environmental factors such as number of days of bright sunshine, phytoplankton blooms, and warm ocean temperatures (Cameron and Fankboner 1986), which may be affected by climate change. Red sea urchins spawn between March and September, green sea urchins between February and March, and purple sea urchins between October and December. Larvae are planktonic for approximately two months prior to their settling on suitable substrate. Juvenile abundance for red sea urchins has been found to be highest where large numbers of adult red sea urchins are present, as the juveniles may sometimes hide from predators beneath the adult spine canopy (Stocker *et al. eds*. 2001). This association is thought to be important in the recruitment success of juveniles to legal harvesting size (Johannessen *et al.* 2005). Green sea urchins are often found with red urchins, though their distribution tends to be patchy. They are thought to be more mobile than red urchins and may make seasonal migrations between deep and shallow waters (Stocker *et al. eds*. 2001). Although fishing for green sea urchins is focused on only a few locations in PNCIMA, they do occur in other areas, and are usually found at depths <20 m. (I. Perry, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4 GROUNDFISH

Our biological understanding of the life histories of many species of groundfish is limited due to their occurrence at depth, even though many are of significant commercial interest. Stock assessment personnel have for the last few years been assembling information on what is known for some species of groundfish in an area roughly equivalent to the PNCIMA region. These data include spatial distribution of commercial catch and catch per unit effort (CPUE, see Figure 1.8), which can identify hot-spots for species aggregations (Johannessen *et al.* 2005). Recent trawl surveys also provide a fishery-independent assessment of groundfish distribution (Map 2.4). Habitat characteristics, such as depth and substrate, appears to be correlated with certain species (e.g., Sinclair *et al.* 2005). Information remains limited for topics which cannot be determined from catch data, such as the location of spawning and rearing grounds, migratory pathways, and critical habitat. For more detailed information, see Appendix G: Groundfish.

2.4.1 Rockfish

There are approximately 40 species of rockfish in BC. In general, rockfish are slow growing and long lived (some over 100 years), taking between five and ten years to mature sexually. The primarily benthic fish are non-migratory, making mostly only localized movements, but some may make seasonal depth migrations. From an ecosystem perspective, considering the many rockfish species and their life stage habitat preferences, the entire coast from subtidal to depths of at least 2000 m could be considered important rockfish habitat (R. Stanley, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Rockfish habitat has thus not been mapped here.

Rockfish are typically grouped into three depth zones: inshore (0-182 m or 0-100 fathoms), shelf (91-182 m or 50-100 fathoms) and slope (>182 m or >100 fathoms) (Table 2.2).

Tables 2.2 – 2.4 provide biological information on species associated with the three rockfish zones listed above. Only commercially important species have been examined in detail in this section due to lack of information on other species. Species unique to the PNCIMA region were noted where applicable; however, most rockfish are distributed throughout the coastal waters of BC (Johannessen *et al.* 2005).

Table 2.2 Commercially important rockfish species (*Sebastes*, *S.*) are listed according to these zones.

Inshore Rockfish		**Shelf rockfish**		**Slope rockfish**	
Tiger	*S. nigrocinctus*	Silvergrey	*S. brevispinis*	Pacific Ocean Perch	*S. alutus*
Yelloweye	*S. ruberrimus*	Canary	*S. pinniger*	Yellowmouth	*S. reedi*
Quillback	*S. maliger*	Yellowtail	*S. flavidus*	Rougheye	*S. aleutianus*
Copper	*S. caurinus*	Widow	*S. entomelas*	Redstripe	*S. proriger*
China	*S. nebulosus*			ShortspineThornyhead	*Sebastolobus alascanus*
				LongspineThornyhead	*Sebastolobus altivelis*

(Bonnet *et al.* 2006)

Inshore Rockfish

In general, inshore species are slow growing, late maturing, long-lived, sedentary as adults, and are associated with specific rocky reef habitats. They mate in the fall and release free-swimming larvae in the early spring. Larvae are pelagic until they settle and generally reside in reefs. Inshore species tend to experience good recruitment every 15-20 years.

Due to declines in the abundance of some inshore rockfish populations, Rockfish Conservation Areas (RCAs) were instated to protect and preserve rockfish biomass (Map 2.5). BC has a total of 89 RCAs covering 2,338 km^2 (Fisheries and Oceans Canada 2004). These protected areas do not prohibit all activities within them.

Table 2.3 Inshore rockfish species (*Sebastes*, *S.*) summary information (sources at end of Table 2.5).

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Yelloweye *S. ruberrimus*	Gulf of Alaska to Baja California.	Shallow waters in the spring, although they are caught mainly in deeper waters. Common around reefs with caves and crevices. 15-366 m.	Mate in fall and spawn in spring.	117	18 yrs (Size Unknown)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Quillback *S. maliger*	Gulf of Alaska to Avila California.	Rocky reefs around caves and crevices, in inlets and shallow rock piles. 9-274 m	Mate in fall and spawn in spring.	76	12 yrs (23-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	Declining
Copper *S. caurinus*	Kenai Peninsula, Alaska to Baja California.	Offshore rocky reefs and in shallow bays to often >20 m, up to 90 m. Prefer rocky to rock/sand bottoms with irregular bathymetry.	Mate in fall and spawn in spring.	45	8 yrs (41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
China *S. nebulosus*	Prince William Sound, Alaska to San Miguel, California.	Along the bottom of the ocean floor around offshore reefs with crevices and caves. 3-128 m.	Mate in fall and spawn in spring.	u	Age Unknown (28-30 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Black *S. melanops*	Amchitka Island, Alaska to Huntingbeach California.	Occur in large aggregates around rocky reefs and soft bottom substrates. Midwater habitats usually around kelp or other cover. Occasionally found in offshore open waters. 0-367 m.	Mate in fall and spawn in spring.	u	Females: 11 yrs Males: 10 yrs (36-41 cm)	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u
Tiger *S. nigrocinctus*	Prince William Sound, Alaska to Point Buchon, California.	Deep waters near rocky crevices and caves. 24-274 m	Mate in fall and spawn in spring.	u	u	Are found in rocky reef habitat as found off of Banks and Aristazabal Islands and many other areas in the QC Basin.	u	u

Table 2.4 Slope rockfish species summary information (sources listed at end of Table 2.5).

Species	**Distribution**	**Habitat**	**Spawn**	**Life Span (years)**	**Age at Sexual Maturity or Size at 50 % Maturity**	**Relevance to PNCIMA Area**	**Stock Status in PNCIMA Area**	
							Abundance	Trend
Yellowmouth *S. reedi*	Gulf of Alaska to northern California. Second most abundant slope rockfish in terms of catch in BC.	100-430 m.	April/May.	70-100	9 yrs 38 cm	Large catches taken from Goose Island and Mitchell's gullies in the QCS.	Average	Expected to decline until next major recruitment occurs.
Rougheye *S. aleutianus*	Japan and Kamchatka Peninsula to Bering Sea and Aleutian Islands, down to southern California.	Prefer boulder fields along the continental slope shelf. 25-2,830 m.	April.	147	Age Unknown Females: 47 cm Males: 45 cm	Significant landings come from Goose Island and Moresby gullies in the QCS.	Low	Uncertain, but thought to remain low for some time.
Shortraker *S. borealis*	Japan, the Okhotsk Sea, and SE Kamchatka to the Bering Sea and Aleutian Islands and down to California.	25-875 m. Larger solitary individuals found on silt or cobble bottoms near boulders.	April..	120	Age Unknown 45 cm	Trawling activity occurs along WCVI. Hook and line activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Not expected to increase in the near future.
Redstripe Rockfish *S. proriger*	Bering Sea to southern California	Areas of high relief and rocky bottoms. 12-425 m.	May-July.	48	Age Unknown 28 cm	Bottom and midwater trawling activity occurs around Goose Island and Mitchell's gullies in QCS.	Low	Declining.
Shortspine Thornyheads *Sebastolobus altivelis*	Northern Baja to the Bering Sea to the Commander Islands, north of Japan.	Uniformly distributed along soft sediments, near rocks or other high-relief structures. 90-1460 m. Migrate into deeper waters as they increase in size.	Spawn in spring. Produce jelly egg mass (20,000-450,000 eggs), which float to surface where development and hatching occur. Pelagic for 14-15 months then settle to depths of 100 m and then migrate to deeper waters.	62 (AK) 100^{+}(Cal.)	16 yrs (AK) 28 yrs (Cal.) 23-25 cm	This species represents approx. 90% of catch from the Goose Island, Mitchell's and Moresby gullies in QCS and Hecate Strait.	u	u
Pacific Ocean Perch *S. alutus*	Southern California to the Bering Sea and southwest to the Kurile Islands.	Prefer rocky, high relief substrate, but are commercially found/harvested over cobble substrate. Live at depths of 40-640 m.	Spawn in March/April in the QCS. Juveniles pelagic for 2-3 yrs. Fecundity: 90,000-510,000 eggs.	100	Females: 8 yrs, 35 cm Males: 6-8 yrs, 34 cm	Hecate Strait and QCS dominate fishing areas for perch – mostly in QCS. Three main locations are the Goose Island, Mitchell's and Moresby gullies.	Stable	Slowly declining.

Table 2.5 Shelf rockfish species summary information.

Species	Distribution	Habitat	Spawn	Life Span (years)	Age at Sexual Maturity or Size at 50 % Maturity	Relevance to PNCIMA Area	Stock Status in PNCIMA Area	
							Abundance	Trend
Widow *S. entomelas*	Southern California to the Gulf of Alaska. Commercial abundance ranges from northern California to central BC. Distribution is difficult to predict.	High relief near edge of continental shelf. 50-375 m.	Spawn late winter or early spring.	58	Females: 14 yrs. Males: 5 yrs. 43 cm	QCS represents a large proportion of coast wide landings. Fishing hot spots include Triangle Island in the winter and Goose Island Bank in the summer.	u	u
Silvergray *S. brevispinis*	Southern California to the Bering Sea. Center of commercial abundance in BC.	High relief near the edge of the continental shelf Commercial fished between 100-375 m.	Mate in spring and spawn mid-summer.	80	Females: 15 yrs. Males: 8 yrs. 38-51 cm	Four stocks in BC, three occur in the PNCIMA region, Hecate Strait, QCS, and WCVI.	abundant in QCS	u
Canary *S. pinniger*	Baja California to the Gulf of Alaska. Center of commercial abundance is northern California to central BC.	High relief areas near the edge of the continental shelf. Around reefs and over soft bottoms. 50-375 m.	Mate in mid-fall and spawn late winter or early spring.	60	Between the ages of 5 and 14 yrs. 58 cm	Two stocks in BC, QCS and WCVI. Most landings come from the central coast of WCVI (60-70 %) and QCS.	u	u
Yellowtail *S. flavidus*	San Diego, California to the Gulf of Alaska. Center of commercial abundance is northern California to northern BC.	Adopts both a near- and off- bottom habitats. Around offshore reefs to depths of 549 m. Have a homing instinct.	Mate in mid-fall and spawn late winter or early spring.	50	Between the ages of 5 and 14 yrs. 36-46 cm	Two stocks, Boundary (southern WCVI to northern Washington, 3C) and Coastal (central WCVI to Alaska, 3D, 5A-5E). Majority of landings come from QCS and south and central WCVI.	Low	Declining

(Fisheries and Oceans Canada 2000b; DFO 1999l; 1999g; 1999h; 1999f; 1999j; 1999e; 1999k; 1999i; 1999a; 1999m; Gotshall 1981; Lamb and Edgell 1986; Stein and Hassler 1989).
u – Information unknown.

2.4.2 <u>Roundfish</u>

Pacific Cod

Pacific cod are a relatively short-lived, fecund species. In the PNCIMA region, Pacific cod densities appear to be highest in the deep troughs in Queen Charlotte Sound, around Goose Island grounds, and southeast Dixon Entrance. They tend to be commercially abundant at depths of 18-130 m but do occur in waters up to 550 m, and prefer sandy or muddy bottoms (Westrheim 1996). Pacific cod exhibit little movement within a given area but do undergo seasonal migrations from shallower waters in the spring and summer to deeper waters in the fall and winter. Spawning occurs once annually between February and March. Eggs are demersal, are slightly adhesive, and are commonly deposited on shell, coarse sand, sandy gravel, muddy sand, and cobble (Westrheim 1996). Hatching occurs after 15-17 days, depending on water temperatures. Larvae are then planktonic and settle near the bottom (at depths of 5-11 m) and incubate for 10-17 days depending on water temperatures. It is during this time that Pacific cod are especially susceptible to environmental changes (Booth 2000). Important spawning and rearing areas are shown in Map 2.6.

Walleye Pollock

Walleye pollock are considered the most abundant fish species in the North Pacific Ocean. In BC, pollock are present throughout the coast. They are semi-demersal and are most abundant along the continental shelf and slope at depths between 100-400 m. However, during various stages of their lifecycle, they may also be found nearshore, in large estuaries, coastal embayments and open ocean basins. Schooling pollock spawn in March and April at depths between 50-300 m and are usually associated with an increase in abundance of Pacific hake (Shaw and McFarlane 1986). Eggs are released into the water, and both planktonic eggs and juveniles appear in the upper water column up to 60 m deep. Schools of juveniles make diel migrations to surface waters at night to feed on plankton and return to deeper waters during the daytime. Juveniles may be found in a variety of habitats including eelgrass beds (over sand and mud substrates), and gravel and cobble bottom types. In addition to the spawning and rearing areas identified during the EBSA process (Map 2.7), past reports have indicated spawning in inlets on east Moresby Island as well as in midwater inlets along Hecate Strait and Queen Charlotte Sound (Shaw and McFarlane 1986).

Pacific Hake

In BC there are two Pacific hake stocks, a non-migratory inshore stock in the Strait of Georgia and a migratory stock offshore of the west coast of Vancouver Island (WCVI), which sometimes extends into PNCIMA. Offshore hake range from southern California to Queen Charlotte Sound with annual migrations into Canadian waters in early spring to late fall (February to November). They are generally found schooling near the bottom or at midwater depths (200-1000 m) over the continental shelf, primarily off of WCVI in Canada. In the past, high levels of biomass have been detected in the PNCIMA region around Brooks Peninsula (Scagel and McFarlane 1995). However, the overall abundance here is generally low compared to numbers off of the WCVI. Significant numbers of hake were observed in PNCIMA in 1998 and 2005, and in 2006 were higher than WCVI (W. Crawford, DFO, Institute of Ocean Sciences, Sidney BC, pers. comm., 2007). The extent to which offshore hake in California move northwards appears to be dependent on water temperatures (specifically the northern extent of warm waters). In El Niño years, larger numbers of hake were observed to migrate into Canadian waters and were found to migrate further north, even as far as Hecate Strait and Dixon Entrance (Map 2.8). An increase in juveniles along the WCVI also suggests that a shift in settlement patterns may also occur during these events (Dorn *et al.* 1999).

Lingcod

Lingcod range from California to Alaska in the eastern Pacific Ocean, centered in BC. They are largely non-migratory and reside in rocky areas at depths of 3-400 m, but are most commonly found between 10-100 m. Lingcod are generally associated with clean waters over rocky substrate, (*i.e.,* where there is an abundance of rocky outcroppings, crevices, caves, or boulders) at shallow depths and high relief bedrock at intermediate depths (LaRiviere 1981; Cass *et al.* 1990; Jamieson and Dixon 2001). They are also commonly associated with 75-100% substrate cover by sessile invertebrates and algae, and with strong currents (up to 4-6 km hr^{-1})(Jamieson and Dixon 2001). In the PNCIMA region, densities appear to be highest in northern Moresby Trough, the southern edge of Dixon Entrance, and around Goose Island Bank.

