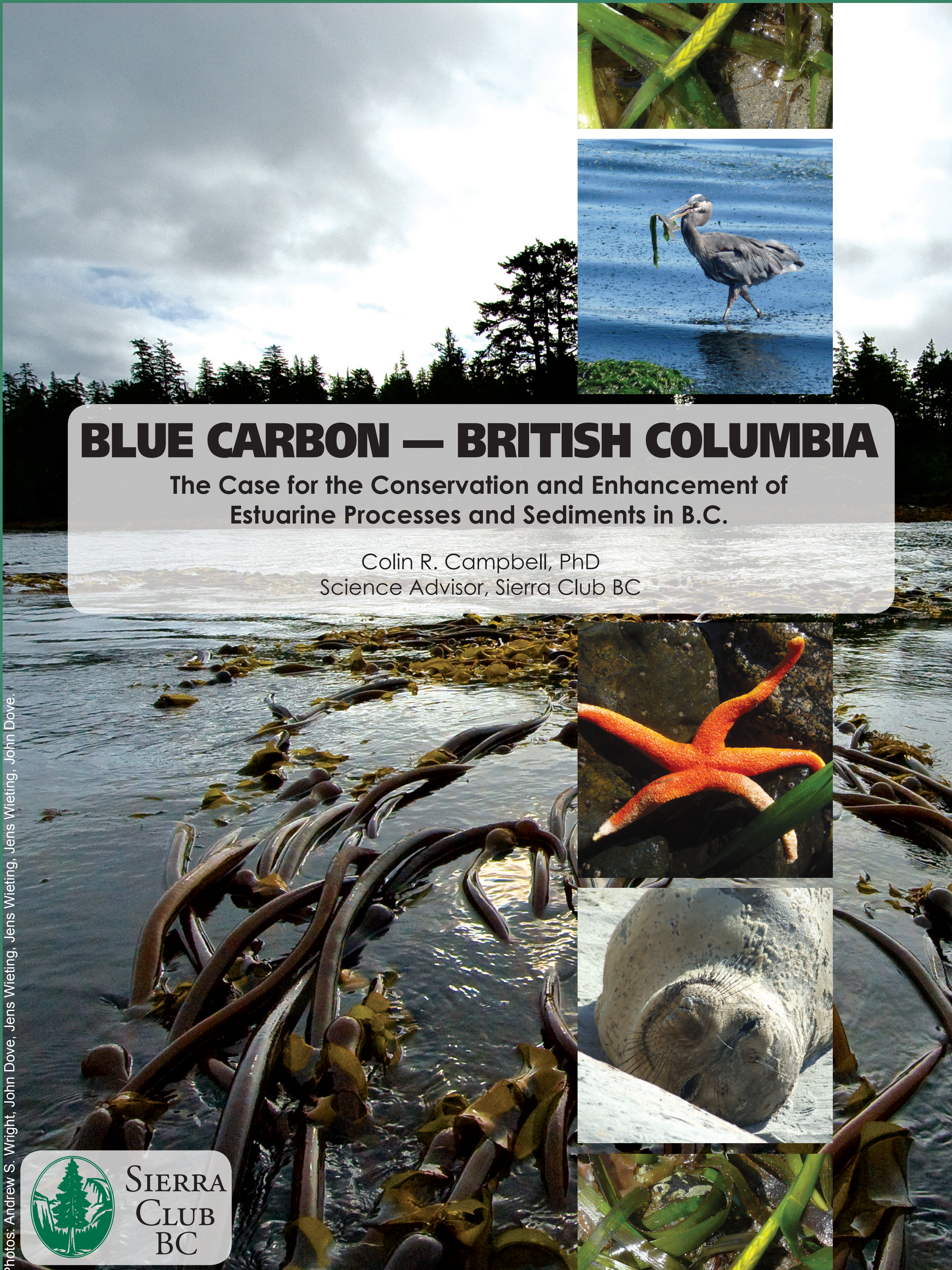

BLUE CARBON — BRITISH COLUMBIA

The Case for the Conservation and Enhancement of Estuarine Processes and Sediments in B.C.

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Photos: Andrew S. Wright, John Dove, Jens Wieting, Jens Wieting, Jens Wieting, John Dove.

Sierra Club BC

Executive Summary

The rich and vibrant estuarine world has long been treasured as a cradle of marine abundance — a crucial breeding and feeding habitat for invertebrates, fish, marine birds and mammals. Where rivers meet the sea and the slope is not too steep, there freshwater, seawater and sediment interact with living organisms and light to form ecosystems of exceptional productivity.

Photo: James Mack

Eelgrass beds have long been treasured as cradles of marine abundance: nurseries for fish and invertebrates, and feeding grounds for marine birds and mammals – including humans.

Unfortunately, estuarine habitats are among the most rapidly disappearing ecosystems on earth. It is a matter of significant concern globally that the mangrove, seagrass and salt marsh ecosystems are under heavy attack, disappearing in aggregate at rates from 2 to 15 times faster than forests. One third of their original area has already been lost, mostly in the past 60 years.

In the midst of this unprecedented habitat loss, new research reveals an unlooked-for potential for mitigating climate change. Like terrestrial forests, these marine gardens capture and store immense amounts of carbon but much more efficiently: at rates up to ninety times the uptake provided by equivalent areas of forest.

Key Estuaries in B.C. with Blue Carbon Potential

- Fraser River
- Chemainus River/Bonsall Creek
- Courtenay River
- Cowichan River
- Georgetown Creek
- Kitimat River
- Nanaimo River
- Nicomekl/Serpentine Rivers
- Skeena/Ecstall/McNeil Rivers

This "Blue Carbon" is stored in sediments where it is stable for thousands of years. In B.C., roughly 400 km^2 of salt marsh and seagrass meadows stash away as much carbon as B.C.'s portion of the boreal forest, and the equivalent of the emissions of some 200,000 passenger cars. In view of these manifold benefits, our estuaries and eelgrass-rich intertidal zones occupy the highest possible priority for conservation, restoration and enhancement.

British Columbia's 442 estuaries have a combined area of 745 square kilometres (km^2). Of the various estuarine habitats, the most critical for carbon sequestration is eelgrass, especially the native *Zostera marina*, followed by salt marsh. Estimates based on the areas and annual average carbon sequestration for each of these habitats indicate a minimum 180,200 tonnes of carbon sequestered each year in B.C. Meanwhile, only 13.5 per cent of the area of this already very limited environment is protected.

Clearly an expanded approach to estuarine protection is required if the sedimentary and other processes that effect Blue Carbon burial are to be preserved, restored and enhanced. Upstream sediment supply must be managed, and subtidal estuarine flats maintained if not enhanced. This requires concerted action at the

Acknowledgements

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Photo: Jens Wieting

Bald eagle with salmon prey. Juvenile salmon spend a crucial portion of their life cycle in eelgrass meadows, putting on weight and adapting to the saltwater habitat before heading out to the open seas.

municipal, provincial and federal levels of government. This is the direction of the future, preferably the very near future.

