

Supplemental Information

Supplementary Note

A proposed blueprint for national assessments of the blue carbon capacity of kelp forests

We present a blueprint for conducting a national assessment of the blue carbon capacity of kelp forest ecosystems (Supplementary Figure 1). Recognizing the significant data gaps and uncertainties that all countries will face in this regard, our reproducible and transparent blueprint workflow involves four main stages. In the first stage, the aim is to extensively collate and synthesize available kelp datasets to identify key data sources and to reveal any data gaps that may hinder the reliable estimation of kelp carbon sequestration processes on a national scale. In the second stage, the aim is to evaluate the potential for natural variation in per-area carbon stocks and fluxes (e.g., productivity) across kelp species and different oceanographic contexts. In the third stage, the aim is to produce an initial estimate of the total carbon stock, production, and export capacity of kelp forests at a national scale, acknowledging the range of potential uncertainties involved. The final stage is to fill current data gaps through targeted sampling and to re-evaluate estimates as new information becomes available. Below is a step-by-step guide, outlining each stage of the assessment, with special considerations and resources for replicating the process in data-limited kelp-dominated systems.

Stage:1 Compile and synthesize available data

- **An important first step is to define the scope of the assessment, including the ecological focus and study domain.** Researchers need to decide what kelp species to include in the assessment, which will ultimately determine the extent of the study domain. Certain countries may primarily have subsurface kelps, while countries on the western boundaries of continents could have surface kelps in addition to subsurface kelp forests, extending from the subtidal into the intertidal zone. National monitoring programs and global kelp occurrence databases can help to identify the primary kelp species found within national jurisdictions^{1,2}. Web portals, such as Algaebase (<https://algaebase.org>) can also aid this process. An appropriate study domain for subtidal kelp forests could extend from mean-low-water out to a specified depth that is informed by *in situ* observations and data describing the maximum depth limit of kelps. Where there is appropriate data, researchers may also choose to extend the study domain to the mean-high-water mark to capture the potential role of intertidal kelps.
- **The next step is to collate available information and datasets on the biomass, plant density, canopy cover, and net primary productivity (NPP) of kelp species from published and unpublished sources.** This step is meant to identify key datasets available for the assessment and to reveal any important data gaps that must be filled to reliably estimate the carbon stocks and production rates associated with kelp species. All NPP (kg DW or WW m⁻² Yr⁻¹) and abundance data (e.g., kg DW or WW m⁻²) can be converted

to carbon stock (Mg C Ha^{-1}) and annual carbon production ($\text{Mg C Ha}^{-1} \text{ Yr}^{-1}$) estimates using published species-specific and coast-specific conversions (i.e., wet-dry ratios and carbon-dry weight ratios) from the peer reviewed literature.³ Plant density and canopy cover datasets are also needed to develop biologically constrained estimates of kelp forest extents, stocks, and production rates across coasts. Researchers can use an existing macroalgal NPP database³ to obtain available information on the NPP rates of kelp species and to structure a search of the peer reviewed literature for other necessary kelp datasets. Existing kelp forest monitoring program data and unpublished datasets can also be useful sources of kelp abundance datasets (i.e., biomass, density, and percent cover).

- **The next step is to use available information and data to estimate the total areal extent of kelp forests.** Areal extent estimates will be needed to extrapolate estimates of kelp carbon stocks, carbon production rates, and carbon export rates to a national scale. For surface kelps, areal extent can be obtained using available high resolution remote sensing products and species distribution modeling studies^{1,2}. In the absence of such data, a suitable reef approach can be employed to obtain a high-, mid-, and low-end estimate for potential extent of kelp forests. Calculating the area of available rocky reef habitat that is above the maximum depth limit of kelp species can provide a useful estimate of the hypothetical maximum limit for kelp forest distributions. However, these estimates can and should be modified using available kelp percent cover and density data to provide a more biologically constrained mid and low-end estimate. Where higher resolution bathymetry data is not available, researchers can obtain grided depth data from the General Bathymetric Chart of the Ocean database (<https://www.gebco.net/>). Additionally, where there is a lack of grided substrate data within national jurisdictions, coarse proxies can be obtained from global datasets^{4,5}.
- **A final step is to compile any available data that allows for the approximation of kelp carbon fluxes and accumulation rates in various potential sinks.** Currently there is limited data on the potential kelp carbon fluxes and accumulation of kelp derived POC and DOC in shelf sediments and the deep ocean. Coarse global estimates can be obtained from Krause-Jensen et al. 2016⁶, although with considerable uncertainty. More resolved estimates of the rate of carbon export (% of kelp production) to the continental shelf break (i.e., below 200 m depth) are also available from ocean transport models of the shelf to open ocean exchange (e.g., ⁷), which can serve to approximate the amount of kelp-derived carbon reaching the deep ocean at an ecoregional scale. However, estimates from ocean transport models still require a thorough interrogation with in-situ experiments and observation studies.