Mating season starts with the onset of adult males migrating to near shore in October (prior to female migration) to establish nesting sites. Nests may be found intertidally down to 100 m depth, but are most commonly found between 5-25 m in rock crevices or on ledges where there is a strong current to oxygenate the egg masses. Spawning occurs annually from December to March, during which time females migrate nearshore to deposit egg masses in the nesting sites previously established by the males. Males then fertilize the egg mass and remain behind to guard the nest until the eggs hatch in early March to late April. Females return to deeper waters shortly after spawning. Once hatched, larvae remain planktonic for 6-8 weeks, reaching approximately 4-5 cm. Larvae settle onto bottom substrates in inshore waters, usually near kelp or eelgrass beds. Juvenile rearing habitat is eelgrass beds and sandy/flat bottom habitat from 0-75 m (J. King, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005). Juveniles, unlike adults, are often found on flat substrates in shallower waters, and later move to areas of high relief and rockiness as they mature. The benthic dispersal of lingcod is believed to be limited, as lingcod have been found to colonize and recruit in localized areas. An area of the northern coast of Vancouver Island is known spawning and rearing habitat (Map 2.9); other areas are not well known (J. Fargo, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

Sablefish

Genetically, sablefish appear to represent a single stock, but movement of adults is limited. In BC, two populations, Alaskan (north) and west coast (south), are separately managed, and these have been delineated based on varying recruitment and growth differences. The distribution of adult sablefish is depth dependent, with older individuals and males most abundant at greater depths (Haist *et al.* 1999).

Spawning occurs both within and outside of the PNCIMA region along the continental slope at roughly 1000 m or greater depths, between January and March. In April/May, larvae rise to surface waters over the shelf and then migrate inshore for approximately 6 months. Young sablefish rear in nearshore waters and shelf habitats until 2-5 years of age, at which point they migrate back to offshore waters and into the fishing grounds (Fisheries and Oceans Canada 2002c).

Juveniles are highly mobile and can move between nursery areas in Hecate Strait to the Gulf of Alaska and the Bering Sea. Spawners, larvae and juveniles can be found in almost all areas of PNCIMA, depending on the strength of recruitment (R.A. Kronlund, DFO, Pacific Biological Station, Nanaimo BC, pers. comm., 2005).

2.4.3 Flatfish

Sole and Flounder

Dover sole: Dover sole are a deep-water species commonly found along muddy bottoms in deep troughs and are generally found in deeper waters during the winter than in the summer (Sinclair 2002; Fargo and Kronlund 1997). In Hecate Strait they spawn annually in deep waters off the west coast of the Queen Charlotte Islands during the late fall and winter at depths between 800-1000 m (Map 2.10) (DFO 1999b; Westrheim *et al.* 1992). Larvae undergo a prolonged pelagic phase offshore in surface waters along the continental shelf for up to 2 years, before they gradually move into deeper waters along the slope as they grow and reach sexual maturity (Fargo and Kronlund 1997; Jacobson and Hunter 1993). As adults, females are generally found in deeper waters than males, and larger Dover soles are generally found deepest, where oxygen concentrations are lowest (Jacobson and Hunter 1993).

English sole: English sole are found between 5-150 m depth, preferring shelf waters and, unlike other flatfish species, are not generally found in deeper waters during the winter months (Sinclair 2002). English sole are associated with sandy-mud substrates and show preference for water temperatures between 7 -10 ^{o}C (Fargo *et al.* 2000).

English sole spawn annually between September and March with peak spawning activity occurring in October/November. Older individuals tend to spawn latest in the fall. They exhibit extreme sexual dimorphism and are non-intermittent spawners (Fargo *et al.* 2000). Fertilized eggs hatch after 6-10 days, depending on water temperatures and salinity. Pelagic larvae drift for 6-10 weeks, many in shallow (0-20 m) bays or estuaries, where they stay until they reach approximately 2 cm. One of the primary English sole nurseries in BC is in the nearshore shallow waters off the east coast of Graham Island (Map 2.10) (Fargo *et al.* 2000). After metamorphosis is completed, individuals settle to the bottom and continue to develop. Between the ages of two and three, they slowly migrate into deeper waters and, by four years of age, they are mixed with adults.

Petrale sole: Petrale sole are found at depths from 18-750 m in areas with sandy substrate (Booth 2000; Eschmeyer and Herald 1983). Petrale make extensive seasonal movements. They are generally found in deeper waters during spawning in the winter, and in shallower waters, particularly around Goose Island, during feeding in the summer (Sinclair 2002; Forrester 1969).

Petrale spawn annually during the winter months off the WCVI and the northern tip of the Queen Charlotte Islands (Map 2.10). Females release eggs into surface waters where they are fertilized and float freely during incubation. After approximately 8 days (varying with water temperature and salinity), the eggs hatch and the larvae remain planktonic, drifting in ocean currents until they reach nursing grounds. Key nursery grounds in the Hecate Strait and Queen Charlotte Sound area are along the eastern boundary of Goose Island Bank and to a lesser extent along Cape Scott (Cook) Bank, Horseshoe Grounds, and "Ole Spot" in area 5C (Map 2.10) (Ketchen and Forrester 1966).

Rex sole: Rex sole are usually found in sand or mud bottom substrates at depths of 18-640 m. The catch distribution, which is higher on the shelf in the troughs and around the edges of banks, suggests they are most abundant at about 60 m (Johannessen *et al.* 2005). According to Hosie (1975), spawning occurs between January and June along the offshore area of Oregon, with peak activity in March/April. Spawning location varies by year.

Rock sole: Rock sole adults show little preference among substrates, although in BC they are most abundant over gravel substrates at depths between 18-55 m (Fargo *et al.* 2000; Booth 2000). Rock sole are essentially a shallow water species (5-80 m) and so adult populations may be separated by the deep troughs found in Queen Charlotte Sound and Hecate Strait (Sinclair 2002; Fargo *et al.* 2000). Rock sole are non-intermittent spawners. They spawn annually, usually at 20-40 m depths, with peak spawning occurring in March/April. Rock sole have separate localized spawning and summer feeding areas. The primary spawning area is located off Cumshewa Inlet near east Moresby Island (Map 2.10). An important nursery area is around Reef Island just south of Cumshewa Inlet (Strong *et al.* 2002). After spawning, adults migrate to feeding grounds in central Hecate Strait. Fertilised eggs are demersal and adhesive, hatching after approximately 10-15 days (Ketchen 1982). Larvae exhibit diel movement and are commonly found in waters between 5-10 m deep during the day, when they feed on copepod nauplii, and at around 30 m depth at night. Wind and tidal currents transport larvae until they settle to the ocean bottom at about 2 cm length. For the first year, juveniles remain in waters between 5-20 m deep, and by 2-3 years of age, have moved to waters 20-80 m deep.

Arrowtooth flounder: Arrowtooth flounder juveniles occur in waters along the continental shelf until an age of 4, after which they migrate into deeper waters to join the adults along the continental slope. Adults are generally found in areas where there is coarse sand substrate, whereas juveniles are often associated with sand or mud substrates. Arrowtooth flounder typically inhabit waters 50-900 m deep and show preference for bottom temperatures of 7-8 ^{o}C. They spawn in the fall and winter months in waters ≥350

m. Their eggs are pelagic; incubation is 3-4 weeks. Larvae are planktonic for 4 weeks before settling as juveniles. As with many other flatfish species, arrowtooth flounder migrate seasonally from deep, winter spawning grounds to shallow, summer feeding grounds. Important spawning and feeding areas in the PNCIMA region have not been identified.

Pacific Halibut

Pacific halibut are commonly found throughout BC's waters along the continental shelf and slope from relatively shallow waters to at least 1000 m (Carl 1971). Mature fish may undergo extensive movement (as far as 3200 km); however, most tend to stay on the same grounds and make only seasonal migrations from shallow feeding areas in the spring to deeper spawning grounds in the winter (Fisheries and Oceans Canada 2002a; Carl 1971). Halibut spawn in waters along the continental shelf at depths between 180-450 m during the winter (November to March; Map 2.11). The PNCIMA region has some locally important spawning grounds including around the Goose Group, around Cape St. James and areas in northern Hecate Strait and Dixon Entrance (Map 2.11) (Fisheries and Oceans Canada 2002a; Carl 1971). Incubation occurs for 15-20 days as eggs rise to the surface. Larvae develop and may be transported by ocean currents great distances in a counter-clockwise direction around the Northeast Pacific Ocean (International Pacific Halibut Commission 1987). Young fish then settle to the ocean bottom in shallow feeding areas before they migrate back into more southerly and easterly waters at 2-3 years of age.

2.5 PELAGIC FISHES

2.5.1 Herring

Pacific herring spawning migrations move from offshore feeding grounds (west coast of Vancouver Island and Hecate Strait in the north) to the inshore spawning grounds during October to December. Herring congregate in large schools over the winter awaiting gonad maturation (Hay 1985; Fisheries and Oceans Canada 1994; Haegele and Schweigert 1985). In BC, herring spawn in late winter, from February to as late as July, with the majority of spawning occurring in March from the high tide line down to 20 m depth (Fisheries and Oceans Canada 1994), although some spawning can be as deep as 60 m. Spawn deposition occurs in high-energy environments on both bottom substrate and vegetation. Temperature and salinity are important in determining when and where herring spawning occurs. Eggs are generally tolerant to temperatures ranging from 5-15 °C and a salinity range of 3-33‰ (Haegele and Schweigert 1985). Eggs hatch in 10-21 days, and larvae concentrate in the surface layer near shore, aggregated by surface currents. Beginning in the late larval stage, herring undergo a diurnal migration, descending to deep water during the day, and rising to the surface at night. Migration of juvenile herring begins in some areas in the fall of their first year and in other areas not until the following summer. Adults are most commonly found in deeper waters (around 100 m). Important areas for herring were identified during the EBSA process; the life history function associated with each area is identified on Map 2.12. Spawning beds from digitized archived surveys for the years 1930-2002 are also shown (McCarter *et al.* 2005).

2.5.2 Eulachon

Major eulachon spawning and larval rearing areas are shown in Map 2.13. Eulachon summer feeding areas are much more extensive than the areas identified during the EBSA process and shown on Map 2.13. Additional areas include: the offshore banks immediately SW and W of Calvert Island (Calvert Island and Pearl Rock Ground) where the eulachon bycatch in shrimp fishing was severe in the late 1990's; the Cape Scott ground; the SE edge and NE corner of the Goose Island bank; the SE edge of Middle Bank (North Bank); the entire 50-100 fathom edge from Rose Spit, Two Peaks, White Rocks, Butterworth edge, Bonilla Island down to the Horseshoe ground and SE to Cape St. James; and the entire Chatham Sound. More information on pelagic species can be found in Appendix H: Pelagic Fishes.

2.6 MARINE MAMMALS AND TURTLES

2.6.1 Cetaceans

For most cetaceans, there is limited knowledge of habitat use within PNCIMA. Canada's Pacific waters are a year round home for some species, while part of annual migration routes or summer feeding grounds for others. It is not clear how important PNCIMA is to the health and stability of cetaceans overall, due to limited data for most species regarding their distribution and their habitat use. Spatial data on cetaceans are being compiled, largely from opportunistic sightings, but also from historical whaling records and habitat modeling. These data sets have been used to produce maps with high levels of uncertainty. Life history functions associated with some areas are identified for gray (Map 2.14), humpback (Map 2.15), and northern resident killer whales (Map 2.16). Important habitat for northern resident killer whales has been identified (Map 2.16), while potential critical habitat for killer whales is still being assessed (Ford 2006). Areas of importance for blue whales (Map 2.17), fin whales (Map 2.18), sei whales (Map 2.19), and sperm whales (Map 2.20), have been identified in the EBSA process (see also Appendix J: Marine Mammals).

2.6.2 Pinnipeds

Steller sea lions and harbour seals remain in BC waters year round. BC waters are also a major migration route and provide vital feeding grounds for California sea lions, northern fur seals and northern elephant seals (Johannessen *et al.* 2005). The PNCIMA region includes all of BC's Steller sea lions rookeries (Map 2.21). Cape St. James and the Scott Islands are critical areas for Steller sea lions. Important areas for feeding and foraging for northern fur seals have also been identified (Map 2.22).

2.6.3 Sea Otters

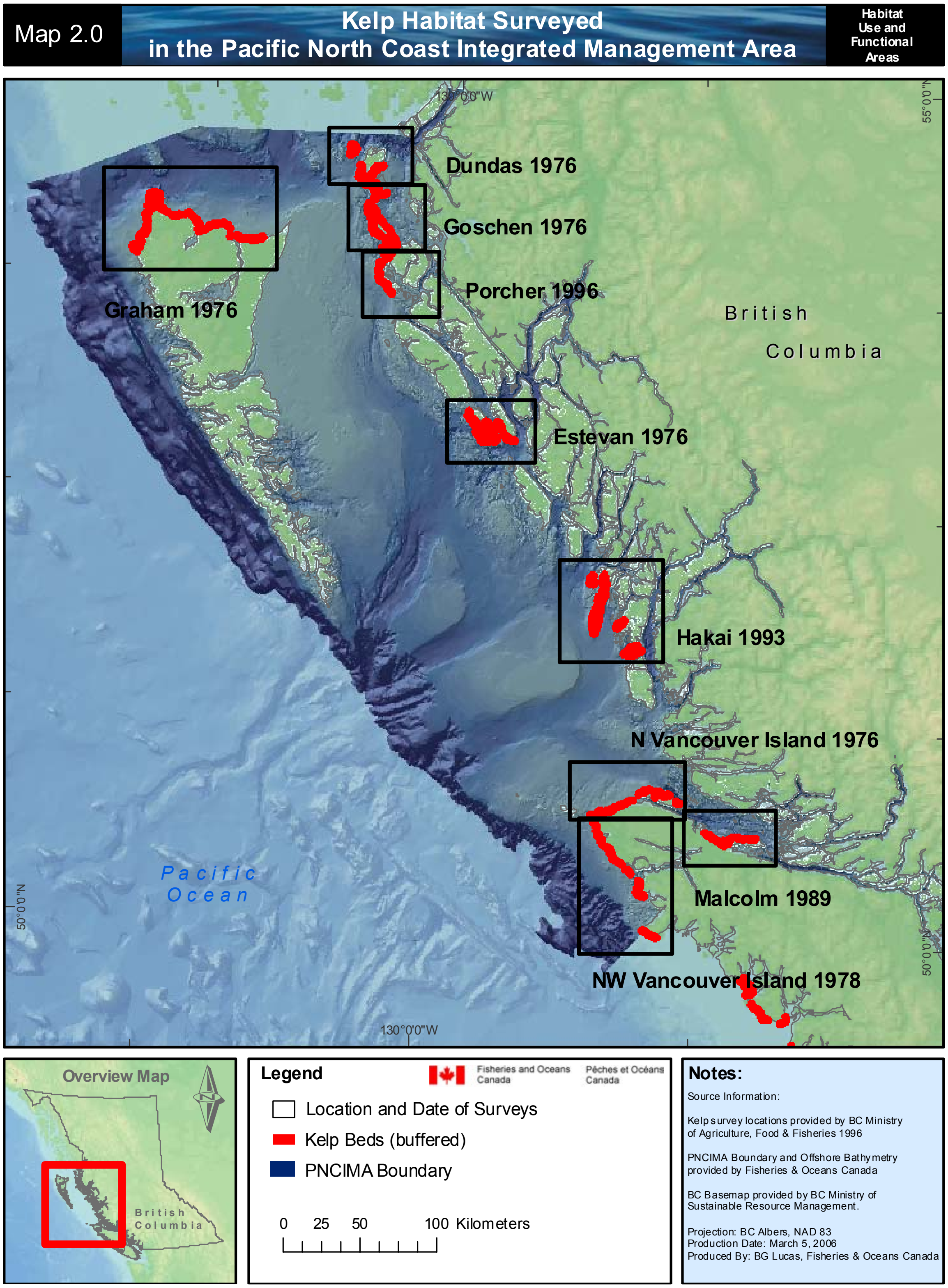
Sea otters have a small population with limited range in PNCIMA (Map 2.23). Their typical habitat is shallow (<40 m), nearshore areas (within 1-2 km of shore) (Reidman and Estes 1990). Kelp beds are important habitat for resting and foraging. Clam beds also provide valuable foraging habitat.