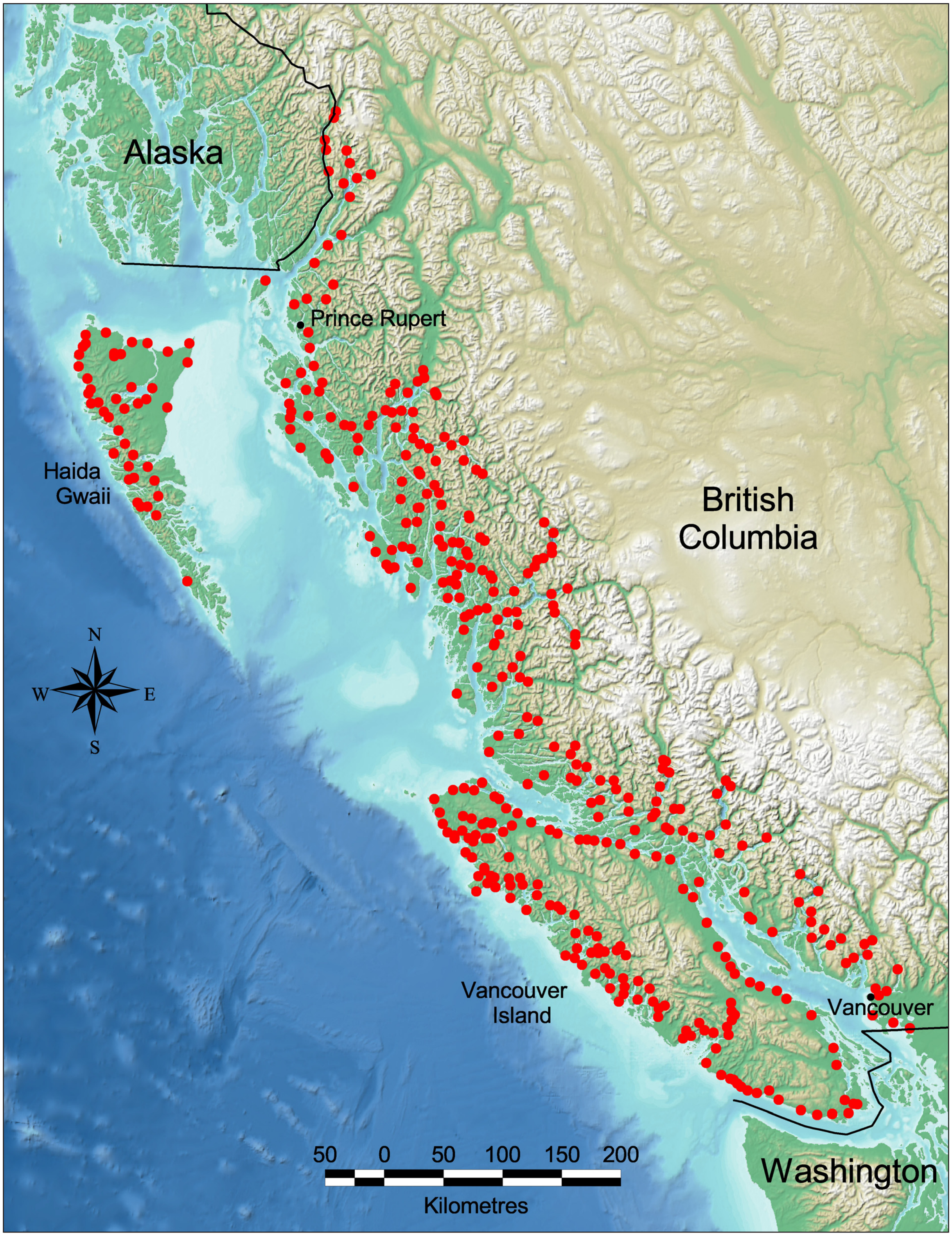
IN B.C., ROUGHLY 400 KM^2 OF SALT MARSH AND SEAGRASS MEADOWS STASH AWAY AS MUCH CARBON AS B.C.'S PORTION OF THE BOREAL FOREST, AND THE EQUIVALENT OF THE EMISSIONS OF SOME 200,000 PASSENGER CARS.

Recommendations

- Conduct a comprehensive mapping survey of the occurrence of sub-tidal eelgrass in B.C.'s coastal waters.
- At the federal level: Prioritise intact estuarine vegetation for protection under the provisions of the Federal *Fisheries Act*. Eliminate any activities that harmfully alter, disrupt or destroy estuarine fish habitat under Section 35(2) of the *Fisheries Act*.
- At the provincial level: Monitor boating and other recreational access to the water, including fishing and shellfish harvesting, to prevent damage to coastal marine vegetation. Control upstream erosion and excessive sediment loading of streams from all development and logging operations.
- At the municipal level: Protect eelgrass beds by eliminating damage from log booms, docks and other structures. Divert runoff of fertiliser, pesticide and herbicide from salt marsh and seagrass habitats. Establish and protect vegetation buffer zones along streams and the shoreline adjacent to salt marshes and eelgrass beds.
- Investigate the potential of increasing carbon sequestration by engineering the appropriate expansion of estuarine sediment areas.