Stage 2: Quantify natural variation in carbon stock, production, and export

- **An important first step here is to evaluate the potential for natural variation within and across kelp species.** We used Bayesian hierarchical models, implemented using the 'brms' package of R, to produce parameter estimates of the average carbon stocks and production rates of different kelp species. Bayesian hierarchical models are parameterized similarly to hierarchical linear regression models. The observed carbon

stocks and production rates of different kelp species are treated as the response variables, while environmental variables (e.g., sea surface temperature, ocean, ecoregion) that potentially influence rates of short-term biomass accumulation and primary productivity are included as fixed effects. Site- and study-level variation can also be accommodated through a model hierarchical structure (i.e., as random effects). A key advantage of using Bayesian approaches is that they provide a posterior distribution a range of possible estimated values given prior beliefs and available data. These prior beliefs can be informed by observations from different systems and species. From this posterior distribution, researchers can calculate a posterior mean and a credible confidence interval (CCI) indicating the range within which the true parameter value is most likely to fall. Additionally, Bayesian models can consider measurements of standard deviation as an additional response term, allowing for adjusted CCIs that reflect greater uncertainty where there is greater variability in kelp biomass and NPP. Researchers can use these credible confidence intervals to identify significant differences in carbon stocks and production rates across kelp species and coasts. Additional information about using the R package “brms” can be found in the literature and the documentation^{8,9}. Scripts for model parameterization, selecting informative priors, and evaluating model outputs, can also found in our [Github](#) repository.

- **The next step is to evaluate the potential for natural variation within and across different regional contexts.** To account for the fact the kelp forests are often multi-species assemblages with different relative compositions, we recommend determining the per-area carbon stocks and production rates of kelp forests as the summed posterior mean estimates for the kelp species found in a particular location, weighted by their observed relative abundance. Additionally, per-area carbon fluxes from kelp forests can be approximated using data on the fraction of kelp detritus that is likely to reach the continental shelf break (i.e., 200 m) from open ocean exchange models⁷. While export does not directly equate to carbon sequestration it can provide a useful proxy in the absence of direct measurements of kelp carbon sequestration in the deep ocean. Where there is limited information on the occurrence and composition of kelp forest communities, a first order estimate could be calculated at the coast scale (e.g., for the Pacific coast of British Columbia). However, where there are more comprehensive datasets, it is recommended to produce more spatially resolved estimates (e.g., at the ecoregion scale).

Stage 3: Develop initial national estimates of the total carbon stocks, production, and export capacity of kelp forests

- **Using the outputs of stages 1 and 2, the next step is to produce estimates of the total national carbon stock, production, and export capacity of kelp forests—as important precursors to carbon sequestration.** The total standing carbon stock, production, and export capacity of kelp forests can be determined by multiplying the per-area estimates by the areal extent estimates. Since surface and subsurface kelps may co-occur, we recommend treating these groups separately. In data limited systems, a first order estimate would be to produce estimates at the coast scale, but in more data rich

systems it may be possible to produce estimates at the ecoregion scale. Then national estimates can be determined by summing across coasts and ecoregions.

- **An important step is to quantify the sensitivity and range of uncertainties surrounding the national estimates.** Given the current data limitations and difficulties with estimating kelp carbon sequestration pathways, assessors may need to use a set of reasonable assumptions. For example, in systems lacking comprehensive habitat maps, assessors may need to make assumptions about the maximum depth limit of kelps, the prevalence of rocky reefs, and the relative abundance of kelp species when estimating the areal extent of subsurface kelp forests. Conducting a sensitivity analysis, where the parameters used are systematically varied, can help evaluate the impact of these choices on the results and the inherent uncertainties involved. Sensitivity analyses can also help identify the highest priorities for future data collection.

Stage 4: Re-evaluate estimates based on new information and data

- **Re-evaluation is integral to ensuring that the assessment remains relevant and accurate over time.** Advances in technology, improved monitoring, and additional research are likely to enhance our understanding of kelp carbon sequestration pathways. Researchers should assess the impact of any changes in methodology, data availability, and environmental conditions on the resulting estimates.
- **Collaboration and transparency are crucial to the revaluation process.** Engaging with experts and incorporating diverse perspective ensures that the assessment benefits from a comprehensive understanding of kelp ecosystems. Clearly documenting any updates, modifications, or changes made to the methodology will ensure the reproductivity and reliability of the assessment. Open communication about the uncertainties and limitations associated with the estimates will help to build trust in the scientific process and the resulting findings.