2.6.4 Reptiles

Leatherback turtles nest on beaches in tropical waters, and make long migrations to their feeding areas that include BC waters. The very limited knowledge of leatherback distribution in BC is from anecdotal reports, opportunistic sightings, and recent cetacean/sea turtle surveys. Sightings within PNCIMA are located on Map 2.24, along with important feeding areas.

2.7 ACKNOWLEDGEMENTS

We would like to acknowledge all the authors of the appendices to this Ecosystem Overview and of the Biophysical Overview Report for PNCIMA (Johannessen *et al.* 2005) for providing the detailed information on which some of this chapter is based. We thank Cathryn Clarke for providing the first draft EBSA maps and report. Cathryn Clarke, Aiden Ryan, and Dwight McCullough assisted with GIS technicalities. Stacey Verrin provided technical editing and helpful suggestions. This chapter was improved by the constructive comments of reviewers.



Notes:

Source Information:

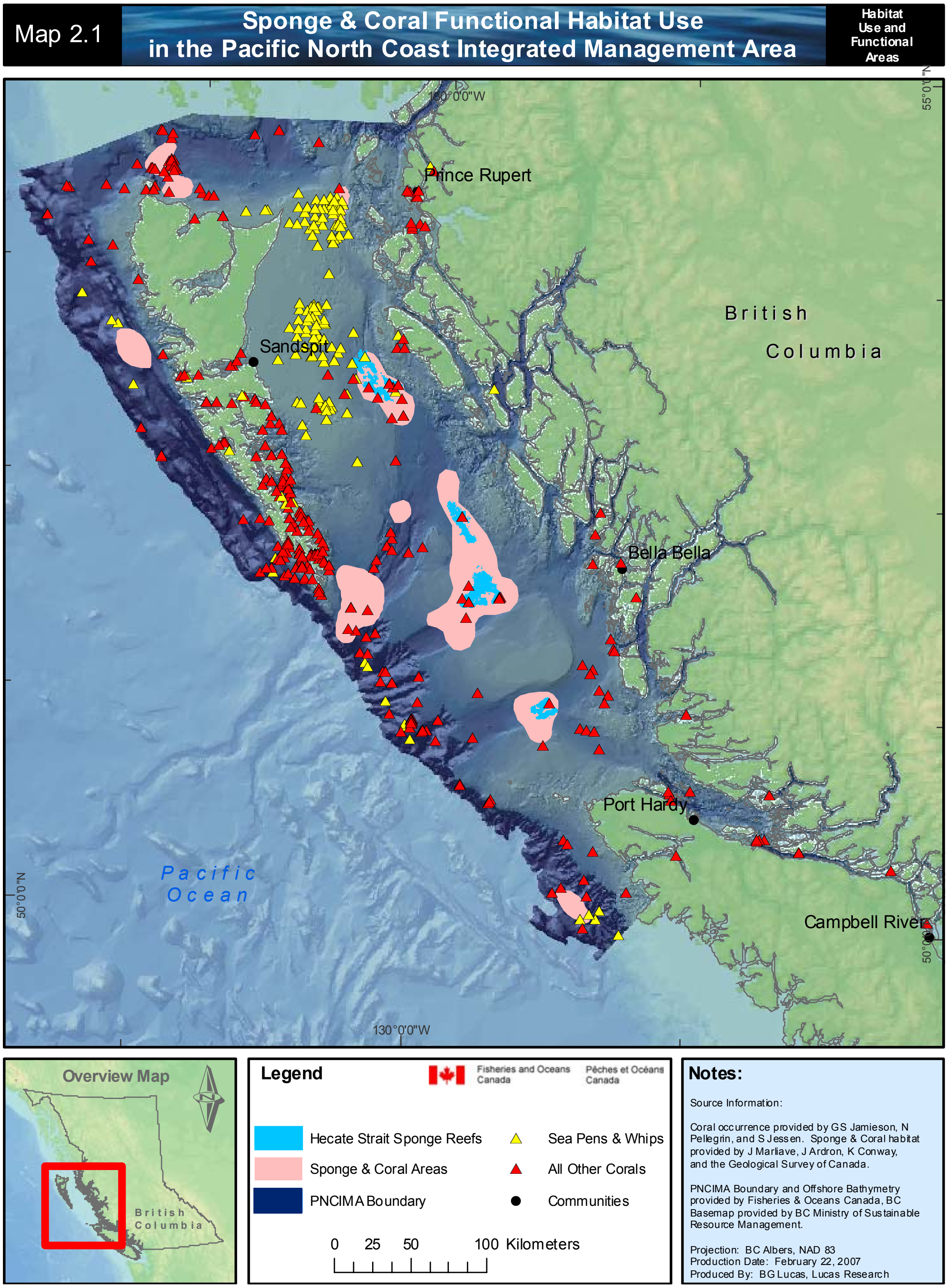
Kelp survey locations provided by BC Ministry of Agriculture, Food & Fisheries 1996

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 5, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.0 Kelp habitat surveyed in PNCIMA (data from BC MAFF 1996).



Notes:

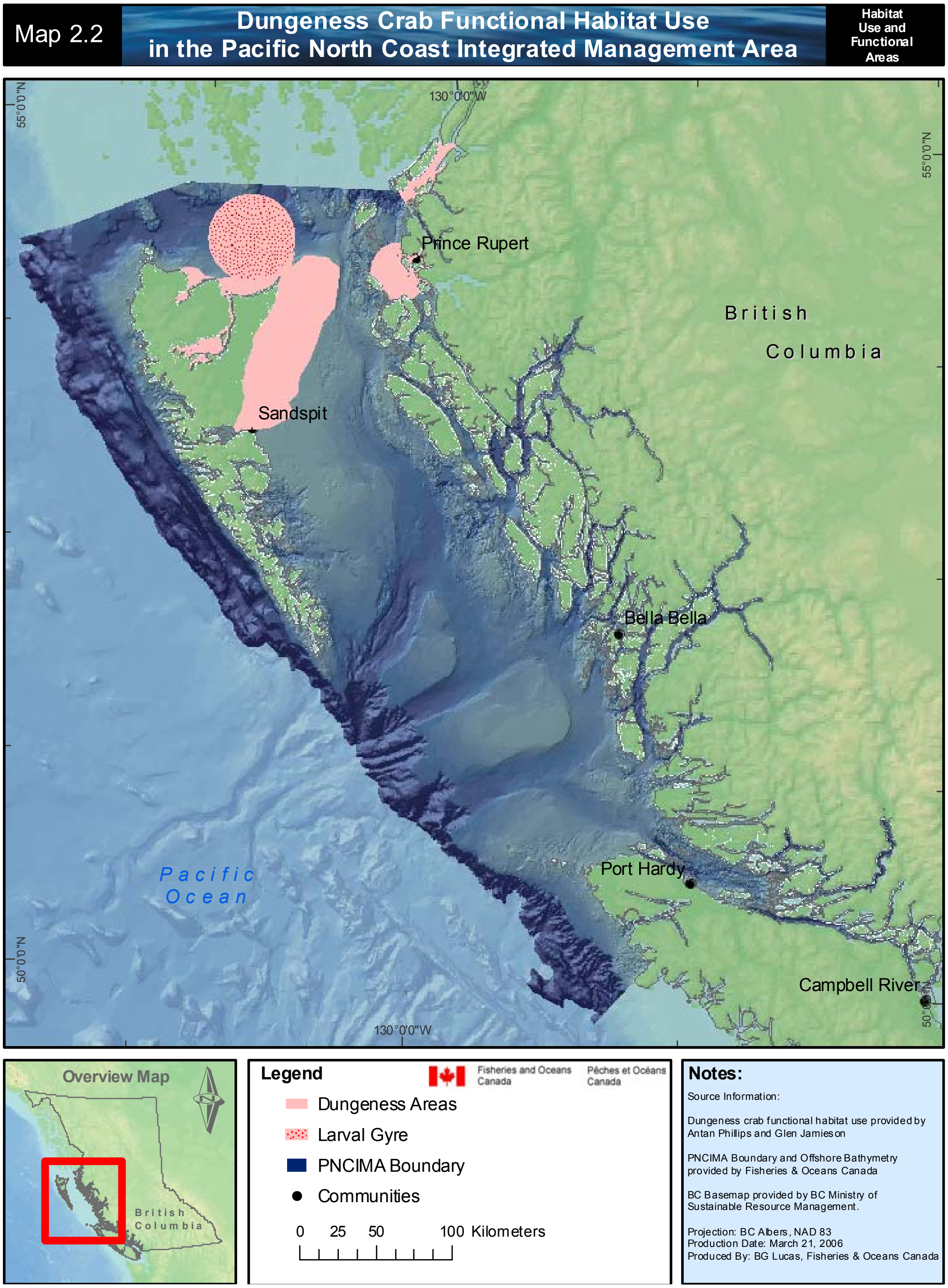
Source Information:

Coral occurrence provided by GS Jamieson, N Pellegrin, and S Jessen. Sponge & Coral habitat provided by J Marliave, J Ardron, K Conway, and the Geological Survey of Canada.

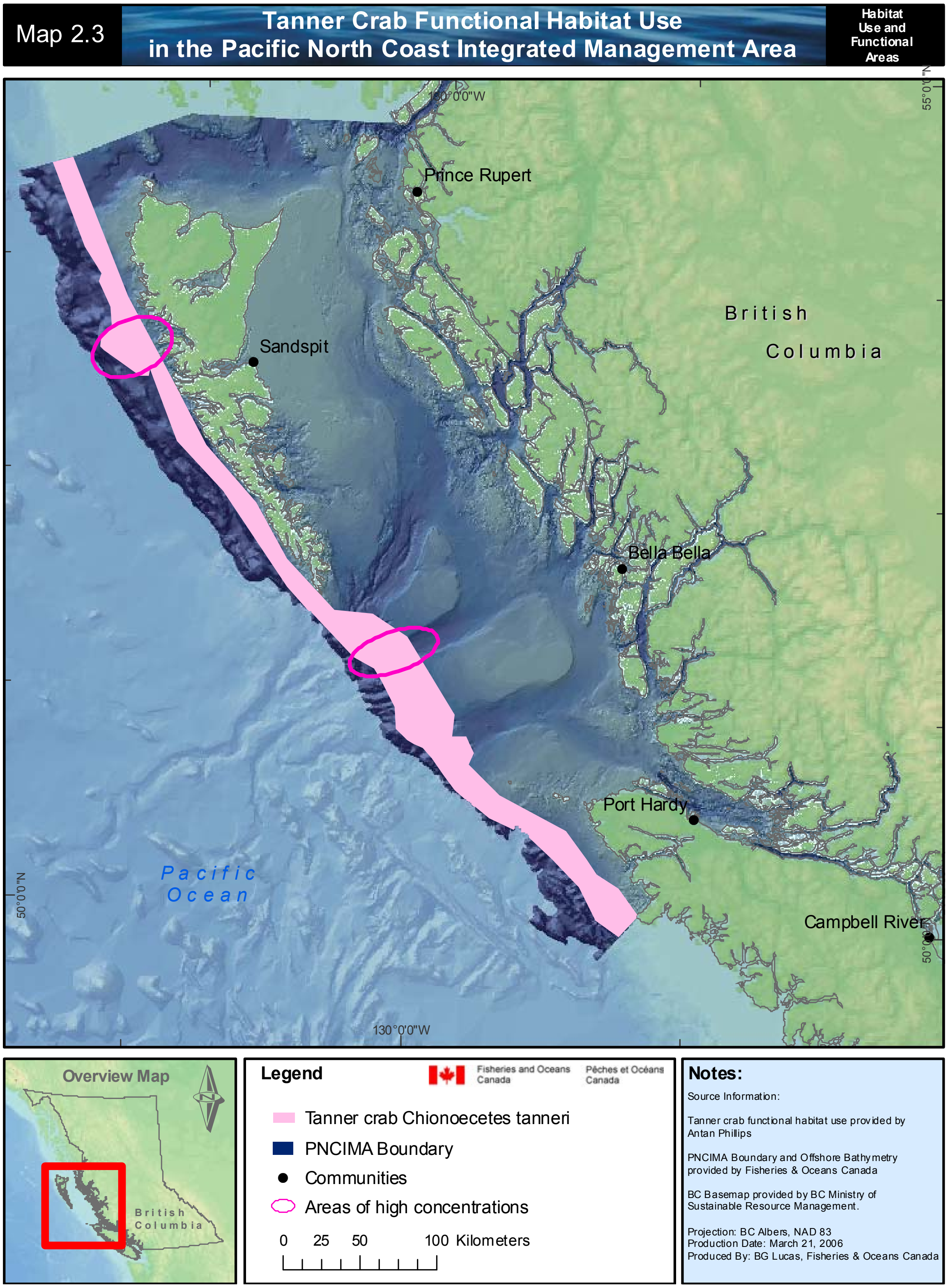
PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada, BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.1 Sponge and coral functional habitat use in PNCIMA.



Map 2.2 Dungeness crab functional habitat use in PNCIMA.



Notes:

Source Information:

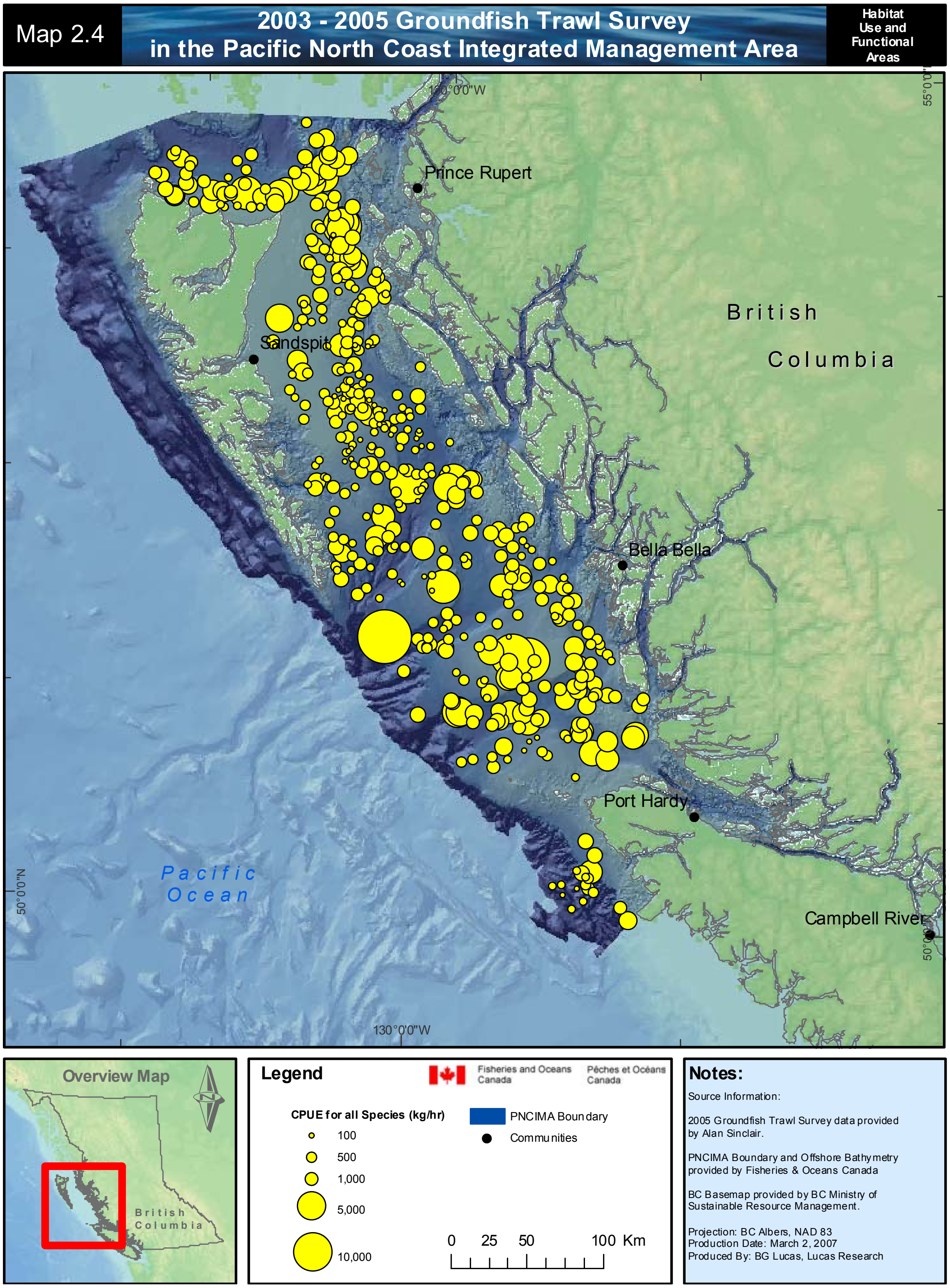
Tanner crab functional habitat use provided by Antan Phillips

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 21, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.3 Tanner crab functional habitat use in PNCIMA.