Photo: Jens Wieting

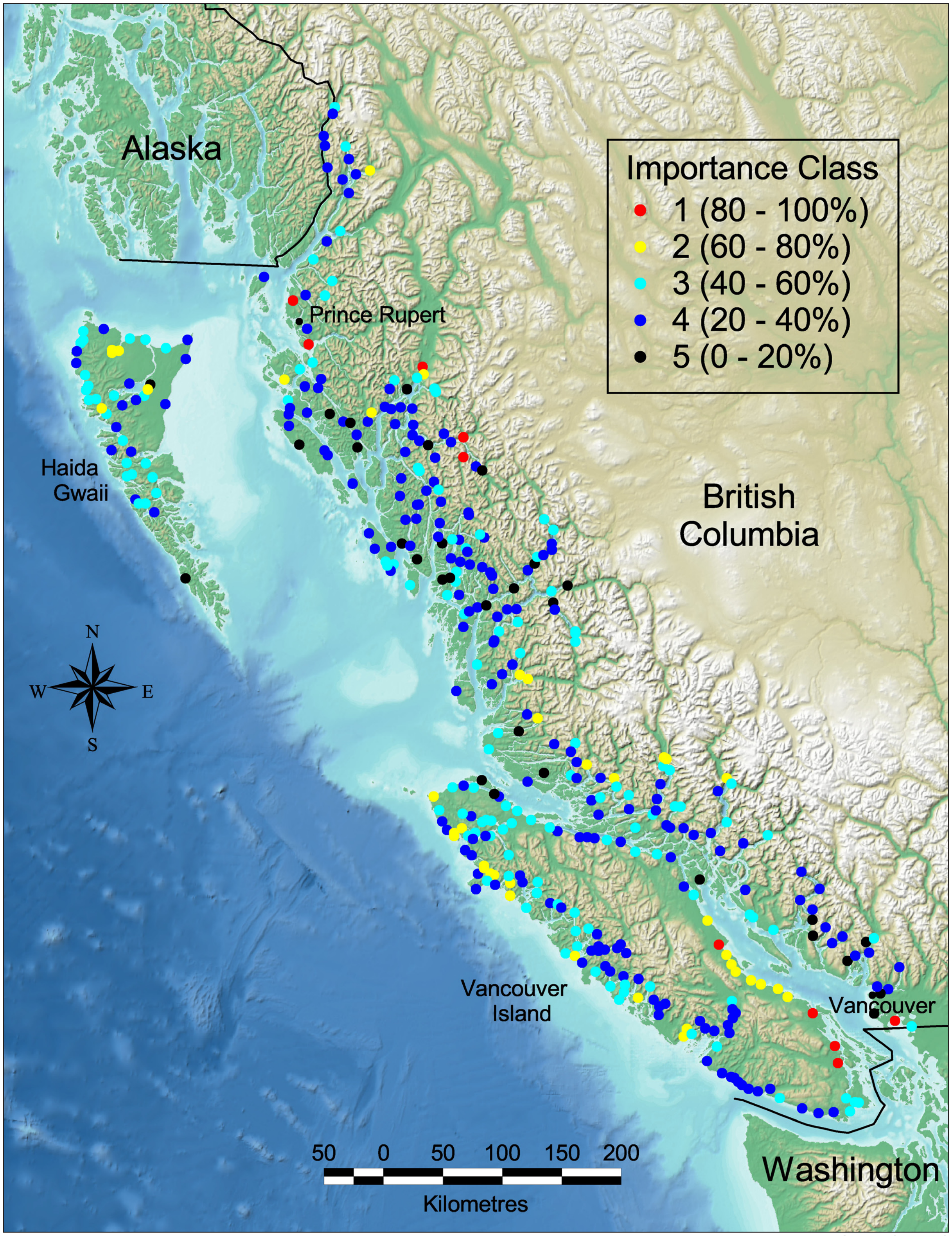
Juvenile crabs thrive in eelgrass meadows, where dense vegetation allows them to hide from predators.



Map: Dave Leversee, Sierra Club BC

Location of the 442 PECP Identified Estuaries in British Columbia.[1]

1. Ryder, J.L. et.al. (2007) An Integrated Biophysical Assessment of Estuarine Habitats in British Columbia to Assist Regional Conservation Planning. Canadian Wildlife Service, Technical Report 476. Fig. 5, p.23.



Map: Dave Leversee, Sierra Club BC

Importance Class of Each Estuary. **The Lower Mainland, the east coast of Vancouver Island, and the northwest coast of Vancouver Island have concentrations of estuaries ranked in the top two classes while other top-ranking estuaries are distributed across the central coast and Queen Charlotte Islands. Please note that this analysis did not include the Fraser River estuary.[2]**

2. Ryder, J.L. et al. (2007) An Integrated Biophysical Assessment of Estuarine Habitats in British Columbia to Assist Regional Conservation Planning. Canadian Wildlife Service, Technical Report 476. Fig. 11, p.34.

Photo: Andrew S. Wright

Blue Carbon: seagrass beds and salt marshes are up to ninety times more efficient at storing carbon than the equivalent area of forest.

Blue Carbon: a Global Perspective

The world is losing its coastal vegetated habitats — mangroves, salt marshes and seagrass meadows — at a rate four times greater than its rainforests. Long valued as vital in the provision of coastal stability and abundant food resources for wildlife and human communities, these invaluable ecosystems are now also recognised for their vast and unique capacity to sequester and isolate carbon for thousands of years.[3]

This “Blue Carbon” exceeds the carbon fixed and stored by plants on land (“Green Carbon”) each year. While perhaps lacking the conservation glamour of rainforests, it is a compelling fact that “the long-term sequestration of carbon by 1km^2 of mangrove area is equivalent to that occurring in 50 km^2 of tropical rainforest.”[4] The values are comparable for seagrass and salt marsh habitats. Knowing this, the wisdom of conserving habitats supporting coastal marine vegetation — primarily in estuaries — is significantly strengthened. There is an equally strong case for restoration, enhancement, and perhaps even creation of these habitats. They serve two crucial and timely functions: the conservation of biodiversity and the moderation of climate change.

Carbon, Hydrocarbons, and Climate

All the transactions of industrial society, which form the very basis of our wealth and lifestyle, derive predominantly from the energy of hydrocarbons, and this includes most of the food we eat.[5] This energy is released when the chemical bonds between carbon and hydrogen are rearranged, in the presence of oxygen, to form carbon dioxide and water: $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2 +$ Energy. This is combustion, the fire of both the hearth and the economy. Its benefits are beyond question. It has given us our civilization and modernity — but its singular and demanding price has turned out to be global warming and ocean acidification.

Information derived from current observations, interpretations of Earth history, and the chemistry and physics of the atmosphere and ocean leave no doubt that the equable climate humanity has known since the beginnings of agriculture is in transition to a new and warmer regime, which will soon exceed the experience of all human history. We need to limit this shift, and there are actions we can still take to reduce the rising concentrations of greenhouse gases. The most important of these actions have to do with controlling the carbon we continue to emit to the atmosphere and subsequently the ocean, both by producing less of it, and removing or

ESTUARINE HABITATS SERVE TWO CRUCIAL AND TIMELY FUNCTIONS: THE CONSERVATION OF BIODIVERSITY AND THE AMELIORATION OF CLIMATE CHANGE.

3. Nelleman, C. et. al. (2009) Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. UNEP, FAO, IOC/UNESCO. Page

4. *Ibid.*

5. Manning, R. (2004) The Oil We Eat http://harpers.org/archive/2004/02/0079915

isolating more of it. These two approaches go hand in hand: both *reduction* and *removal* of carbon are crucial to stabilizing the climate.

Reducing the amount of carbon we produce:

It is standard practice to calculate reductions in ongoing carbon emissions as a percentage of the emissions of an agreed baseline year. While sound in principle, many jurisdictions introduce confusion by varying their choice of percentage and baseline year.

A less confusing way to frame the challenge is in terms of absolute amounts of CO_2, in billions of tonnes (Gt) that can be released before certain thresholds of global average temperature and/or oceanic acidity (pH) are likely to be crossed. The less we emit, the higher the probability we can restrain global warming and keep ocean pH from exceeding dangerous thresholds. Equitably dividing the responsibility for carbon emissions is the great social challenge of our time.