Conclusion

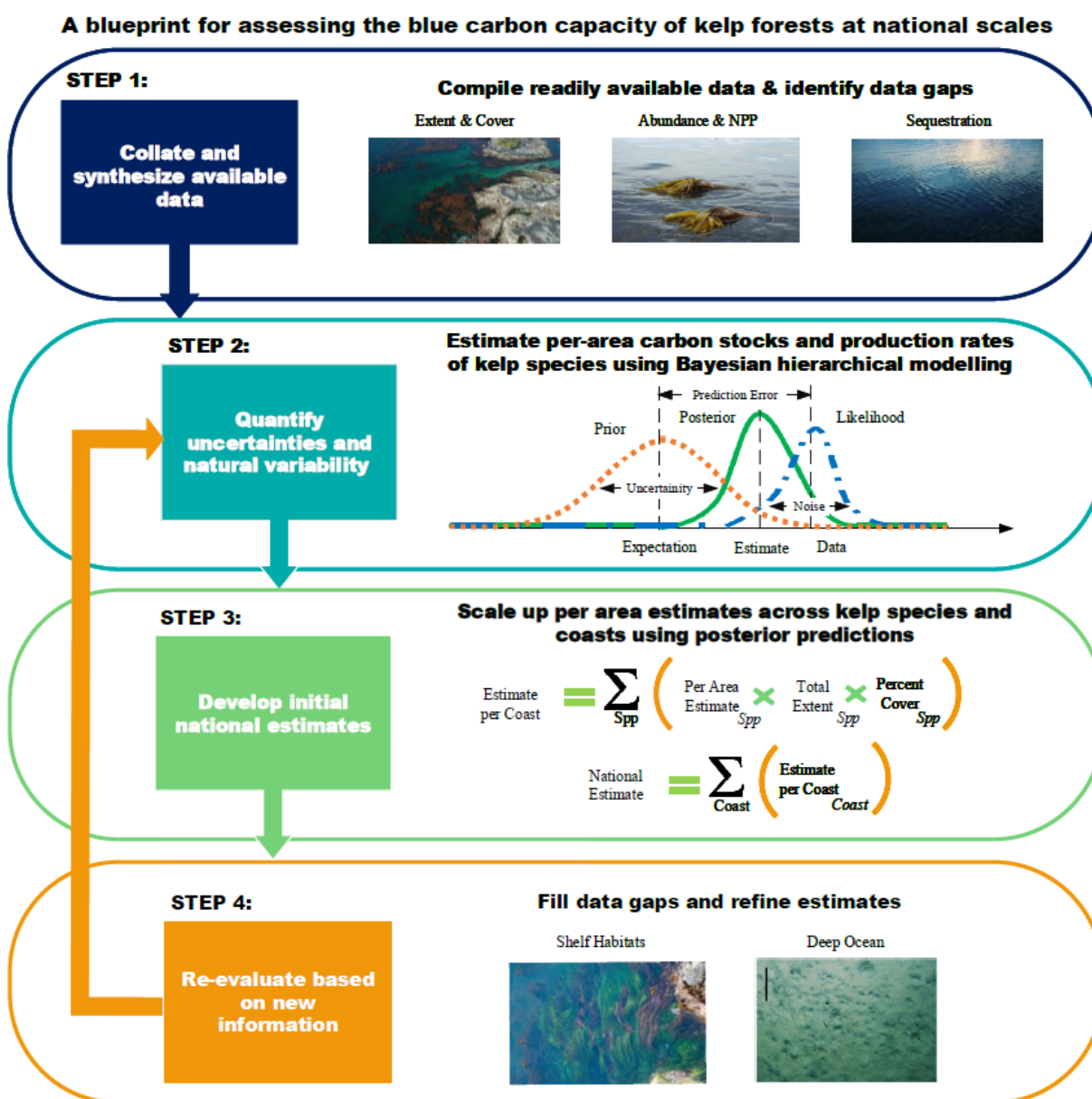
This blueprint offers a reproducible and transparent guide for assessing the blue carbon capacity of kelp forests in national jurisdictions. Researchers can adapt these methods, considering the regional context and data gaps, to contribute valuable insights into the capacity for kelp forests to support NCS at national scales. The four-stage workflow outline in this blueprint aims to address challenges posed by data limitations and uncertainties, promoting a rigorous and iterative approach to enhance the reliability of estimates over time.