Source Information:

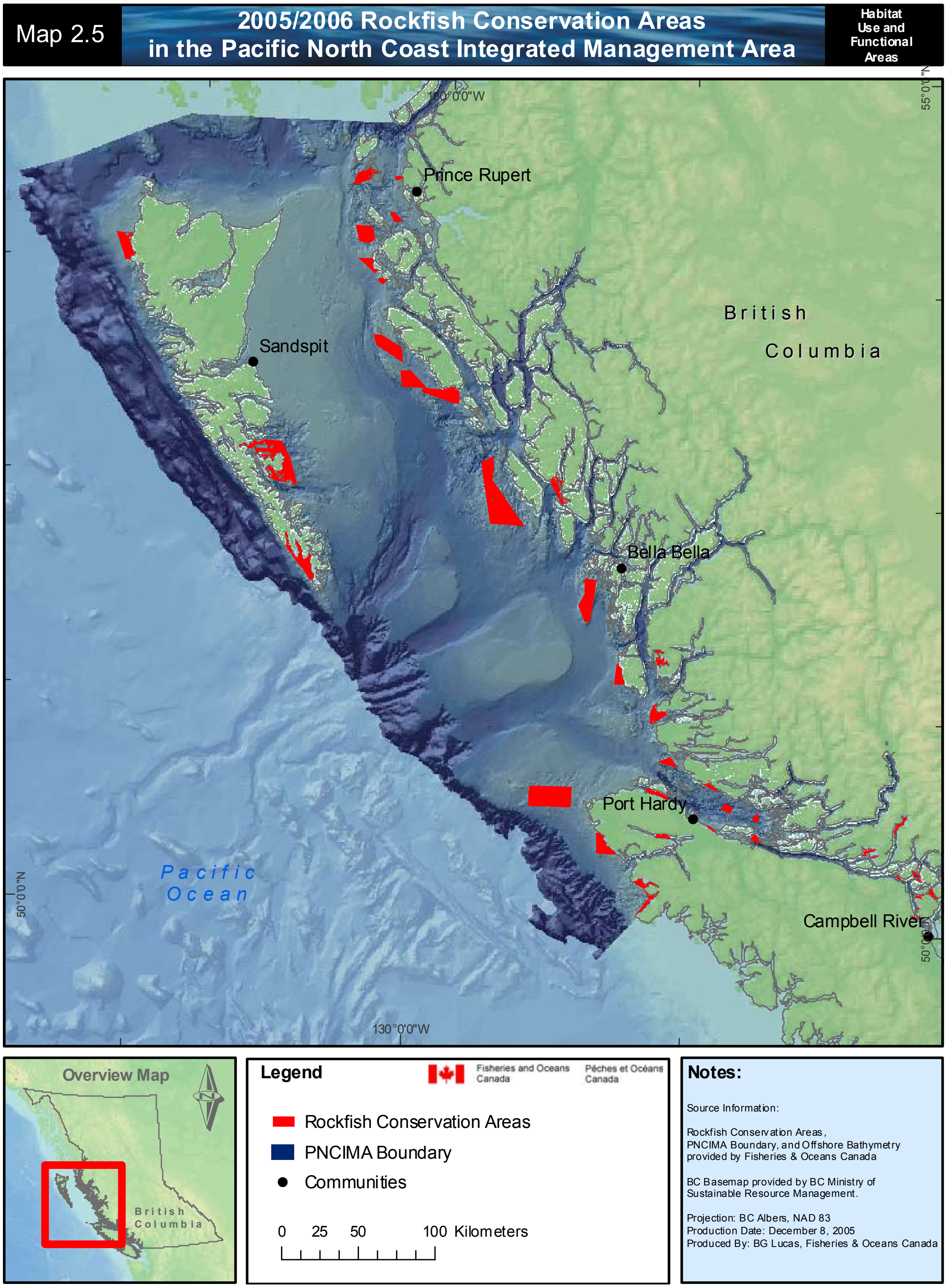
2005 Groundfish Trawl Survey data provided by Alan Sinclair.

PNCIMA Boundary and Offshore Bathymetry provided by Fisheries & Oceans Canada

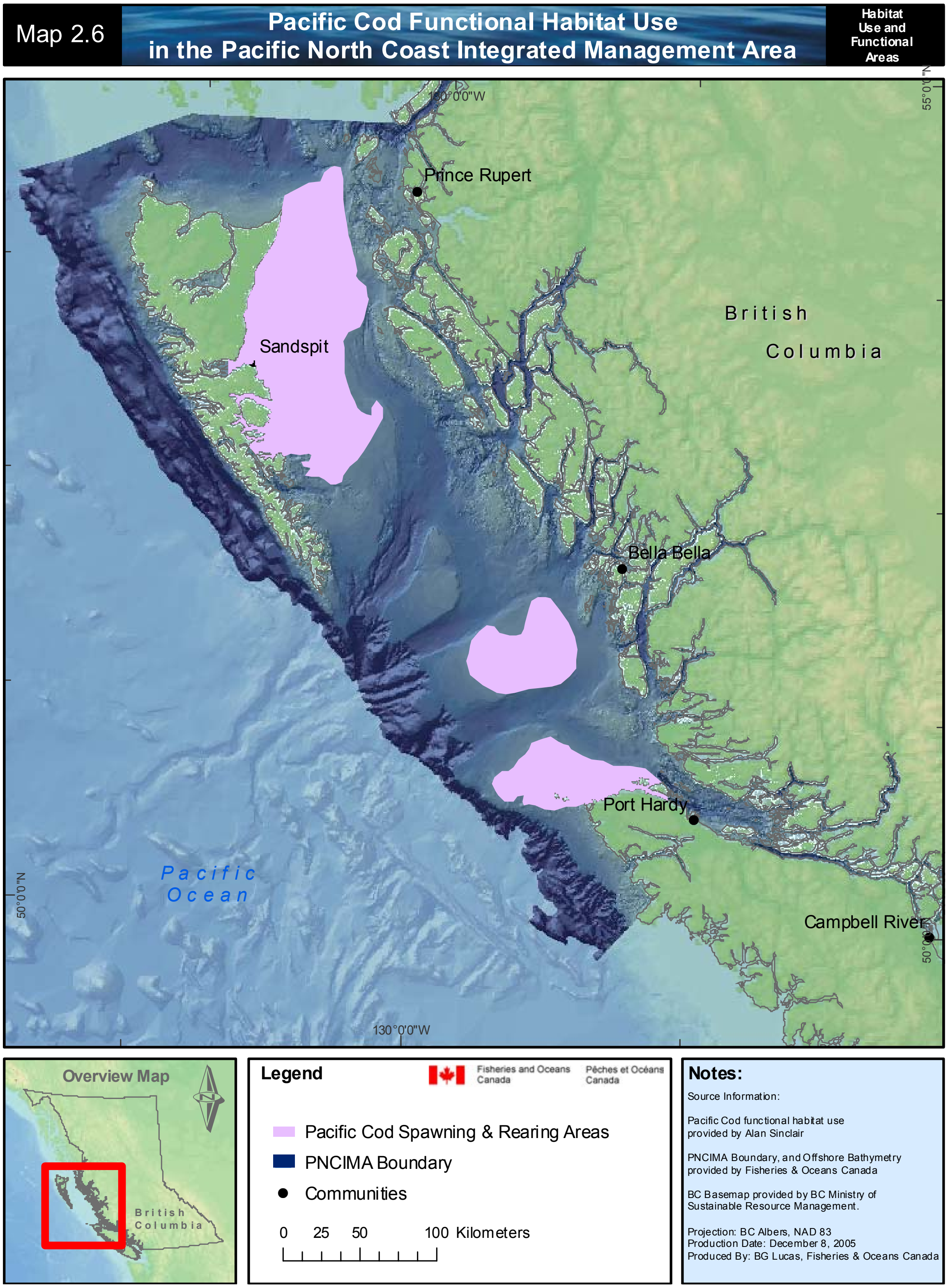
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: March 2, 2007
Produced By: BG Lucas, Lucas Research

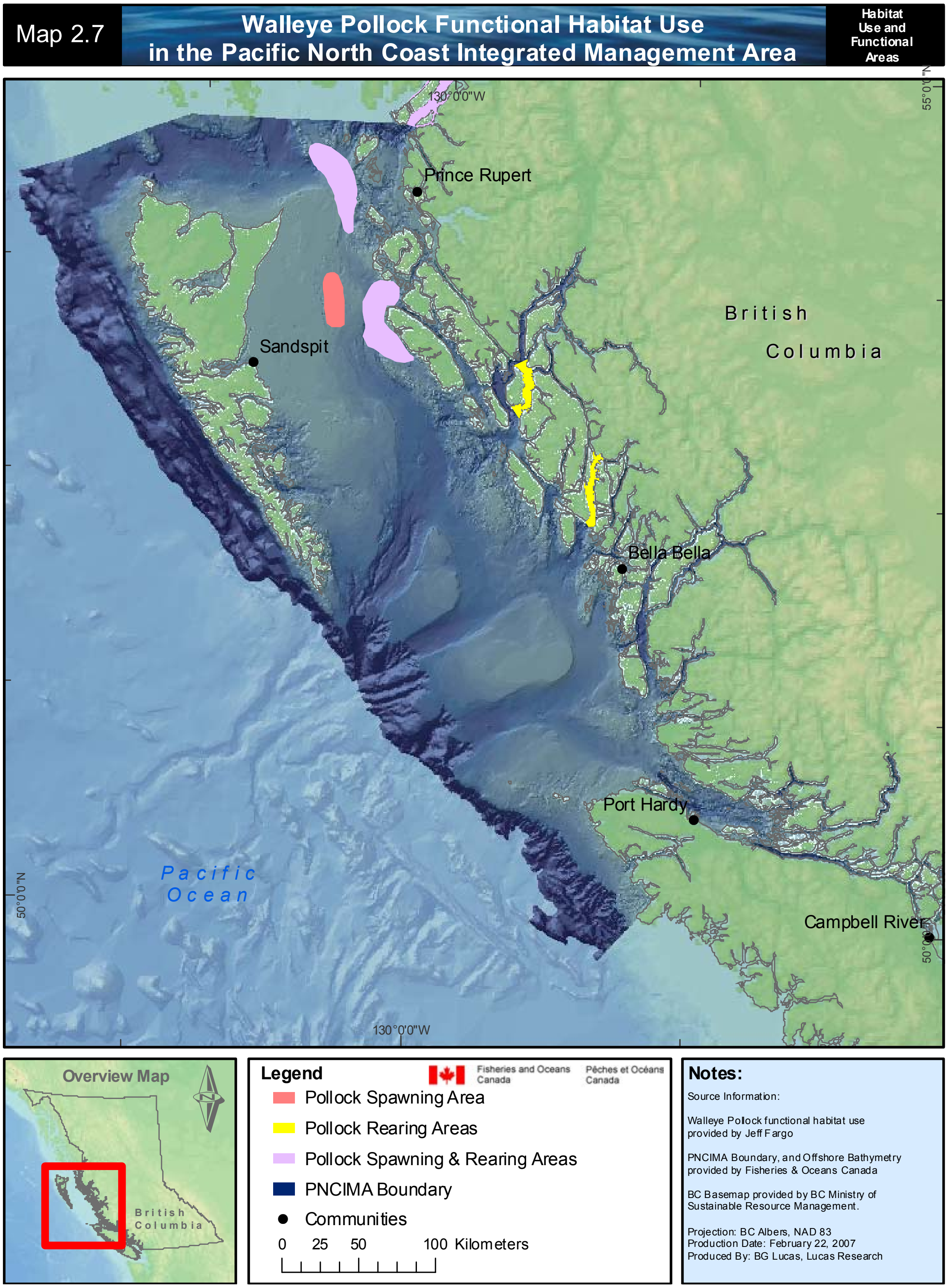
Map 2.4 Catch per unit effort (CPUE) for all species in the 2003-2005 groundfish trawl surveys in PNCIMA (A. Sinclair, unpublished data).



Map 2.5 2005/2006 rockfish conservation areas.



Map 2.6 Pacific cod functional habitat use in PNCIMA.



Source Information:

Walleye Pollock functional habitat use provided by Jeff Fargo

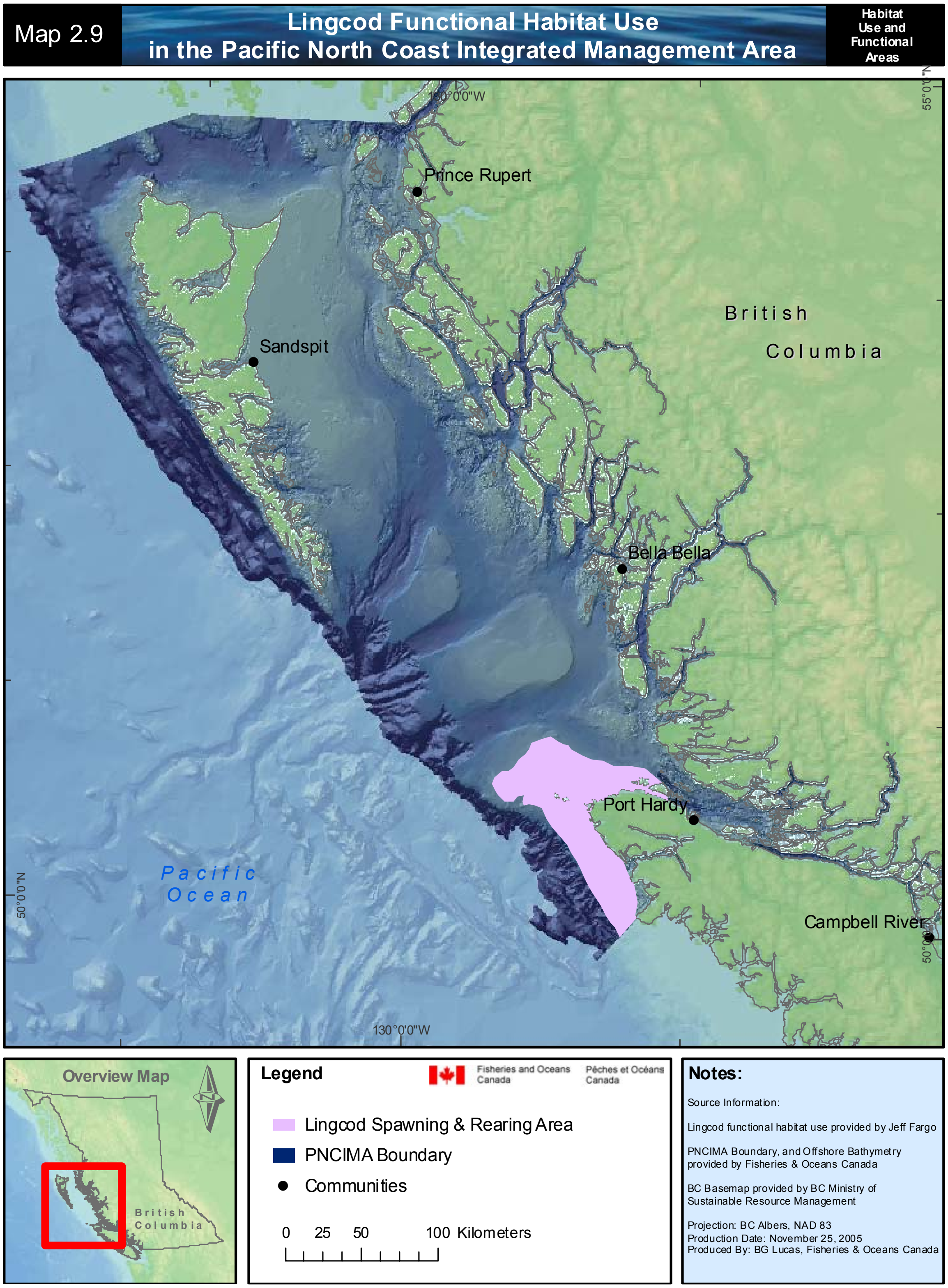
PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