For example, if we accept the IPCC[6] calculation that there is a better than 66% chance that climate sensitivity (defined as warming resulting from the doubling of CO_2)[7] falls between 2°C and 4.5°C, and proceed prudently by assuming the higher value, then modelling demonstrates that "if society accepts that the 2°C threshold is the upper bound of acceptable global warming, we have 484 billion tonnes of allowable carbon emissions to play with starting January 1, 2007, until the day we finally bring our emissions to zero."[8] Right now we continue to use up 10 billion of those tonnes each year, so even without economic growth, that allotment would be gone by 2055 and we would be committed to breaking the 2°C threshold.

Removing or isolating some of the carbon already in the atmosphere:

The measure of our carbon challenge makes very clear the value of natural "sinks" that can isolate carbon for long periods. There is already a recognized connection between the preservation of biodiversity and the carbon sequestration potential of forests.[9] We propose that estuarine plant communities — which in temperate zones include seagrass meadows and salt marshes — are equally important candidates for protection given their important biodiversity values and much higher efficiency in sequestering carbon. Indeed, there is a strong case for going beyond simple protection by extending and creating more of these highly beneficial habitats.

Photo: Andrew S. Wright

Purple Sea Star — a keystone species in many intertidal regions.

Excessive CO_2 dissolved in ocean water has already caused ocean acidity in the surface layers to increase by 30 per cent. Increasing acidity has a profound impact on primary producers in the marine food chains which provide nutrition for innumerable species — including humanity.

6. IPCC – Intergovernmental Panel on Climate Change
7. Climate sensitivity is the global average temperature increase consequent on doubling atmospheric CO_2 (from 280 to 560 ppm).
8. Weaver, A. (2008) Keeping Our Cool – Canada in a Warming World. Viking. p.254
9. Wieting, J. (2009) http://www.sierraclub.bc.ca/quicklinks/publications/CoastForestReport2009_email.pdf

Photo: Pharis Patenaude

The natural productivity of estuaries and their role in carbon removal calls for concerted efforts at all levels of government to protect these benefits.

Blue Carbon is biologically fixed by marine vegetation and microorganisms and sequestered by burial in seafloor sediments. This parallels the geological processes which formed oil, gas and coal. If left undisturbed, Blue Carbon repositories are secure for millennia.

Carbon in the Oceans: Dangerous in Seawater, Safe Buried in Sediments

The world's dependence on hydrocarbon energy is so great that we now liberate roughly 8.5 billion tonnes of carbon (GtC) from the combustion of coal, oil and gas every year. Approximately 30% of this dissolves immediately into the oceans, at the astonishing rate of nearly one million tonnes of CO_2 every hour.[10] In the past 200 years approximately 525 Gt of carbon have entered the ocean from the atmosphere. Compared with the 40,000 Gt of carbon already in the oceans this seems modest, a mere 1.3% increase, but the ocean mixes so slowly that this "new" carbon is still concentrated in the upper few hundred metres. Because it reacts chemically with water, creating carbonic acid as well as carbonate and hydrogen ions ($CO_2 + H2O \leftrightarrow HCO3^- + CO_3^= + H^+$) it has already had a profound effect, increasing the acidity of the uppermost ocean by 30%. Business-as-usual carbon dioxide emissions until 2050 would more than double that number, a "guardrail" or threshold we must not cross.[11]

Changes of this magnitude are already a matter of deep consequence. The more acidic the environment the more difficult it is for shelled organisms to access the calcium compounds required to build their shells and skeletons, limiting their growth and reproductive success. Experiments have shown that shells begin to disintegrate as acidity increases — a process akin to what happens to human bones in osteoporosis.[12] It is a momentous challenge to the ecology of the ocean as a whole, since some of these organisms are primary producers and others lie near the very base of the marine food chain — including copepods and other zooplankton, favourite prey for salmon. We do not yet know if other organisms will provide effective substitutes, but there is some palaeontological evidence they have done so in the past under comparable conditions, albeit rather slowly from the human perspective.[13] What we do know is the fundamental primacy of the oceans in geochemical cycles; also the fact that 99 per cent of the biosphere by volume is oceanic. We of the land would miss the benefits of a healthy ocean far more than the ocean would miss us!

10. 3.67 tonnes of CO_2 contain 1 tonne of carbon (and 2.67 tonnes of oxygen)

11. German Advisory Council on Global Change (WBGU), 2006, The Future Oceans — Warming Up, Rising High, Turning Sour, accessed at www.wbgu.de/wbgu_sn2006_en.pdf

12. Bradshaw, K. (2007) http://soundwaves.usgs.gov/2007/01/SW200701-150.pdf

13. Erba, E. et. Al. (2010) Calcareous Nannoplankton Responses to Surface-Water Acidification Around Oceanic Anoxic Event 1a. Science 23 July 2010; Vol. 329. No. 5990. pp. 428-432 http://www.sciencemag.org/cgi/content/abstract/329/5990/428

Out of harm's way: biologically sequestered marine carbon.

Blue Carbon is carbon that is fixed into living tissue by shallow-water marine plants via the process of photosynthesis. It is then buried in sediments, isolating it from further circulation in the carbon cycle, generally for some thousands of years. It is a biological and geological process, distinct from the dissolution of CO_2 in seawater, where it reacts chemically with water to make carbonic acid, as described above.

The formation of Blue Carbon is effectively the reverse of combustion. Shallow-water plants fix carbon and release oxygen by photosynthesis (CO_2 + H_2O + light → CH_2O + O_2 ↑) where CH_2O is the generic symbol for carbohydrates. Carbohydrates (composed of Carbon, Hydrogen and Oxygen) in the dead remains of biological tissue become buried in estuarine sediments, isolated from the activity of microbial decomposers, replicating in part the geological processes which formed oil, gas and coal. Carbohydrates become hydrocarbons (Carbon and Hydrogen only) during a long history of deep burial over millions of years during which heat drives off the oxygen in a process called pyrolysis.