Supplementary References 1:

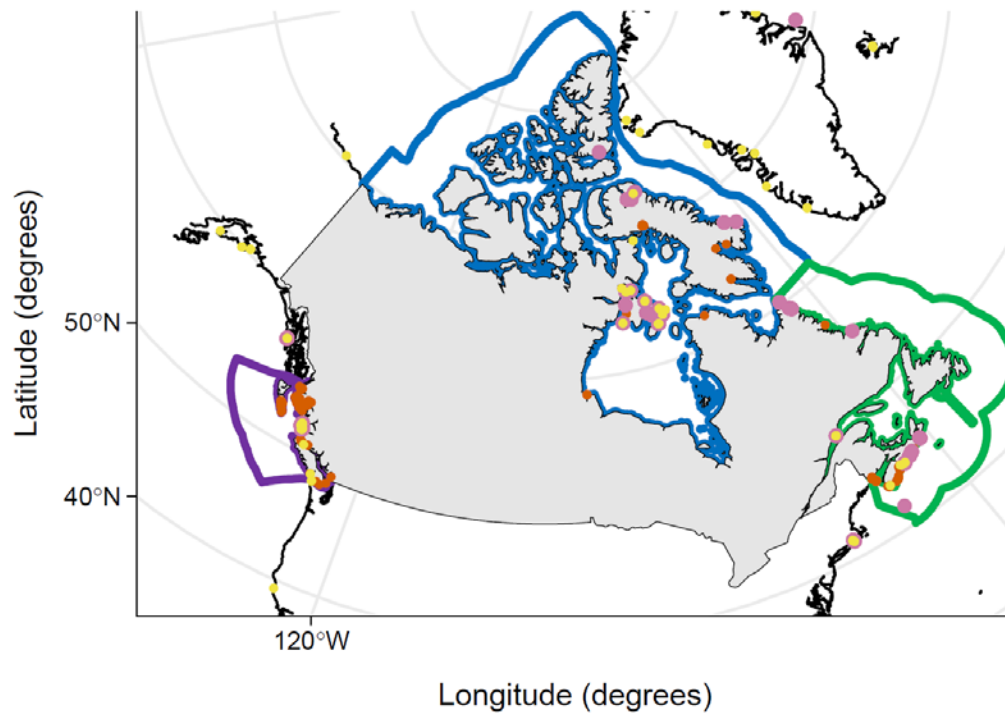
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Supplementary Figures

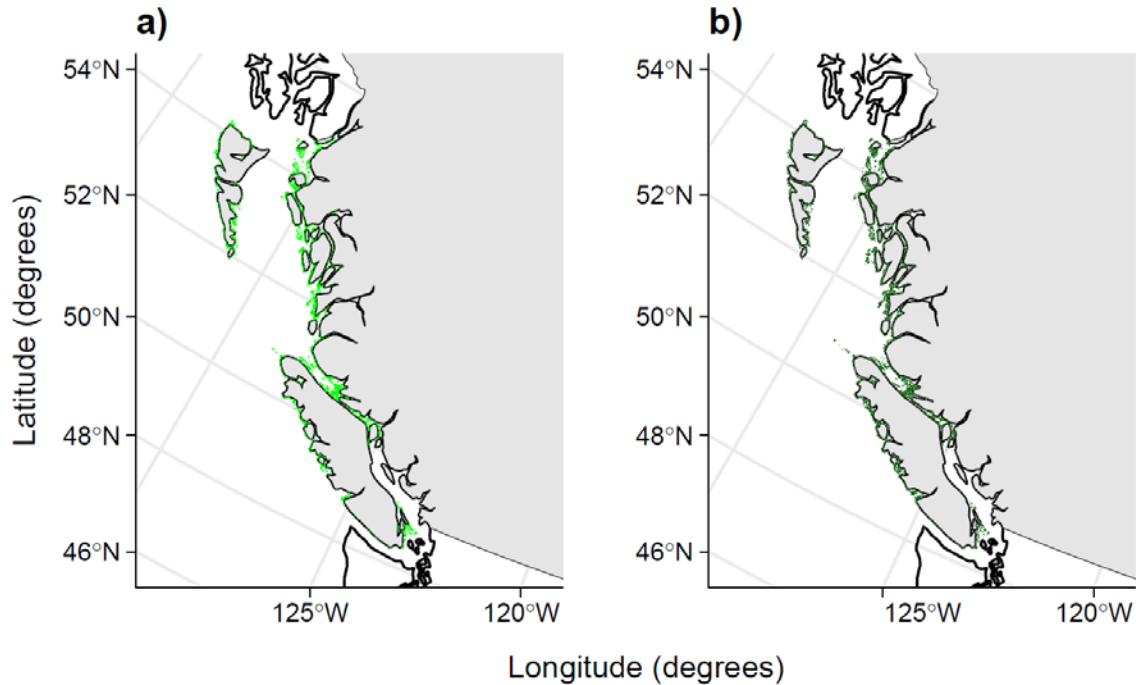
Supplementary Figure 1. A proposed blueprint for national assessments of the blue carbon capacity of kelp forests. Our proposed blueprint involves steps to compile and synthesize available kelp data (Step 1), quantify uncertainties and natural variability in potential rates of carbon production and storage by kelp species (Step 2), develop initial estimates of the carbon production, storage, and export capacity of kelp forests at national scales (Step 3), and refine assessments based on new information and data (Step 4).