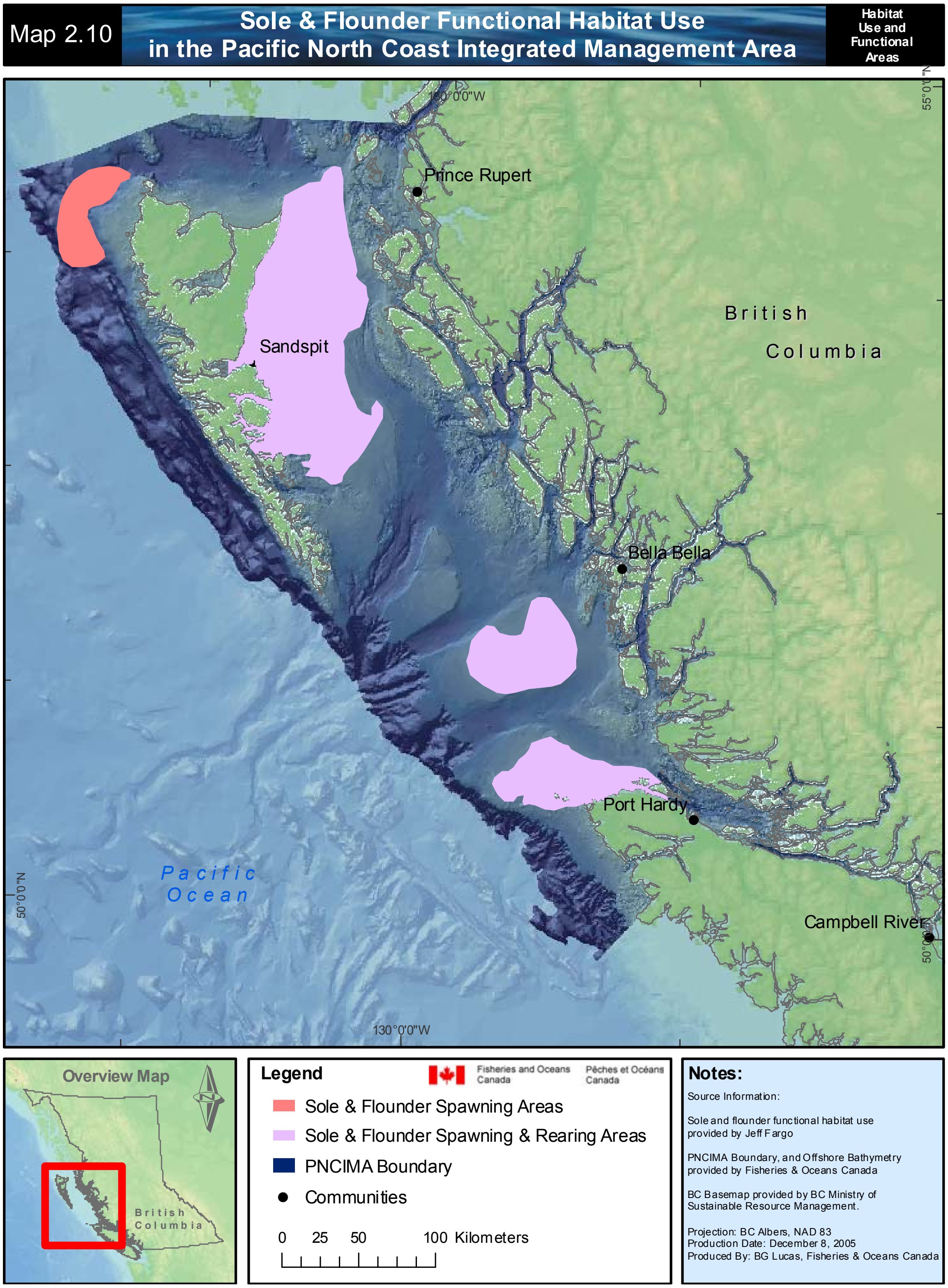
Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.7 Walleye pollock functional habitat use in PNCIMA.

Map 2.8 Hake functional habitat use in PNCIMA.



Map 2.9 Lingcod functional habitat use in PNCIMA.



Notes:

Source Information:

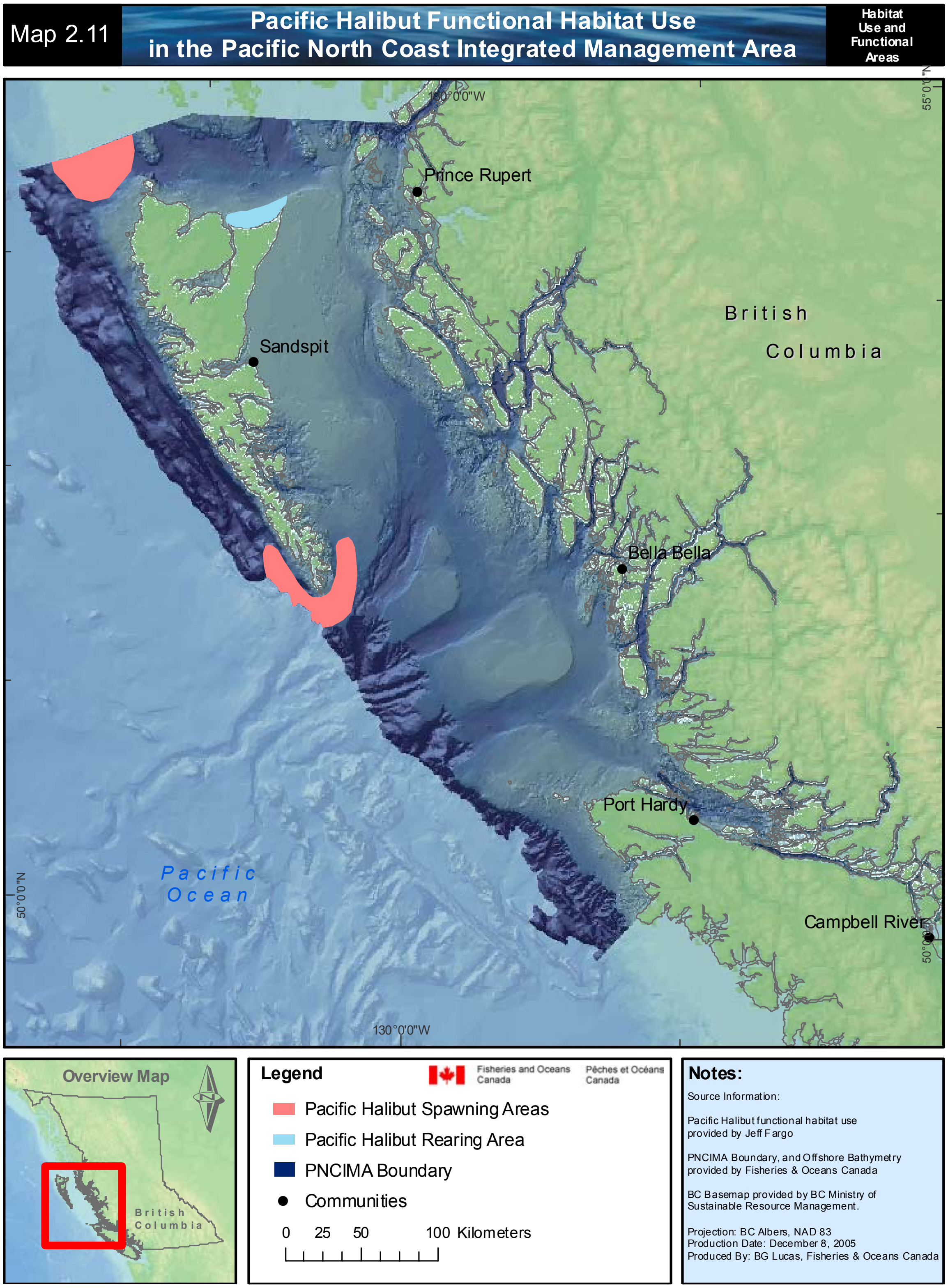
Sole and flounder functional habitat use provided by Jeff Fargo

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.10 Sole and flounder functional habitat use in PNCIMA.



Source Information:

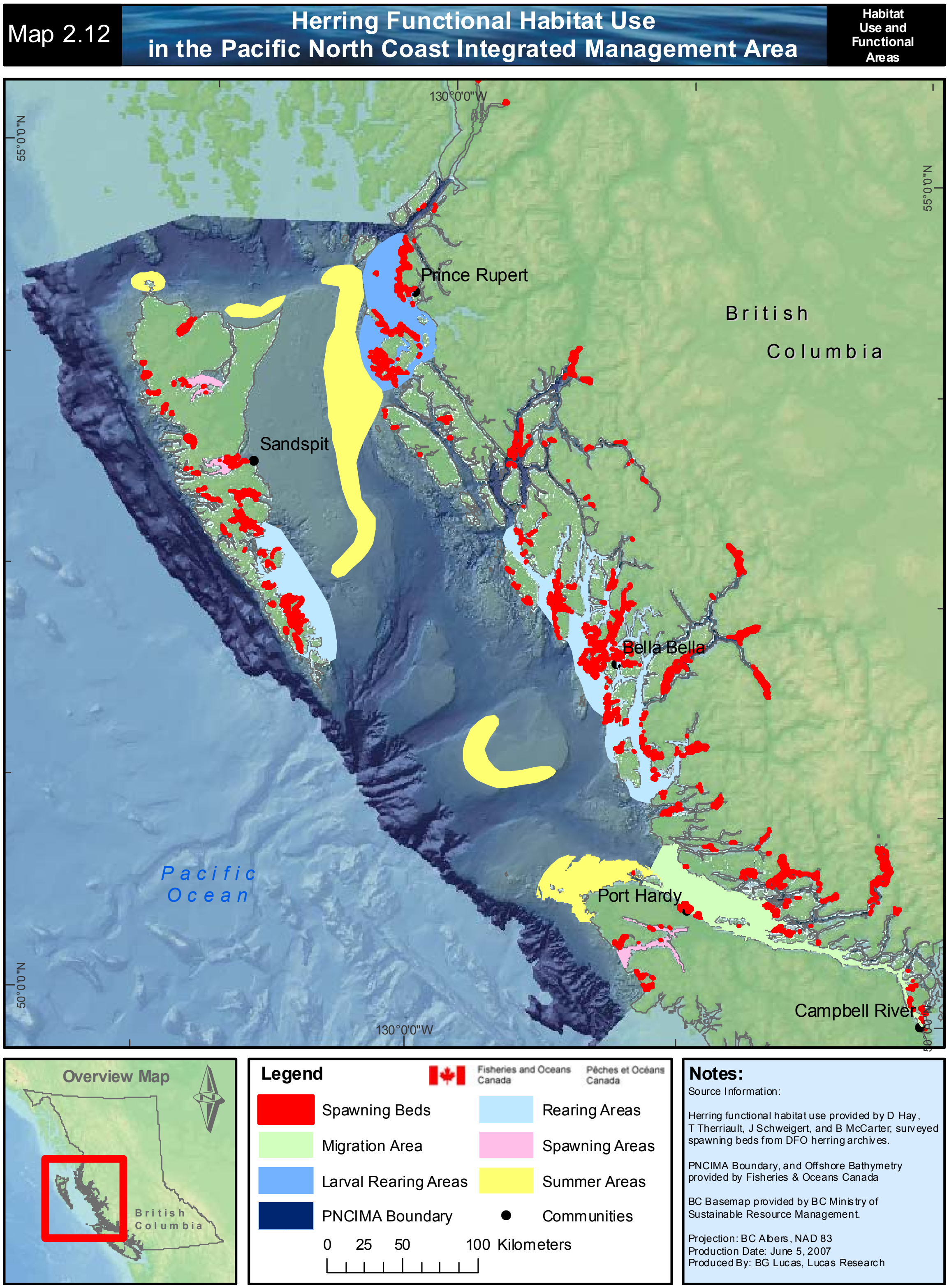
Pacific Halibut functional habitat use provided by Jeff Fargo

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: December 8, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.11 Pacific halibut functional habitat use in PNCIMA.



Notes:

Source Information:

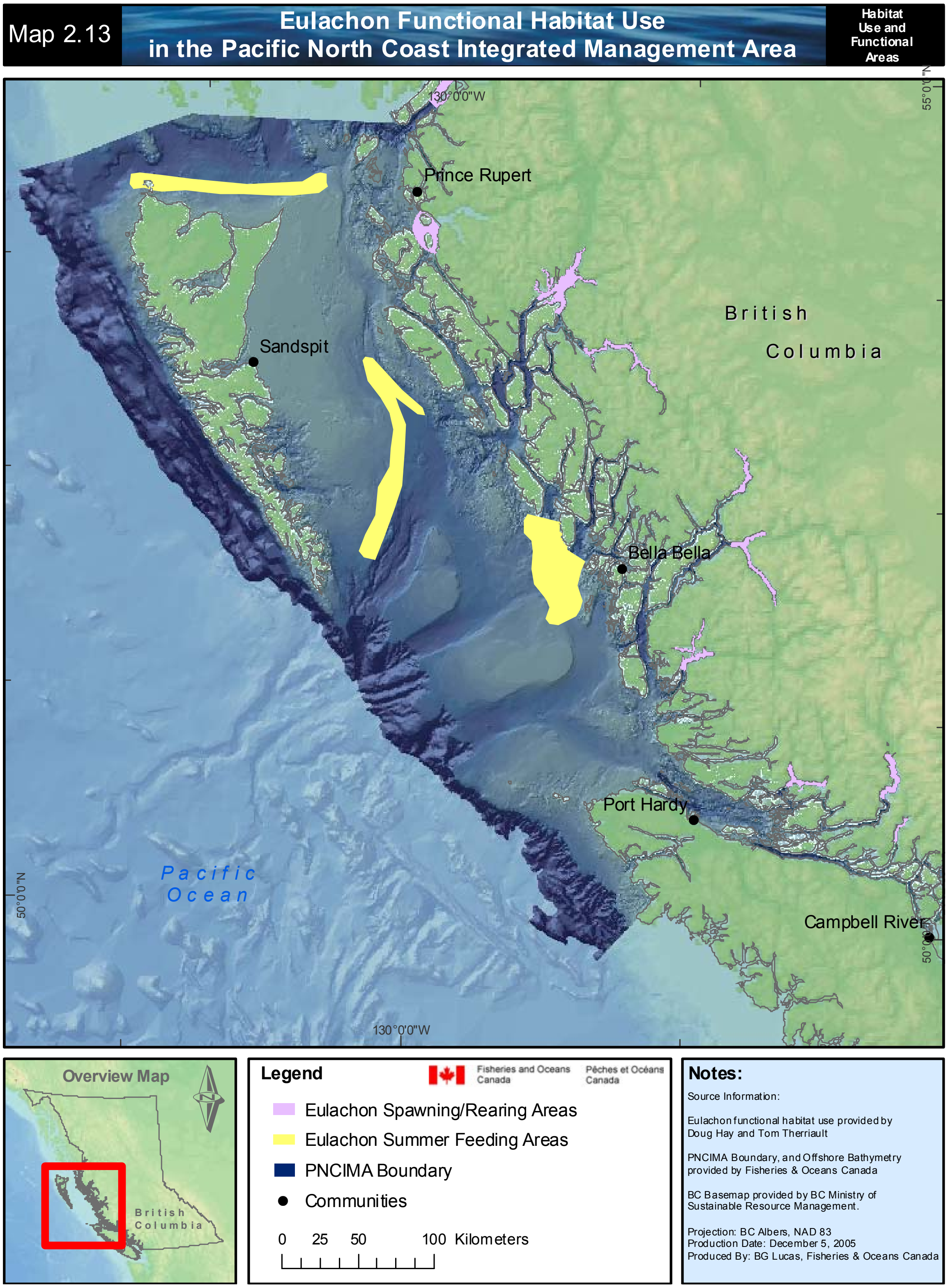
Herring functional habitat use provided by D Hay, T Therriault, J Schweigert, and B McCarter; surveyed spawning beds from DFO herring archives.