Oceanic carbon sinks:

The table below shows that the oceans contain by far the majority of carbon in circulation on the surface of the planet, about 50 times as much as the atmosphere and 20 times that of the terrestrial biosphere and soils. The high concentration in the deep sea is mediated by the so-called "solubility pump" and assisted by the cold temperatures of deep water. Of all the CO_2 that crosses the air-to-water boundary, only 1 per cent

WE OF THE LAND WOULD MISS THE BENEFITS OF A HEALTHY OCEAN FAR MORE THAN THE OCEAN WOULD MISS US.

remains as a dissolved gas. The rest reacts chemically with water to create carbonic acid, as described above, or is transferred by surface water slowly sinking and circulating to the depths. Some carbonates also reach the deep sea via the constant fallout of wastes and corpses (the "biological pump"), but this process is fundamentally limited by the availability of nitrate (NO_3^-) and will likely not increase in capacity. Indeed, there is evidence our increasing harvests of sea life are significantly depleting the biological carbon of the oceans.[14]

Carbon residing in deep ocean water eventually circulates back to the surface via the Great Ocean Conveyor. The only "permanent" sequestration of carbon from deep ocean water is to the deep sediments which are eventually returned to the lithosphere via subduction of the sea floor down the deep ocean trenches — at an estimated rate of about 0.2 Gt/yr, i.e. a mere 200 million tonnes compared to the 10 billion tonnes we emit annually from fossil fuels and land use changes. In the original world this nicely balanced the annual CO_2 increment from volcanoes.

The rough equivalence of deeply buried carbon and the Blue Carbon captured and stored each year in shallower sediments is notable. Estimated at 120 to 329

Carbon Sink	Reservoirs GtC[a]	GtC added/yr
Atmosphere	750	
Terrestrial Biosphere	610	0.105 – 0.202
Soil	1580	
Oil & Gas	300	
Coal	3000	
Ocean Deep Water	38,100	
Ocean Surface Water	1020	2.45
Dissolved Organic Carbon	650	
Marine Biosphere	3	
Deep Ocean Sediments	150	0.2
Blue Carbon Sediments	85[b]	0.235 – 0.45

a. IPCC data in Figure 1, Nelleman, C. et. al. (2009) Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. UNEP, FAO, IOC/UNESCO.
b. Laffoley, D. & G. Grimsditch ed. (2009). The Management of Natural Coastal Carbon Sinks. IUCN, Gland, Switzerland. (Calculation from data in table p.48)

14. http://www.sciencenews.org/view/generic/id/48484/title/Sperm_whales_as_a_carbon_sink

GIVEN THE MEASURE OF OUR CARBON CHALLENGE, IT IS IMPERATIVE TO PROTECT EXISTING CARBON SINKS, BOTH MARINE AND TERRESTRIAL. THE LONG-TERM STABILITY OF STORAGE IN MARINE SINKS — MEASURED IN THOUSANDS OF YEARS — GIVES THEM AN EDGE COMPARED TO FOREST SINKS.

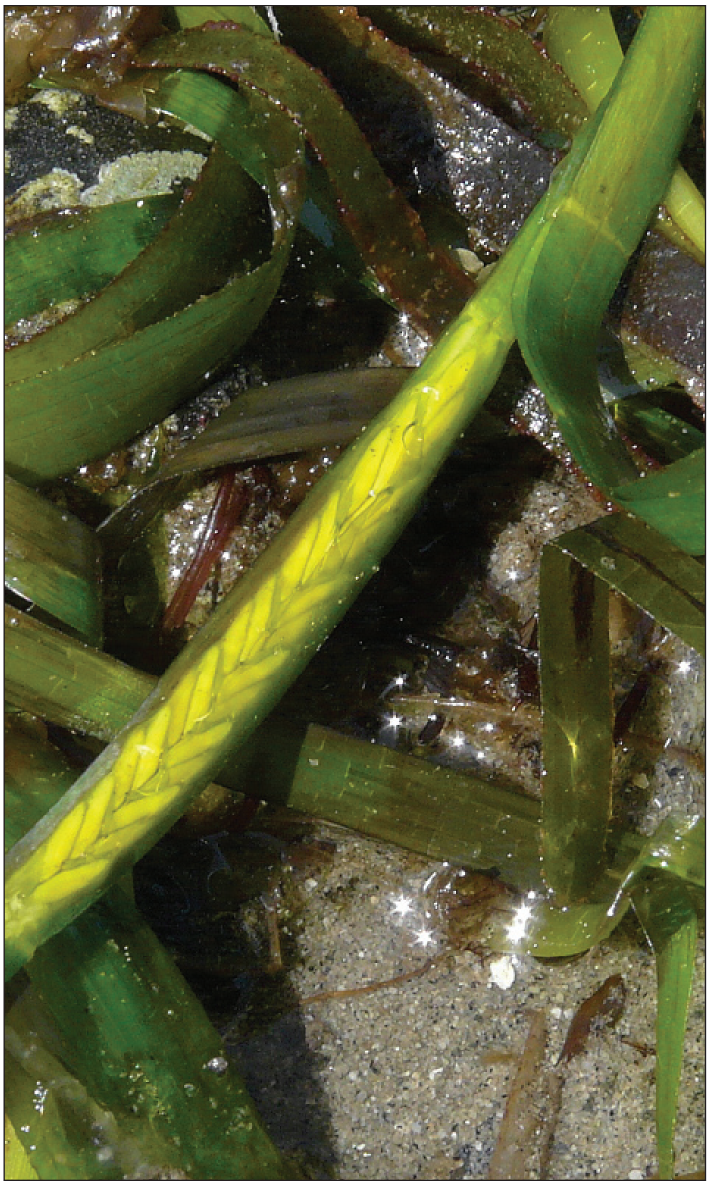


Photo: John Dove

Eelgrass is recognizable by its long, strap-like leaves. It is found in shallow marine sediment, right up into the intertidal zone. In B.C., its real abundance is below the low-tide level.

million tonnes (0.12 – 0.33 GtC) annually,[15] Blue Carbon sequestration occurs over a mere 0.5% of the ocean floor, while deep burial occurs over approximately 50% of the ocean floor. Forests, which are receiving considerable attention as carbon sinks,[16] require a 20 to 50 times greater area to match the capacity of Blue Carbon repositories. Also, the longevity of forest carbon storage is measured in centuries at best whereas the Blue Carbon repositories are considered secure for millennia if they are undisturbed.

Estuaries — Mixing Water, Land, Life and Light

One of the beneficial outcomes of the great ice melt that occurred after the peak of the last glaciation some 18,000 years ago is the rich and vibrant estuarine world. Where rivers meet the sea and the slope is not too steep, there freshwater, seawater, sediment, nutrients, plants, animals, microbes, viruses and light interact to form ecosystems of exceptional productivity and, it turns out, with a unique capacity to sequester carbon- rich organic compounds in continuously deposited sediments.

Where the sedimentation rate in estuaries is sufficiently high, the surface of the sea floor is constantly pro-grading, building up and burying the deeper sediments beyond the reach of decomposition, and locking carbon away, potentially for many thousands of years. Already these kinds of sediments hold ~85 GtC.[17] Indeed, the action of rising sea level, if not too rapid, could preserve this valuable process by compensating the rising sea floor with a deepening water column above.