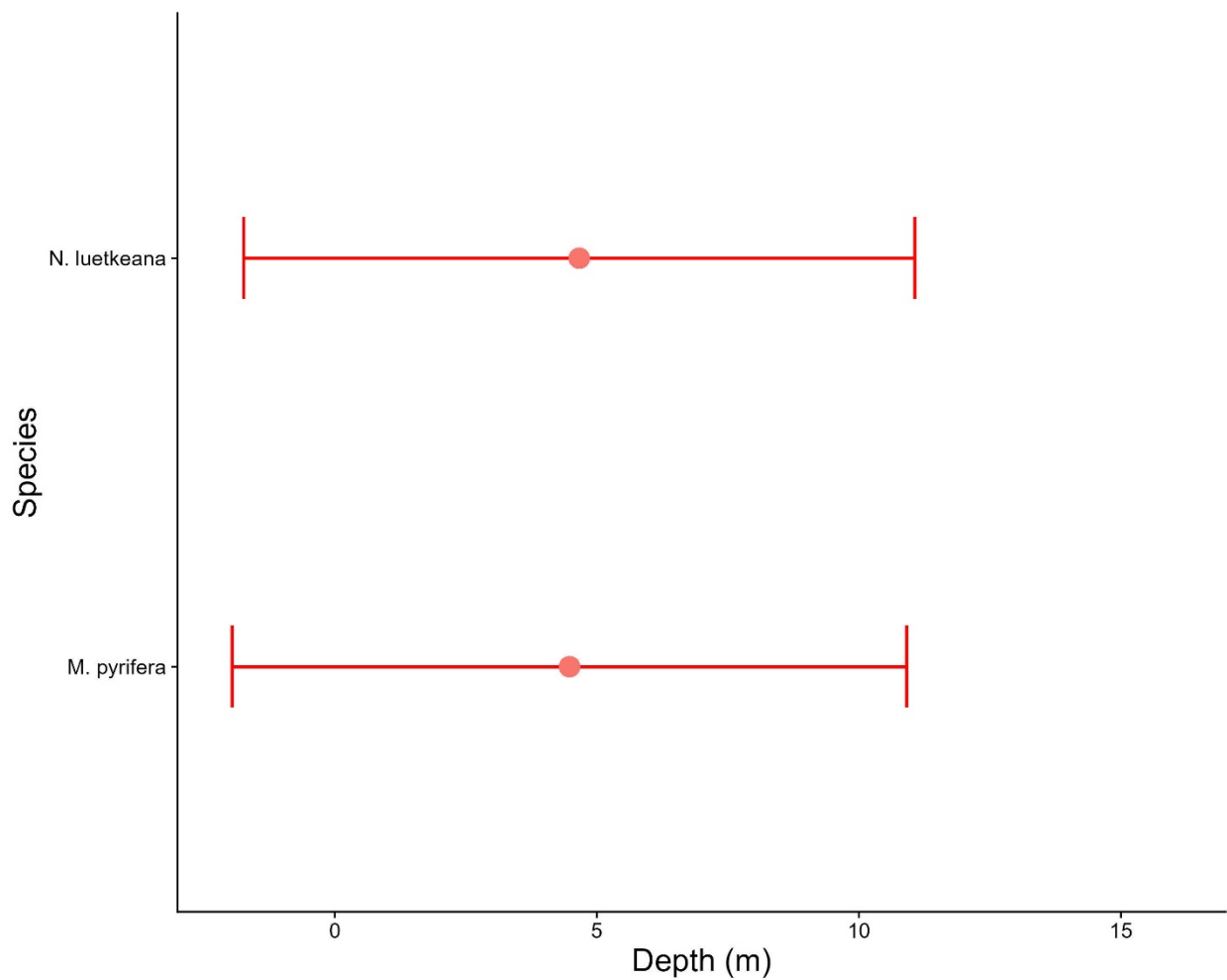
Supplementary Figure 2. Distribution of datasets used in the assessment. Coasts are depicted by different colors for the Pacific (purple), Arctic (blue), and Atlantic coasts (green). Kelp biomass and density records are denoted by pink circles; net primary productivity records are denoted by yellow circles; and kelp percent cover records are denoted by orange circles.