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: June 5, 2007
Produced By: BG Lucas, Lucas Research

Map 2.12 Herring functional habitat use in PNCIMA.



Source Information:

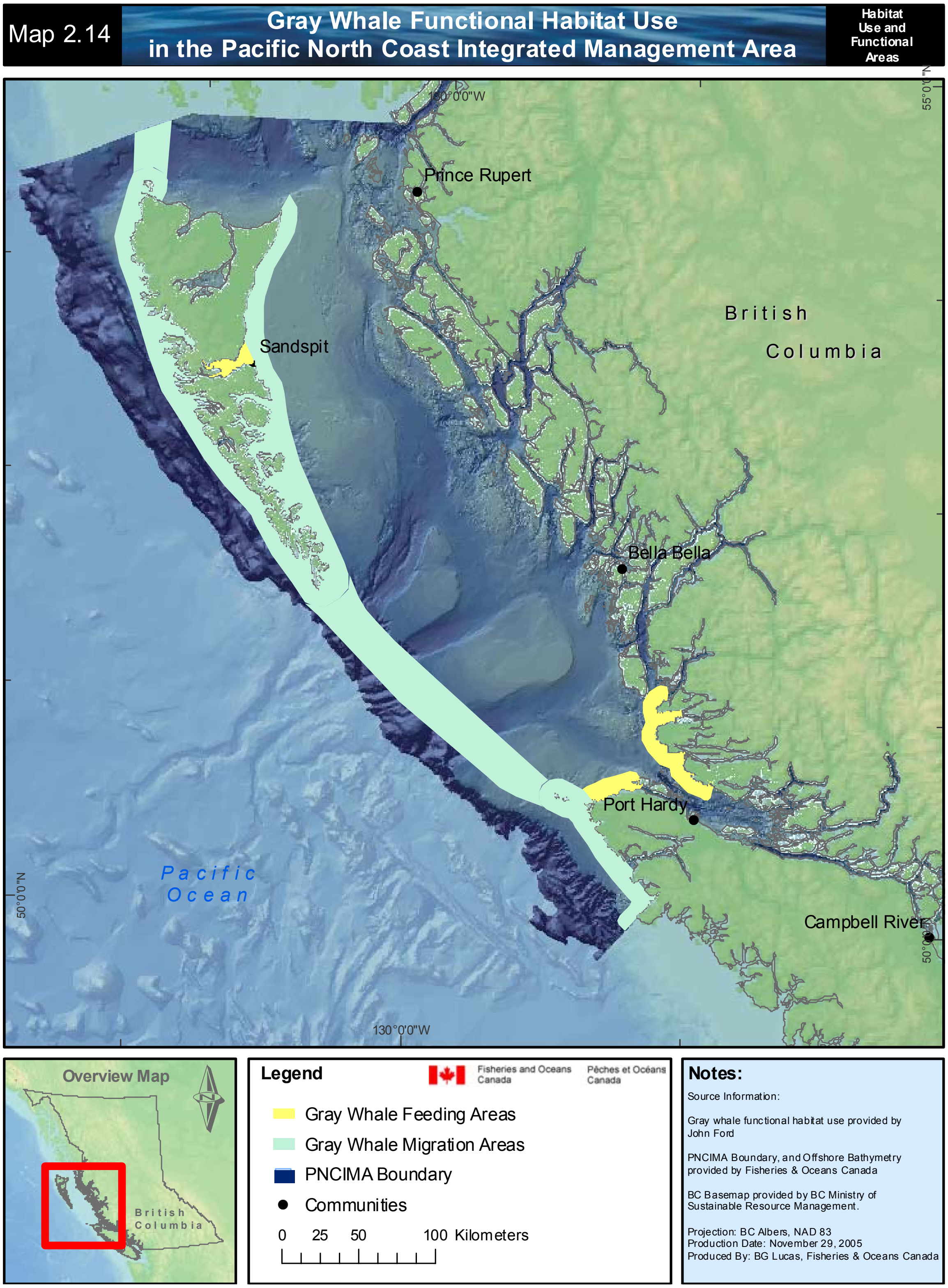
Eulachon functional habitat use provided by Doug Hay and Tom Therriault

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: December 5, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.13 Eulachon functional habitat use in PNCIMA.



Notes:

Source Information:

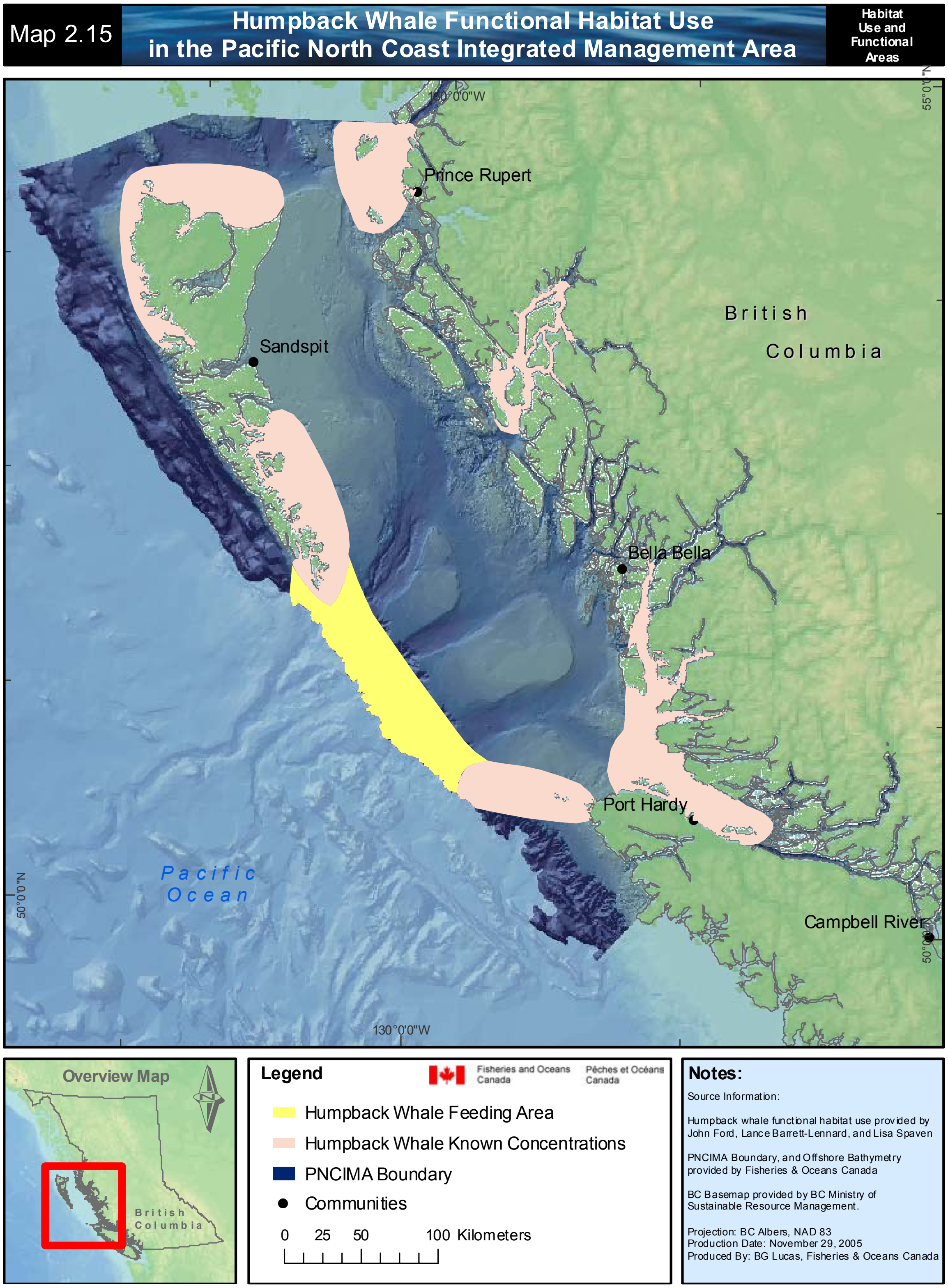
Gray whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

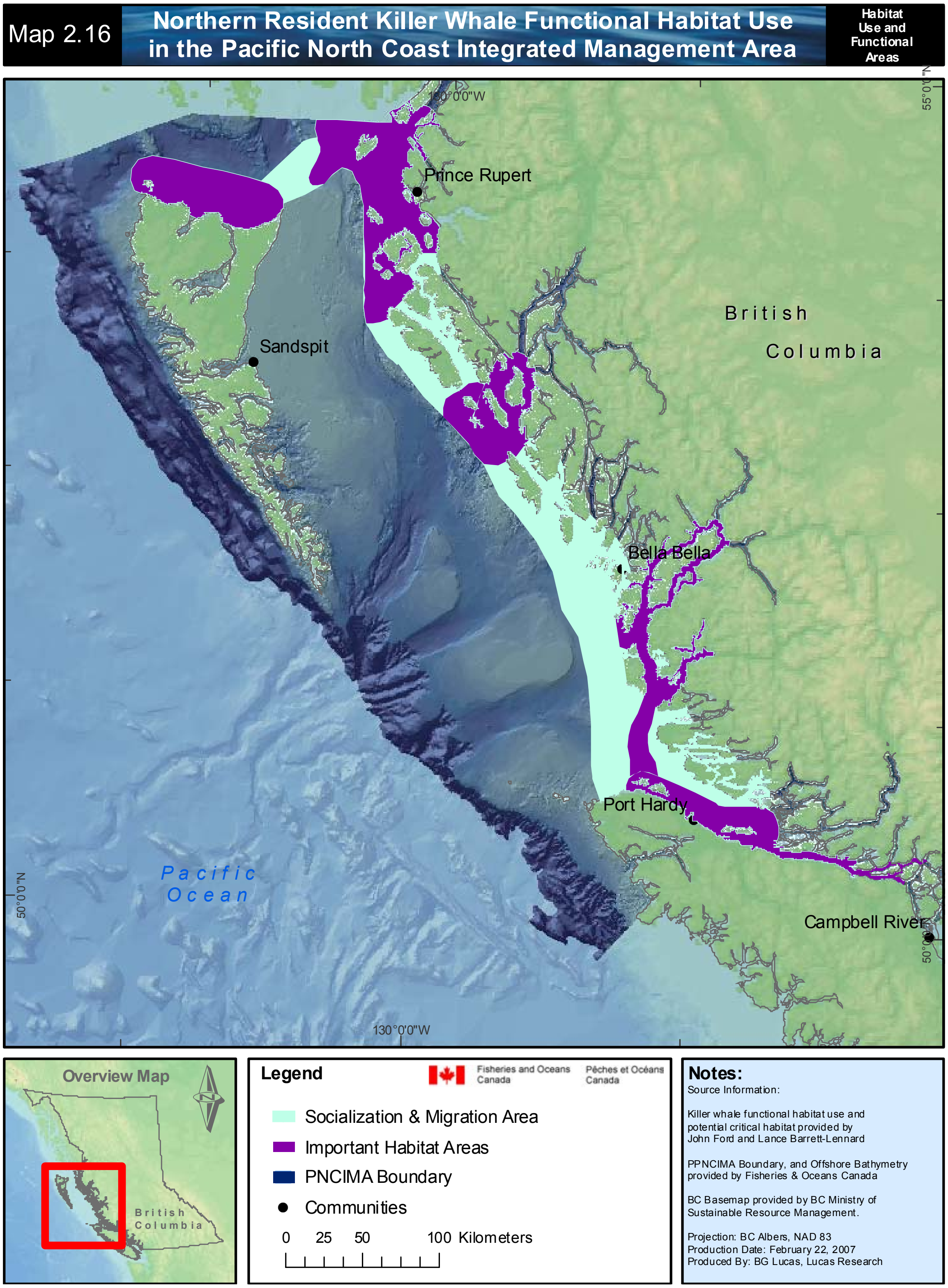
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 29, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.14 Gray whale functional habitat use in PNCIMA.



Map 2.15 Humpback whale functional habitat use in PNCIMA.



Notes:
Source Information:

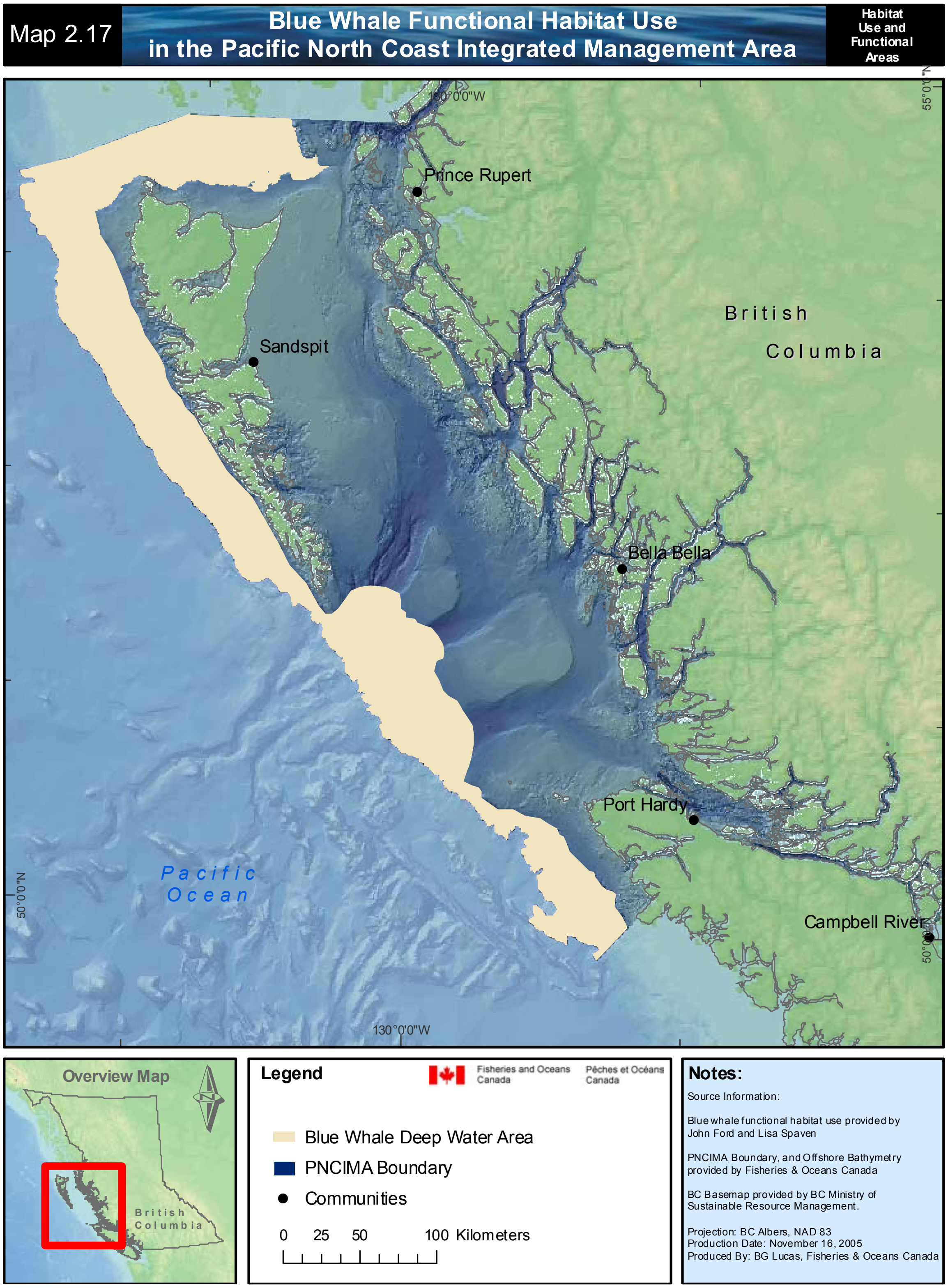
Killer whale functional habitat use and potential critical habitat provided by John Ford and Lance Barrett-Lennard

PPNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.16 Northern resident killer whale functional habitat use in PNCIMA.