The physiological stress imposed by varying salinity excludes most but selects a relatively few tolerant species which, lacking heavy competition and predation, can grow and reproduce rapidly and become highly abundant. The constant inflow of nutrients from the river, much of it derived from the woody debris of streamside forest, is slowed, trapped and held by the plants, barrier islands and sandbars common in estuaries. This constant inflow of nutrients is a major key to the characteristically rapid biological turnover of the estuary, where the biomass of plants is less than in an equal land area by a factor of thousands. Simultaneous with the constant inflow of fresh river water is the routine exchange of seawater by the tides,

15. Nelleman, C. et. al. (2009) Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. UNEP, FAO, IOC/UNESCO. Page 37
16. http://www.sierraclub.bc.ca/quick-links/publications/CoastForestReport2009_print.pdf
17. Laffoley, D. & G. Grimsditch ed. (2009). The Management of Natural Coastal Carbon Sinks. IUCN, Gland, Switzerland. (Calculation from data in table p.48)

replenishing oxygen, plankton and other nutrients, and flushing excess wastes.[18]

In the high intertidal zone of suitable estuaries are found salt marshes. Below the low water mark but still in the zone of freshwater influence, seagrass meadows flourish. Tropical regions also harbour intertidal mangrove swamps, hugely effective as repositories of Blue Carbon. These fortuitous incubators support a diverse array of ecosystems in many layers: some buried in the sediment, others on the sediment surface, rooted in the sediment, on the surface of those rooted plants, in the water column, on the tidally exposed land and even in the air.

Life in the Intertidal Zone

Salt marshes are flooded and exposed by every tide and thereby experience the greatest extremes in both moisture and salinity. Across their range, from the intertidal to the terrestrial, the trained eye of a botanist can distinguish the salinity gradient by the successive plant associations comprising the marsh. The physical and chemical extremes whittle the species present to just a few major plant types and species, commonly halophytes which store freshwater in their tissues and which modify their leaves to reduce its loss. The by-products of decomposition are often toxic to other organisms, accentuating the harshness of an already taxing environment.[19]

Although seagrass meadows straddle the intertidal zone, it is in the shallows immediately below the lowest tides, where the influence of freshwater is still felt and the sunlight still reaches the seafloor, that seagrass meadows flourish. In B.C. two species of eelgrass comprise the greater proportion of the seagrass community, the native species *Zostera marina*, and the introduced *Z. japonica*. Three species of surfgrass (*Phyllospadix*) and one ditchgrass (*Ruppia*) also occur. Growing best in waters in the salinity range of 10-30 parts-per-thousand (where normal seawater is ~35 ppt) sea grasses are flowering plants with a complex root system that encourages sediment trapping. Seagrasses provide habitat to a diversity of organisms, from microbes to juvenile salmon.[20]

The actual mechanism of organic sediment production is complex and yet to be fully understood. Carbon is sequestered in the stems, leaves, roots and rhizomes of the standing plants, the macroflora. More carbon — sometimes a great deal more — is embodied in the microbial epiflora that live attached to the stems and leaves, especially of seagrasses. Their biomass/productivity can range from 8 to 120 per cent of

Photo: John Dove

Eelgrass bed at low tide. Davie Bay, Texada Island.

It is a matter of significant concern globally that the mangrove, seagrass and salt marsh ecosystems that constitute the Blue Carbon sinks are under heavy attack, disappearing in aggregate at rates from two to 15 times faster than forests.

18. Estuaries in British Columbia; http://www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf
19. Butler, R. (2003) The Jade Coast: The Ecology of the North Pacific Ocean. Key Porter. P.102
20. Butler, R. (2003) The Jade Coast: The Ecology of the North Pacific Ocean. Key Porter. P.101

Photos: Jens Wieting

Seagrasses provide a bountiful table for vegetarians (like this American Wigeon, middle). Shorebirds, such as the Black Oystercatcher (top) and Short-billed Dowitcher (bottom), prefer meaty delicacies, also to be found in great abundance in estuarine habitats. Different lengths of bills enable different species of shorebirds to feed in the same habitat without direct competition for food.

BIODIVERSITY HOTSPOTS: ABOUT 80 PER CENT OF COASTAL WILDLIFE IS DEPENDENT ON ESTUARIES FOR SOME PORTION OF THEIR LIFE CYCLES.

the host plants.[21] Then there is the free-floating phytoplankton taking advantage of the slowed water movements above the vegetated seafloor and the abundance of nutrients coming from the land via the rivers.

There is also a nutritional pathway in the ocean, called the "microbial loop," which results from an abundance of organic matter, primarily carbohydrates, being dissolved in the sea water. There is no such equivalent free-floating source in the atmosphere.

This odd circumstance relates directly to the relative scarcity of biologically available nitrogen in seawater. In shallow coastal seas, light, CO_2 and water are available in abundance to phytoplankton. Carbohydrates are readily manufactured, but not proteins and nucleic acids which require nitrogen. The cells exude excess carbohydrates into the water, which are accessed mainly by bacteria which exist in enormous numbers (up to 1 billion/litre).[22]

A diverse abundance of organisms is supported by this extraordinary complexity, ranging from viruses, bacteria and archaeans through algae and angiosperms to invertebrates of many kinds (including nematodes, copepods, annelids, molluscs and crustaceans) to fish, reptiles, birds, and mammals living in the ocean, in the rivers and on land – including humans.

Not all the carbon buried in these sediments is fixed by the plants that give structure to the habitats. A significant proportion derives from plankton and terrestrial sources,[23] via particles deposited when they impact the seagrass fronds and lose momentum sufficiently to precipitate them out of the water column. The leaves and roots of the plants effectively sieve plankton from seawater by taming its motion. The numbers are significant.

In total, these vegetated ecosystems accumulate between 0.12 and 0.33 GtC/yr, which equal approximately 3.3 per cent of all anthropogenic carbon emission. Remarkably, the 0.5 per cent of the sea floor covered by these ecosystems accumulates 50 per cent of the carbon that reaches the entire sea floor in

21. Butler, R. (2003) The Jade Coast: The Ecology of the North Pacific Ocean. Key Porter. p.103
22. Denny, M. (2008) How the Ocean Works: An Introduction to Oceanography. Princeton. pp. 129-131
23. Laffoley, D. & G. Grimsditch ed. (2009). The Management of Natural Coastal Carbon Sinks. IUCN, Gland, Switzerland. pp. 6-7.

sediments, which makes them 180 times more effective in this regard than the average for the open ocean.[24]

Conservation, Restoration, Enhancement

It is a matter of significant concern globally that the mangrove, seagrass and salt marsh ecosystems that constitute the Blue Carbon sinks are under heavy attack, disappearing in aggregate at rates from two to 15 times faster than forests. Indeed, one third of the original area has already been lost, mostly in the past 60 years.[25] These rates are continually increasing, and existing restoration projects fall far short of balancing the losses.