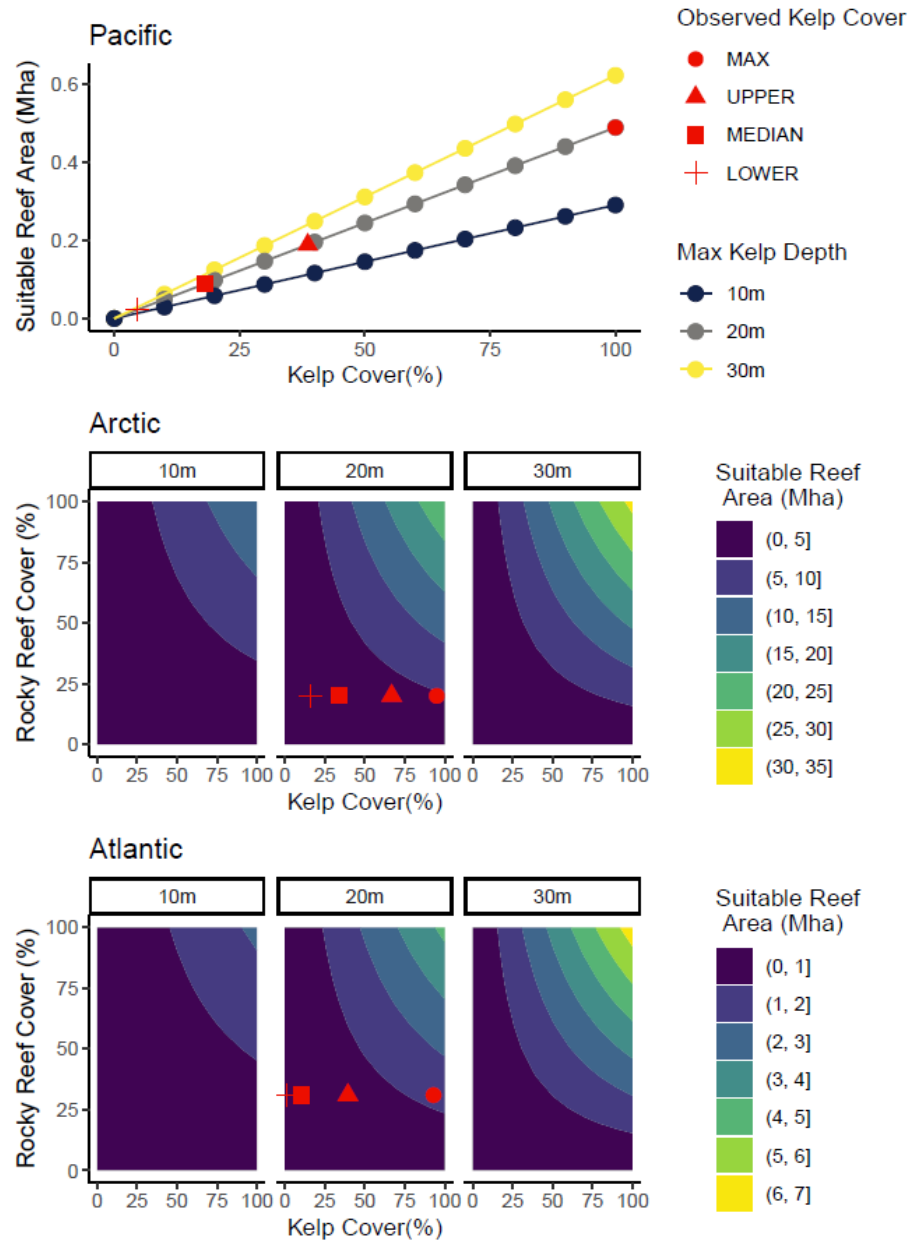
Supplementary Figure 3. Surface kelp forest distribution according to available datasets from the Pacific Coast of Canada. A high extent estimate a) for surface kelps was determined using shoreline maps derived from aerial surveys conducted by the British Columbia ShoreZone Survey Program completed from 2004 to 2007, representing the linear shoreline extent of surface kelps. This was calculated as the intersection between the observed shoreline extent and the area of adjacent rocky reef shallower than 10m water depth. A low extent estimate b) for surface kelps was then determined using maps derived from remote sensing data from the Sentinel-2 program, representing the average annual detection of surface kelps at peak biomass between 2015 and 2019.