Legend

- ▭ Blue Whale Deep Water Area
- ■ PNCIMA Boundary
- ● Communities

0 25 50 100 Kilometers

Notes:

Source Information:

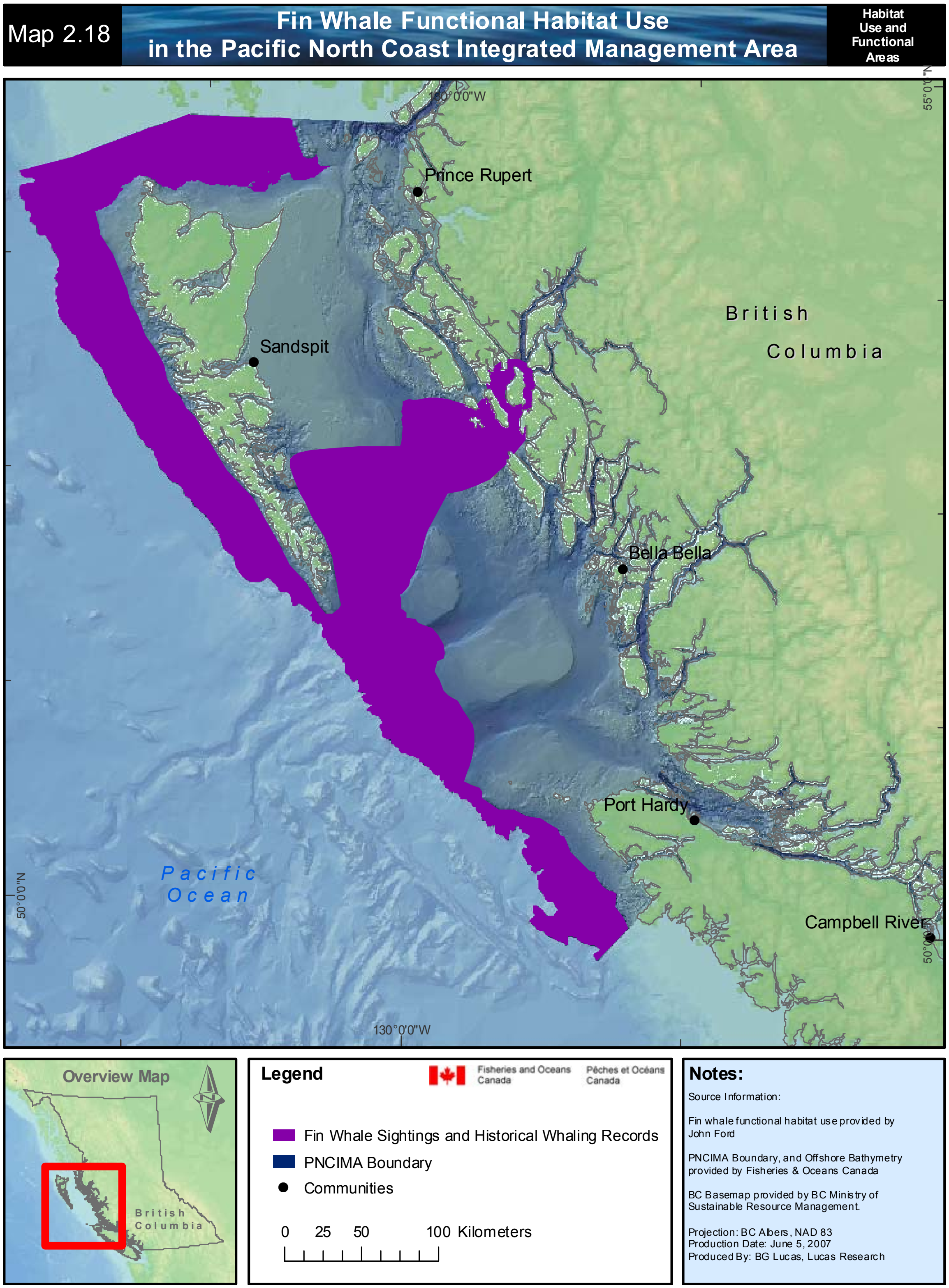
Blue whale functional habitat use provided by John Ford and Lisa Spaven

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 16, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.17 Blue whale functional habitat use in PNCIMA.



Source Information:

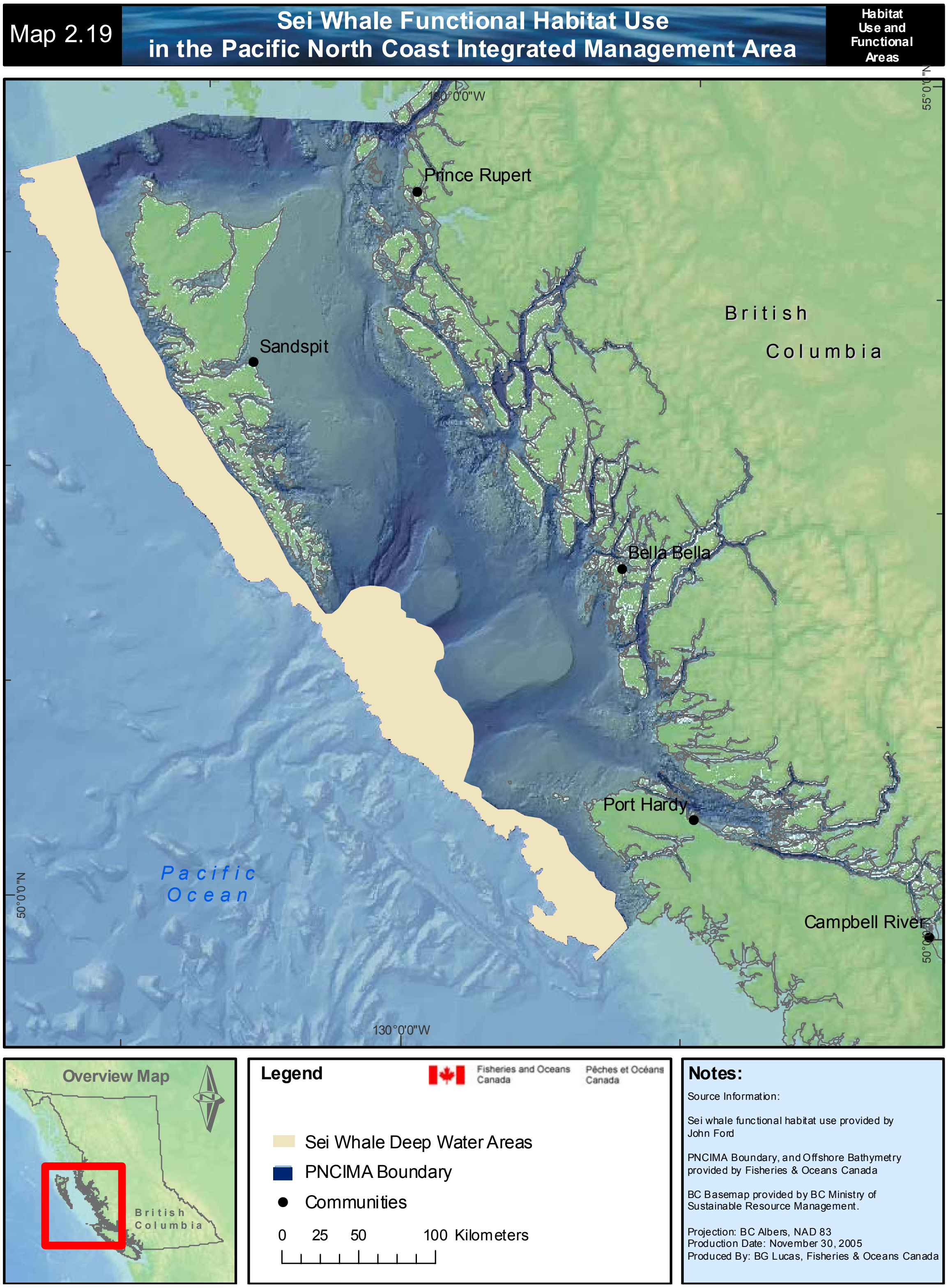
Fin whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: June 5, 2007
Produced By: BG Lucas, Lucas Research

Map 2.18 Fin whale functional habitat use in PNCIMA.



Source Information:

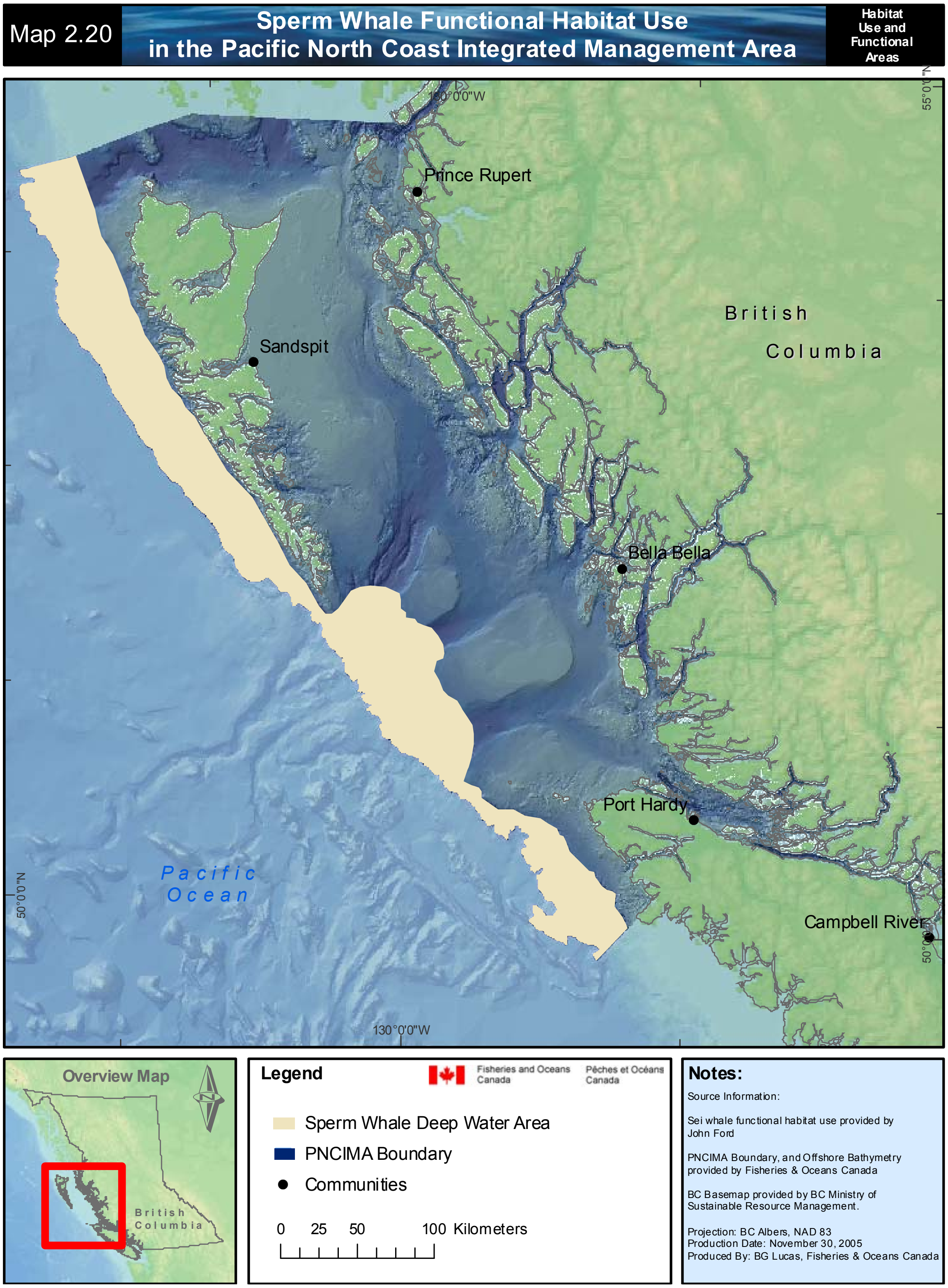
Sei whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.19 Sei whale functional habitat use in PNCIMA.



Source Information:

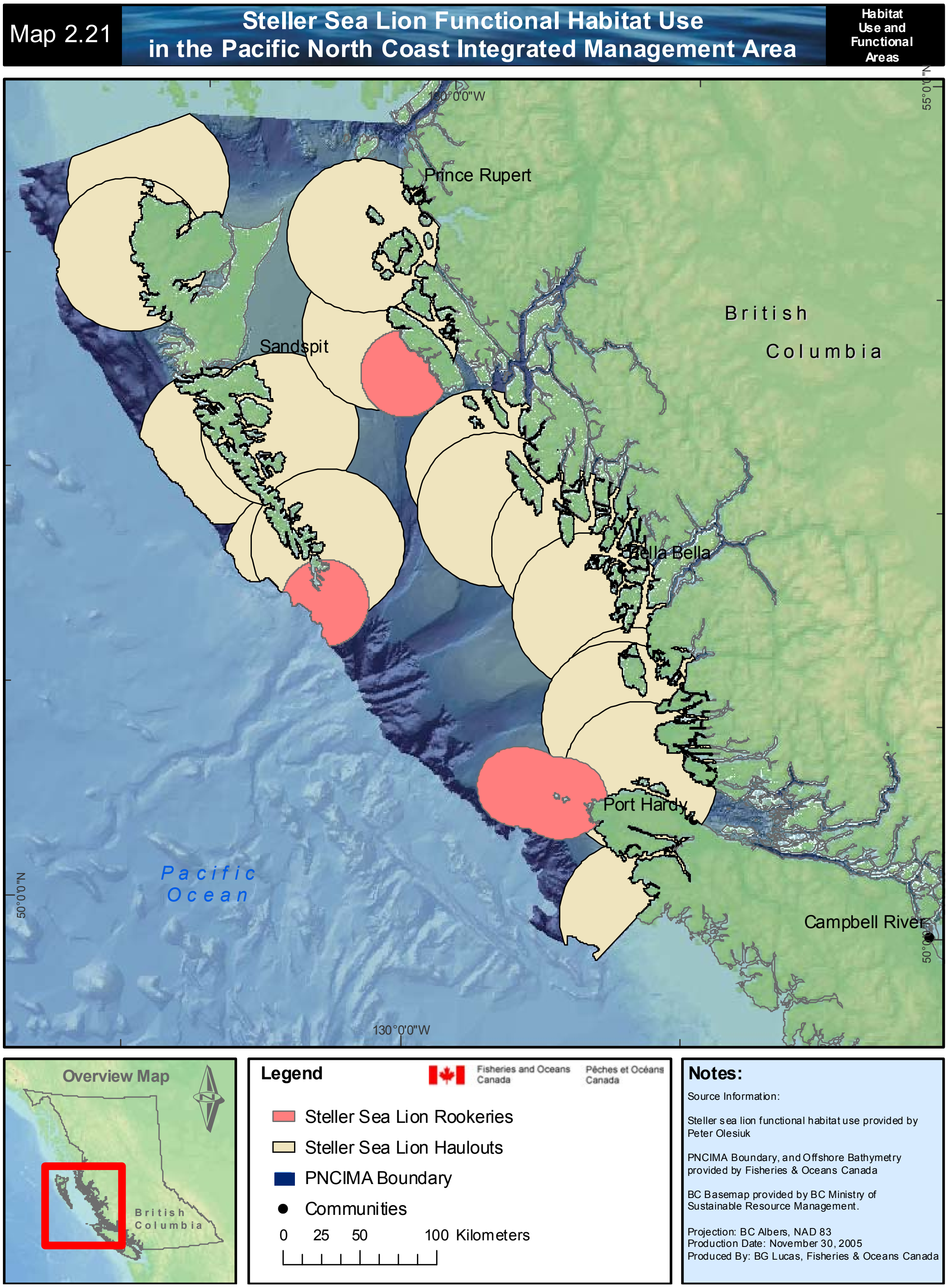
Sei whale functional habitat use provided by John Ford

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.20 Sperm whale functional habitat use in PNCIMA.