In addition to their role as carbon sinks, the estuarine habitats fulfill other vital ecological and social functions. Taken together, these benefits are a powerful argument for the mitigation of impacts and managed adaptation to inevitable change.

The list of processes that impact coastal ecosystems is a description of the side-effects or externalities of modern living. Deforestation, agricultural pollutants, industrial runoff, over-fishing, invasive species, oil spills, dredging, infilling, mining, biodiversity loss— all pushing these systems way beyond their capacity to buffer the impacts.

Mitigation of carbon emissions demands protection and restoration of these biological hotspots for carbon burial in the oceans — and a case could be made that they might in fact be enhanced, much as West Coast First Nations extended shellfish beds by building subtidal stone walls to trap more sediment and increase the area of "clam gardens."[26] Ancillary benefits include oxygenation of coastal waters, service as fish and invertebrate nurseries, and physical protection of the shoreline from ever-increasing flooding and storm surges created by extreme weather events.

The countless benefits such an environment delivers for human use have long been recognized. For example, the sheer density of archaeological artefacts from the perimeters of the Danish and other North Sea estuaries since the ocean established its present level about 6,000 years ago is elegant testimony to human productivity based on those resources. So numerous are the bone, wood and stone artefacts utilized to exploit this environment that the National Museum in Copenhagen displays cascading piles of tools and artefacts that most museums would carefully mount and label individually. A strong case can be made that the productivity of estuaries in many places, including the B.C. coast, supported the emergence of modern human society, a gift scarcely reciprocated by our destruction of these habitats in the quest to graze cows instead of preserving their natural productivity and benefits.

Geo-Engineering Estuaries?

Clearly, no matter how rapidly society reduces carbon emissions they will continue for many years — and they have to end up somewhere. Ideally, carbon sinks would keep carbon out of the atmosphere and out of solution in seawater in order to avoid crossing critical temperature and acidity thresholds. Growing awareness of the seriousness of ocean acidification[27] has caused technical interventions under the rubric of geo-engineering to be proposed, [28] [29] and increasingly considered inevitable.

Of all the relevant geo-engineering proposals, there are only two that would remove CO_2 from the atmosphere without causing an increase in ocean acidification— the adding of carbonate (e.g. finely ground limestone) directly to seawater, and the mimicking of natural silicate weathering reactions using HCl extracted from the ocean, leaving an increased alkalinity and capacity to convert dissolved CO_2 into bicarbonate (HCO_3^-).

Unlike grandiose geo-engineering solutions, natural carbon sinks encourage a far more benign form of intervention, namely preservation, restoration, enhancement and expansion of existing Blue Carbon systems.

24. Nelleman, C. et. al. (2009) Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. UNEP, FAO, IOC/ UNESCO. P.37
25. Nelleman, C. et. al. (2009) Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. UNEP, FAO, IOC/ UNESCO. Fig.16, pp.36-37
26. Williams, J (2006) Clam Gardens: Aboriginal Mariculture on Canada's West Coast; Transmontanus
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Photo: Andrew S. Wright

A traditional fish trap in the Great Bear Rainforest, testimony to the estuary's great abundance.

The nature of West Coast geology and the down-cutting effect of glacial ice on rock have resulted in steep, sometimes almost vertical coastlines, and restricted the presence of estuarine flats to just 2.3 percent of the B.C. coastline. Even so, 80% of coastal wildlife is dependent on estuaries for some portion of their life cycles.[31] And now we know how effectively they store carbon. These are valuable places, destined to come under increasing pressure for alternative development as population pressure increases, especially in the Lower Mainland of British Columbia.

British Columbia's 442 estuaries[32] have a combined area of 745 square kilometres (km^2) or 74,585 hectares, 63 per cent of which is occupied by the four largest estuaries,[33] including a whopping 29 per cent by the Fraser River estuary alone. Of the various estuarine habitats, the most critical for carbon sequestration in B.C. are the eelgrass beds, especially those of the native *Zostera marina*, which are known to fix up to 500 $gmC/m^2/year$,[34] while salt marsh on average sequesters 210 $gmC/m^2/year$.[35] Eelgrass beds are incompletely mapped in B.C.; a compilation by the B.C. Marine Conservation Analysis (B.C.MCA)[36] estimates 335 km^2, which is inevitably an underestimate since it derives primarily from low-tide aerial surveys and likely misses the greater abundance in its preferred habitat, the subtidal zone. The 'marsh/swamp' category in B.C. occupies a modest eight per cent of total estuarine habitat, a total of 60.47 km^2.[37] Given its considerable capacity to sequester carbon we can only regret the loss of 99 per cent of the original salt marsh on the Fraser River delta to dykes and the plough, converted over a century to agricultural and urban uses.[38]

Both techniques require full-cycle carbon analysis to determine under what conditions the outcome would be positive, but the fact that all the limestone presently mined, 3 billion tonnes each year, would only neutralize 3% of the acidity caused by our emissions sets the scale of the challenge quite clearly.[30]

In sum, the constraints that caution imposes on geo-engineering options, the sheer scale of the acidity and climate problems, and the preliminary status of workable fixes, make clear the inherent value of existing ecological processes known to sequester carbon. Natural sinks provide not only capacity, but encourage a far more benign form of intervention, namely preservation, restoration, enhancement and expansion of existing Blue Carbon systems. Engineering estuarine conditions in the coastal zone, where appropriate, is likely less fraught with unknowns than other proposed tactics. The small-scale engineering interventions for enhancing mariculture that were undertaken by coastal aboriginal people in B.C., scaled up in suitable estuarine localities, are likely an appropriate way to go.

The Estuaries of British Columbia

Between the Alaskan overhang and the Washington State line lies 900km of ocean, but the complex coastline of indented fjords and numerous islands gives B.C. approximately 25,700 km of shoreline in contact with that ocean. This vast distance amounts to 10 per cent of the entire Canadian shoreline, and is equal to a trip more than halfway around the Earth's equator.

30. Weaver, A (2008) Keeping Our Cool. Viking. p.124

31. Estuaries in British Columbia; http://www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf
32. Defined as the intersection with the coastline of rivers wider than 20m, or of fourth order or higher.
33. Fraser; Skeena/Ecstall/McNeil; Nicomekl/Serpentine; Nass complex. Ryder et.al. (2007)
34. Phillips, R.C. (1984) The Ecology of Eelgrass meadows of the Pacific Northwest. U.S. Fish and Wildlife Service; Army Corps of Engineers
35. Laffoley, D. & G. Grimsditch ed. (2009). The Management of Natural Coastal Carbon Sinks. IUCN, Gland, Switzerland. p.48
36. B.C.MCA, Karyn Bodtker, personal communication.
37. Ryder et.al. (2007) Table 3; Footnote 5.
38. Butler, R. (2003) The Jade Coast: The Ecology of the North Pacific Ocean. Key Porter.