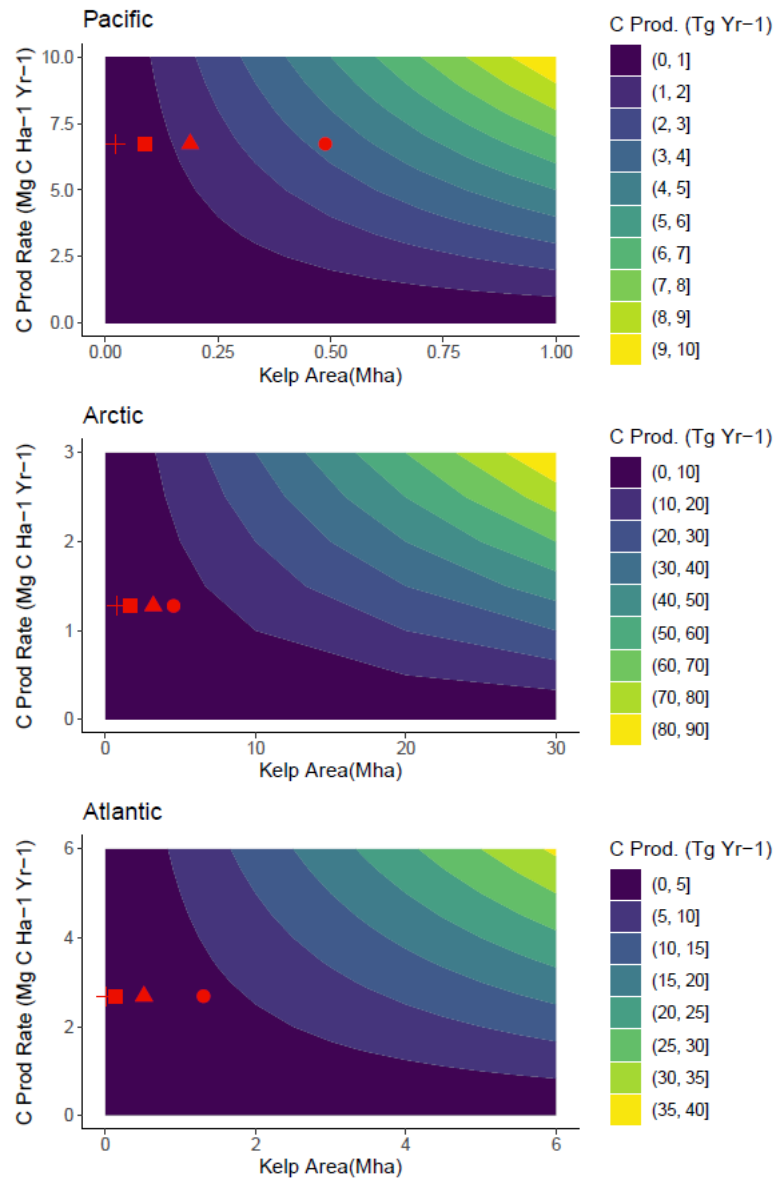
Supplementary Figure 4. Depth distribution of surface kelps, *Macrocystis pyrifera* and *Nereocystis leutkeana*, from in-situ remotely operated vehicle surveys along the Pacific Coast of Canada. Red dots show the mean observed depth distribution for each species, with two standard deviations surrounding the mean (red whiskers).