Notes:

Source Information:

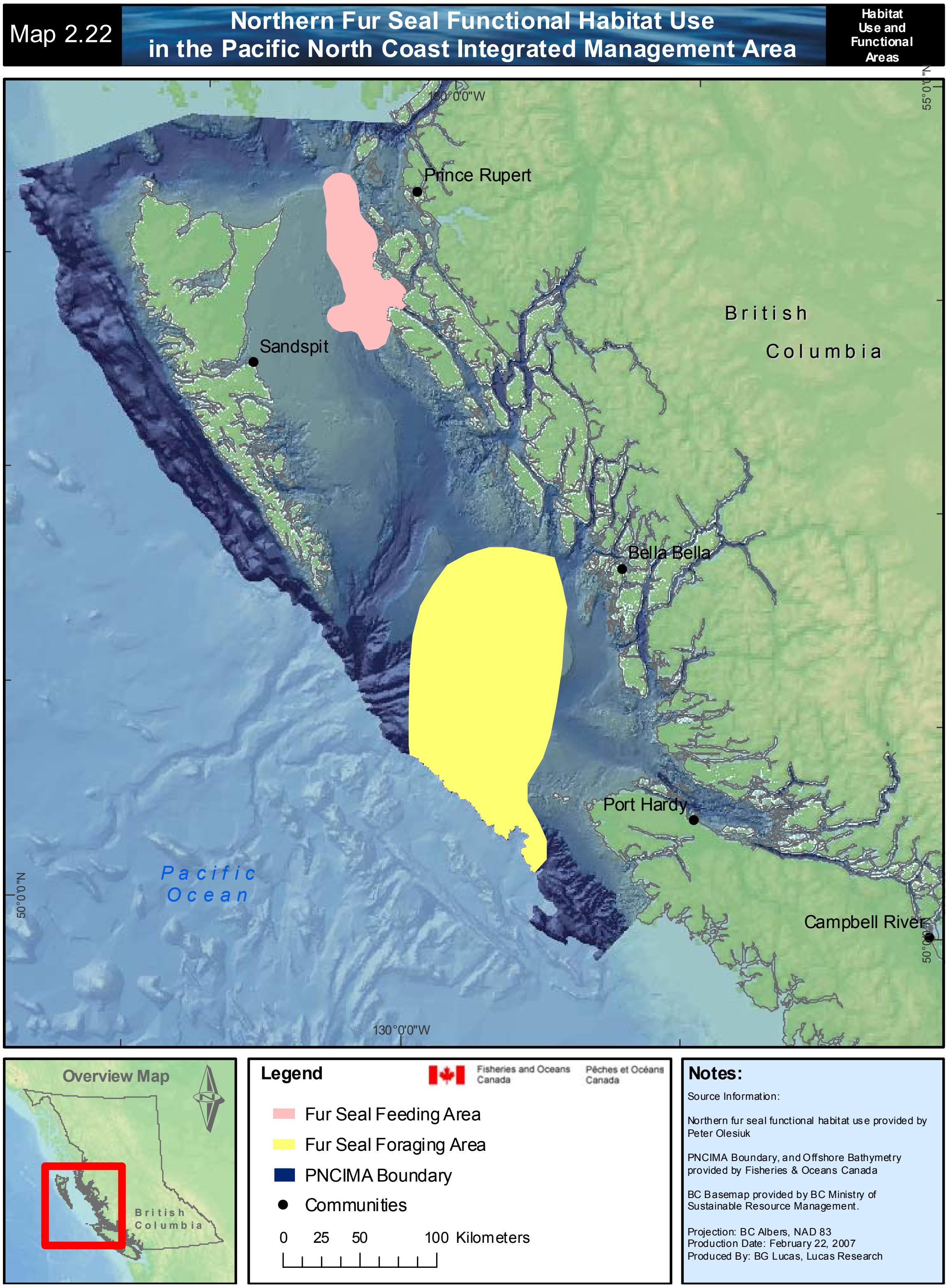
Steller sea lion functional habitat use provided by Peter Olesiuk

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: November 30, 2005
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.21 Steller sea lion functional habitat use in PNCIMA.



Source Information:

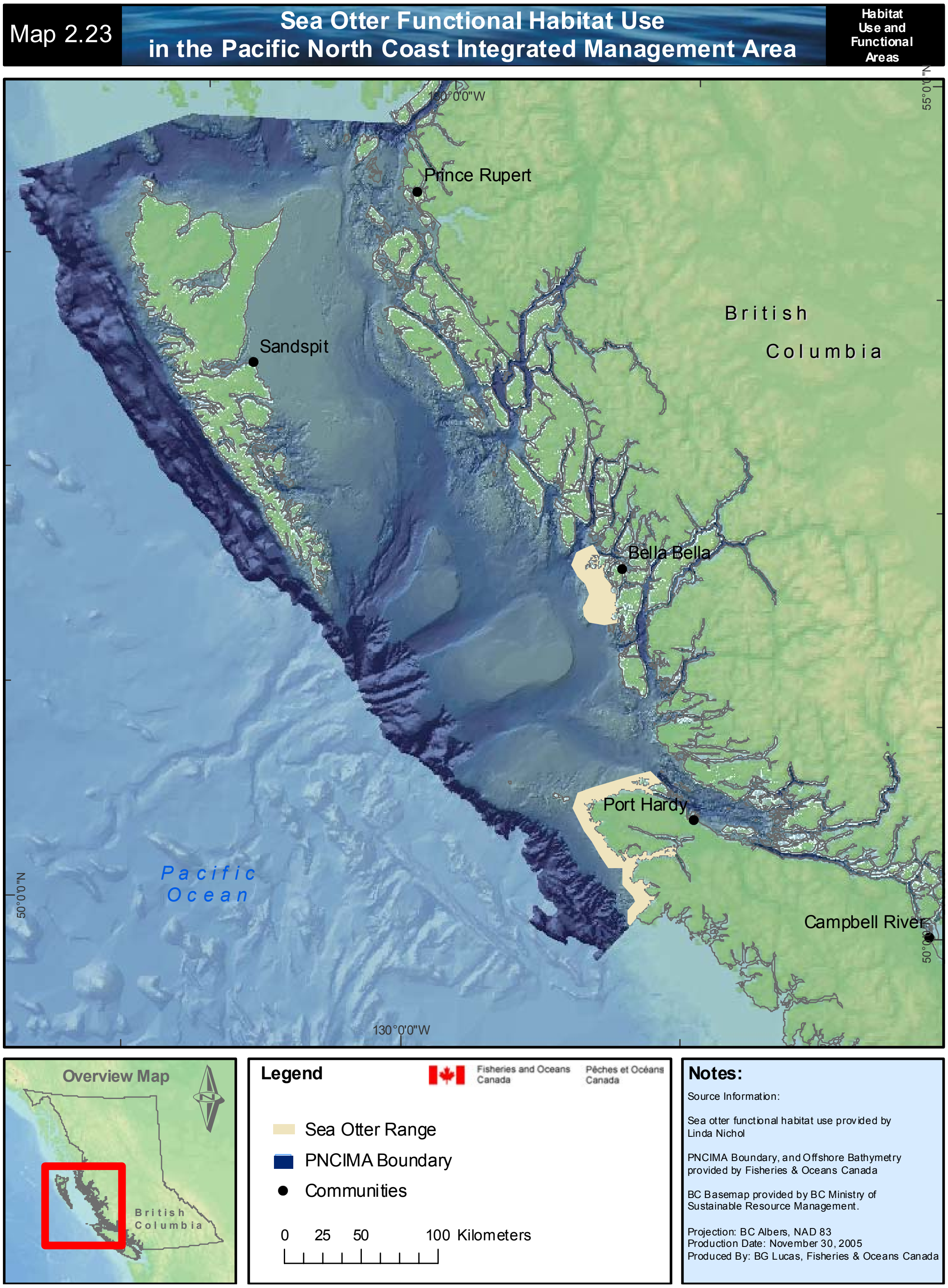
Northern fur seal functional habitat use provided by Peter Olesiuk

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

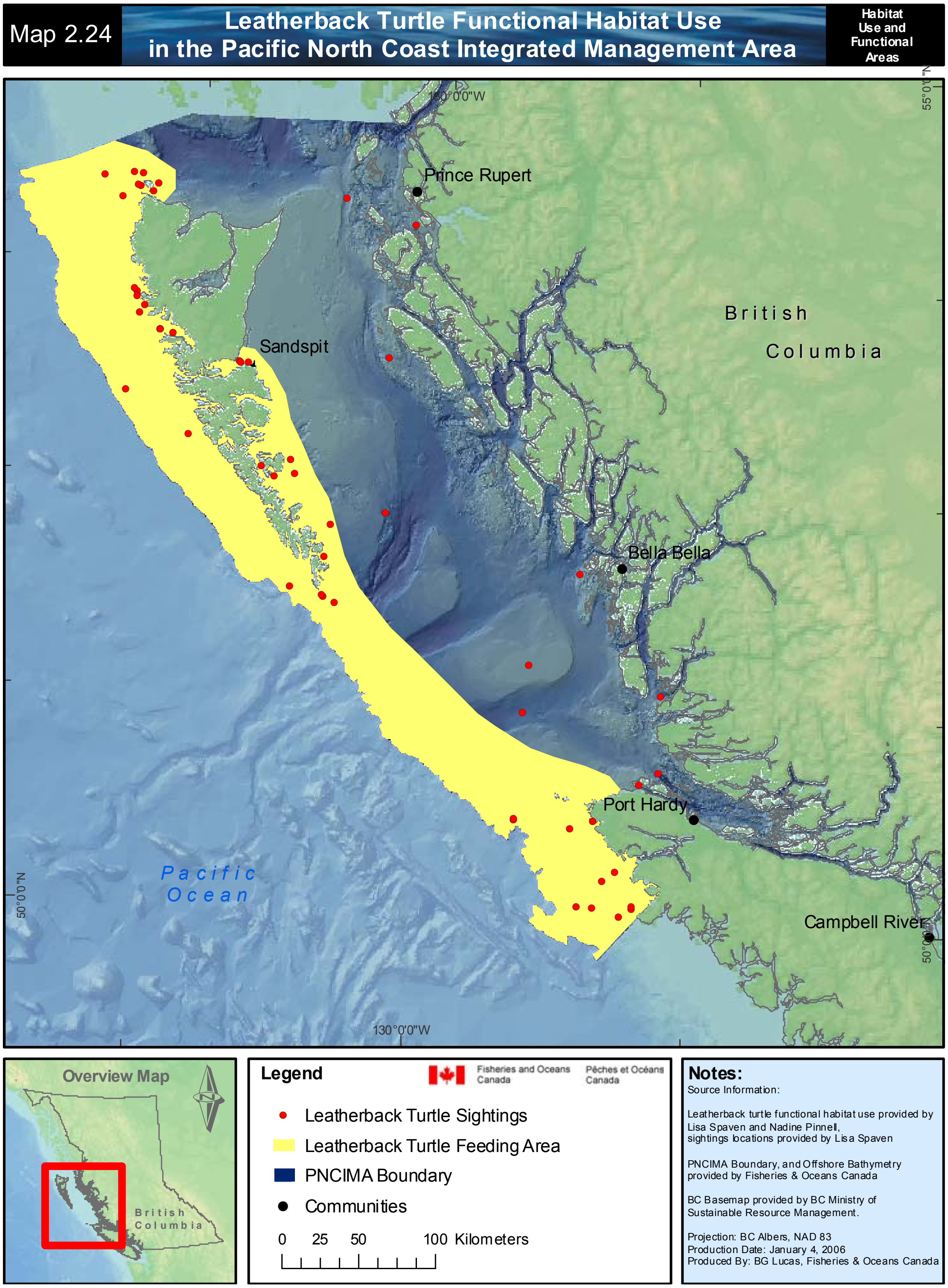
BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: February 22, 2007
Produced By: BG Lucas, Lucas Research

Map 2.22 Northern fur seal functional habitat use in PNCIMA.



Map 2.23 Sea otter functional habitat use in PNCIMA.



Notes:

Source Information:

Leatherback turtle functional habitat use provided by Lisa Spaven and Nadine Pinnell, sightings locations provided by Lisa Spaven

PNCIMA Boundary, and Offshore Bathymetry provided by Fisheries & Oceans Canada

BC Basemap provided by BC Ministry of Sustainable Resource Management.

Projection: BC Albers, NAD 83
Production Date: January 4, 2006
Produced By: BG Lucas, Fisheries & Oceans Canada

Map 2.24 Leatherback turtle functional habitat use in PNCIMA.

GLOSSARY

Accreted – Accretion is a process in which parts of the Earth's crust are solidified into larger bodies of rock.

Agglomerative clustering – Start by treating each object as a separate cluster, then group them into bigger and bigger clusters.

Anthropogenic – Human-caused.

Benthivores – An animal which feeds on animals that live on the sea floor.

Convergent – Processes by which water and particles in the water are aggregated.

Coriolis force – An apparent force exerted on moving parcels of water due to the rotation of the Earth; e.g. net movement of water is to the right of the wind direction in the Northern Hemisphere.

Demersal – On or associated with the sea floor.

Dendrogram – A tree-form diagram that is a graphic depiction of hierarchical relationships between sequences or organisms.

Detritus – Dead particulate organic material.

Diel – A daily cycle. Diel variation usually occurs once for every 24 hr period.

Downwelling – Sinking of higher density water, uaully driven by surface winds from a particular direction.

Ekman downwelling – Downwelling of surface water driven by the wind.

Epifauna – Animals that live on the surface of the sea floor.

Fecund – Species that have a high reproductive output based on when and how often they reproduce.

Fluvial – Related to flowing water; fluvial erosion refers to erosion by moving water, such as rivers.

Gametogensis – The formation of male and female gametes (egg and sperm) by meiosis.

Gonad – Reproductive organ.

Ichthyoplankton – Finfish and invertebrates which live by floating in the water; usually refers to the larval stages of finfish and invertebrates which can move against ocean currents as adults.

Inexorable – Relentless, inevitable.

Littoral – The coastal, near-shore, areas of an ocean or sea.

Macrophyte –Large aquatic plants.

Megalopa – Late larval stage.

Metamorphosis – Change in form during development.

Monotonic increase – Consistently increasing.

Moulting – To shed outer shell or exoskeleton.

Non-intermittent spawners – Individuals release all their eggs at one time.

Ontogenetic variability (in diet) – Variability relatied to the origin and development of individual organisms.

Piscivore – An animal which feeds on fish.

Planktivore – An animal which feeds primarily on plankton; plankton is the collective group of tiny plants and animals that float or drift near the surface of a body of water; plankton is very low on the aquatic food chain and therefore a vital element in that ecosystem.

Planktonic – Drifting small organisms that inhabit the water column of the ocean.

Sexual dimorphism – A distinct difference in appearance between males and females of the same species.

Terranes – A section of the earth's crust that has collided with and and become attached to a different part of the Earth's crust, as in a continental margin**.**

Upwelling winds – Winds that drive upwelling of denser and cooler water towards the ocean surface.

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