Calculations based on the areas and annual average carbon sequestration for each of those habitats noted above indicate a minimum 180,200 tonnes of carbon sequestered each year in B.C., compared with 80,000 — 220,000 tonnes/yr for B.C.'s boreal forests[39] — which occupy 90 times the area of B.C. estuaries. Blue carbon sinks in B.C. are capable of balancing the emissions of approximately 200,000 passenger cars.[40] Again, this is likely a low estimate since eelgrass certainly occupies more area than recorded at present. The actual amounts of carbon sequestered would be even higher if we began to restore salt marsh.

Blue Carbon Sites in B.C. — Status and Opportunity

British Columbia has long recognized the importance of estuaries to wildlife, fisheries and the economic wellbeing of coastal communities, including First Nations. In 1987 the Pacific Estuary Conservation Program (PECP) formed as an alliance of government and conservation organizations[41] with the goal of identifying a network of biologically representative sites to contribute to the conservation of biodiversity in British Columbia. They worked to protect estuaries for the long term by securing, often via landowner agreements, shoreline and intertidal estuarine habitats to support the North American Waterfowl Management Plan's task of maintaining the integrity of the Pacific Flyway. [42]

One important outcome of this cooperative venture was a ranking of B.C.'s 442 estuaries into 5 importance classes (important to water birds) according to their particular combination of size, habitat type and rarity, herring spawn occurrence, water bird use and intertidal biodiversity.[43] While the study cautions against extrapolating this kind of importance to other categories, it is nevertheless the case that estuaries that ranked high in the PECP assessment were both large in area and had proportionately large areas of intertidal delta (with eelgrass) or adjacent salt marsh.

The following are the key estuaries in B.C. with Blue Carbon potential:

- Fraser River
- Chemainus River/Bonsall Creek
- Courtenay River
- Cowichan River
- Georgetown Creek
- Kitimat River
- Nanaimo River
- Nicomekl/Serpentine Rivers
- Skeena/Ecstall/McNeil Rivers

It is readily seen that they are also prime areas for human impact; indeed much has already occurred. These estuaries and a very large number of smaller ones are becoming increasingly important as the significance of natural carbon sequestration is appreciated. The same 2007 PECP study notes that 43 per cent of B.C.'s estuaries are threatened by coastal development, modification and pollution.[44] Important protections are in place but are inevitably limited and variable in their effects. Excluding the Fraser River and Boundary Bay (which contain 20,970 ha intertidal habitat), there are 10,073 ha of protected area within 34,970 ha of intertidal habitat based on 440 estuaries.[45] This means that just 13.5 per cent of the area of this already very limited environment is protected; indeed only 123 estuaries (28 per cent) had conservation areas present within the intertidal zone, while the remaining 317 estuaries, mostly medium and small, have no conservation protection at all. The picture is not clear at present in regard to sub-tidal marine protected areas designated for eelgrass habitat, or precisely what area of salt marsh is protected in any way.

GIVEN ITS CONSIDERABLE CAPACITY TO SEQUESTER CARBON WE CAN ONLY REGRET THE LOSS OF 99 PER CENT OF THE ORIGINAL SALT MARSH ON THE FRASER RIVER DELTA TO DYKES AND THE PLOUGH, CONVERTED OVER A CENTURY TO AGRICULTURAL AND URBAN USES.

39. http://cmsdata.iucn.org/downloads/carbon_managment_report_final_printed_version_1.pdf p.48, Table 1
40. http://www.sierraclub.bc.ca/wild/blue-carbon-2013-good-news-from-the-ocean/
41. Collectively the Canadian component of the Pacific Coast Joint Venture: Canadian Wildlife Service, Fisheries and Oceans Canada, B.C. Ministry of Environment, B.C. Habitat Conservation Trust Fund, Ducks Unlimited Canada, Nature Conservancy of Canada, Land Conservancy of B.C., Nature Trust of B.C..
42. http://www.ducks.ca/province/bc/partners/pecp/pdf/pecp.pdf
43. Ryder, J.L. et.al. (2007) An Integrated Biophysical Assessment of Estuarine Habitats in British Columbia to Assist Regional Conservation Planning. Canadian Wildlife Service, Technical Report 476.
44. Ryder, J.L. et.al. (2007) An Integrated Biophysical Assessment of Estuarine Habitats in British Columbia to Assist Regional Conservation Planning. Canadian Wildlife Service, Technical Report 476. p.iii
45. Personal Communication, Dan Buffett, Ducks Unlimited. 2005 data from 2007 Province of B.C. Environmental Trends Report (http://www.env.gov.bc.ca/soe/et07/) and 2006 Alive and Inseparable British Columbia's Coastal Environment (http://www.env.gov.bc.ca/soe/bcce/images/bcce_report.pdf).

Because so much valuable estuarine land is in the heavily populated southern Mainland/Strait of Georgia region, much of the focus of the Seagrass Conservation Working Group (SCWG)[46] is focused in this coastal area. The SCWG is a consortium of community conservation groups, government agencies, First Nations and individuals who are concerned with near-shore habitats such as eelgrass, spawning sites for forage fish and marine riparian areas.

Since 2002, community groups have mapped eelgrass beds and used outreach to schools, the public and local governments for conservation goals. Sierra Club BC's vision is that growing awareness of the need to recognize Blue Carbon will allow all groups active in estuarine protection to bring greater professional and governmental influence to bear on the conservation challenge.

Clearly an expanded approach to estuarine protection is required if the sedimentary and other processes that effect Blue Carbon burial are to be preserved, restored and enhanced. Upstream sediment supply must be managed, and subtidal estuarine flats at least maintained if not enhanced. This is the direction of the future, preferably the very near future.

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Recommendations

- Conduct a comprehensive mapping survey of the occurrence of sub-tidal eelgrass in B.C.'s coastal waters.
- At the federal level: Prioritise intact estuarine vegetation for protection under the provisions of the Federal *Fisheries Act.* Eliminate any activities that harmfully alter, disrupt or destroy estuarine fish habitat under Section 35(2) of the *Fisheries Act*.
- At the provincial level: Monitor boating and other recreational access to the water, including fishing and shellfish harvesting, to prevent damage to coastal marine vegetation. Control upstream erosion and excessive sediment loading of streams from all development and logging operations.
- At the municipal level: Protect eelgrass beds by eliminating damage from log booms, docks and other structures. Divert runoff of fertiliser, pesticide and herbicide from salt marsh and seagrass habitats. Establish and protect vegetation buffer zones along streams and the shoreline adjacent to salt marshes and eelgrass beds.
- Investigate the potential of increasing carbon sequestration by engineering the appropriate expansion of estuarine sediment areas.

46. http://www.stewardshipcentre.bc.ca/eelgrass/index.html