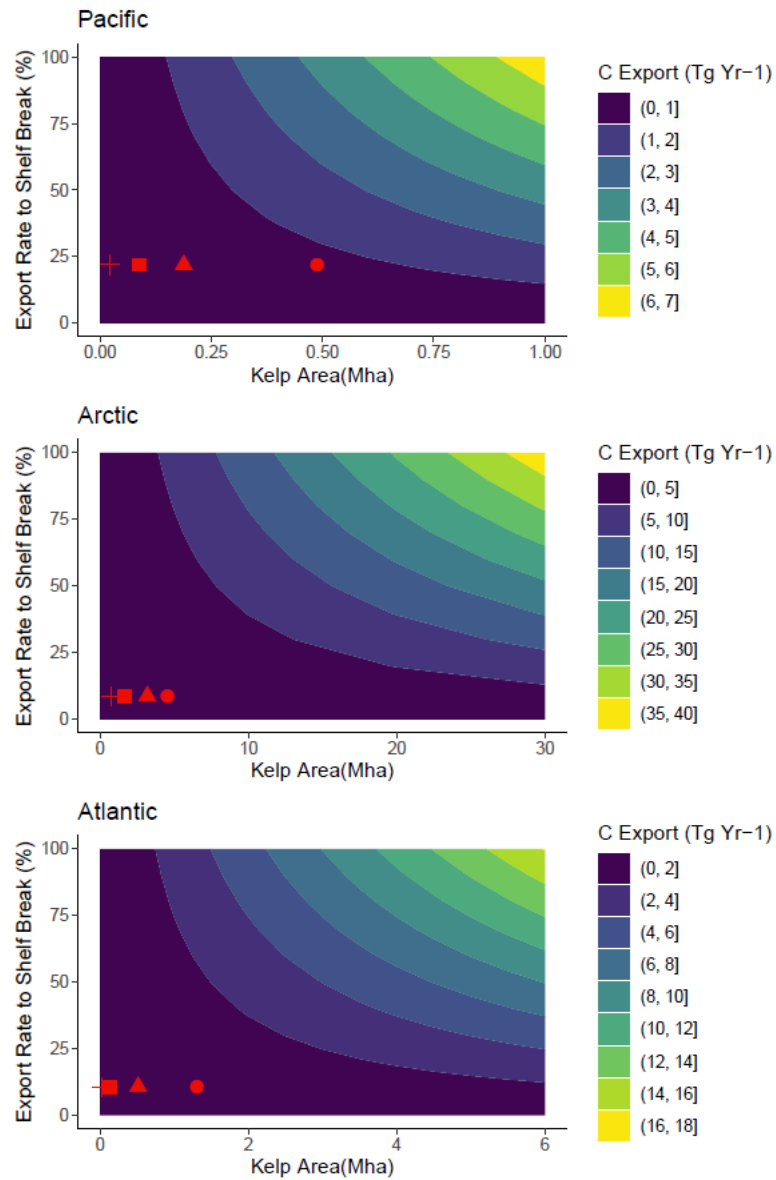
Supplementary Figure 5. Sensitivity of areal extent estimates for subsurface kelp forests to changes in rock cover (%), kelp percent cover (%), and kelp maximum depth (m) parameters.



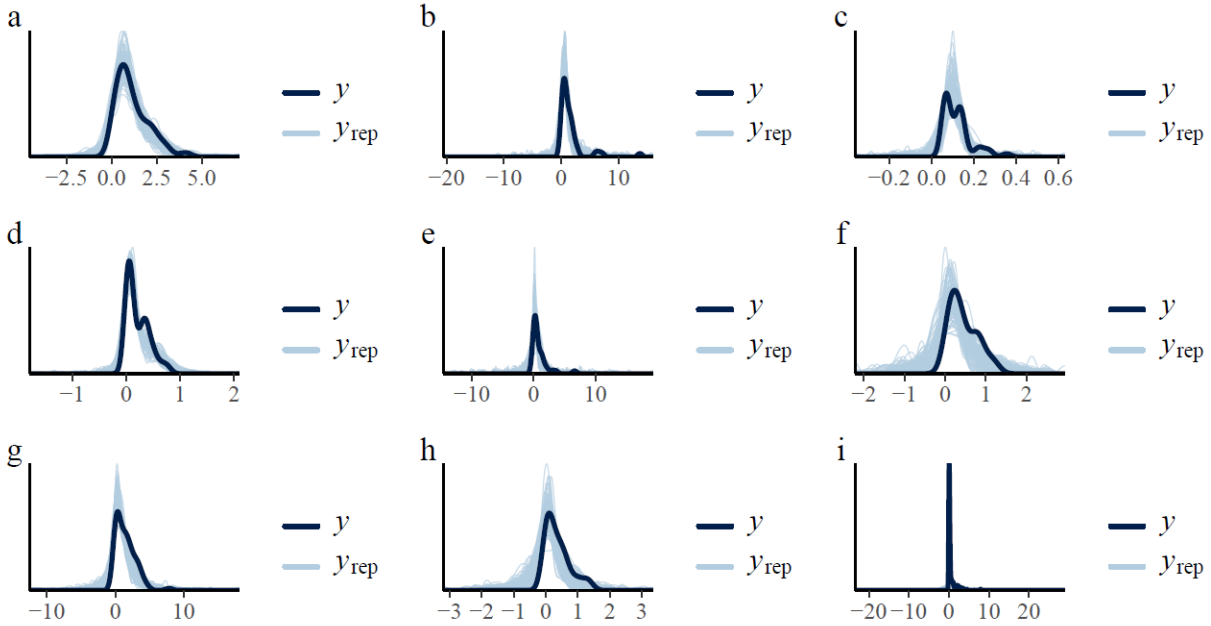
Supplementary Figure 6. Sensitivity of standing annual carbon production estimates for subsurface kelp forests to changes in kelp area (Mha) and per area rates of kelp primary production $\text{Mg C ha}^{-1} \text{ yr}^{-1}$. Red symbols indicate the estimates representing the lower (plus sign), median (square), high (triangle), and maximum (circle) extent of subsurface kelps in Canada.



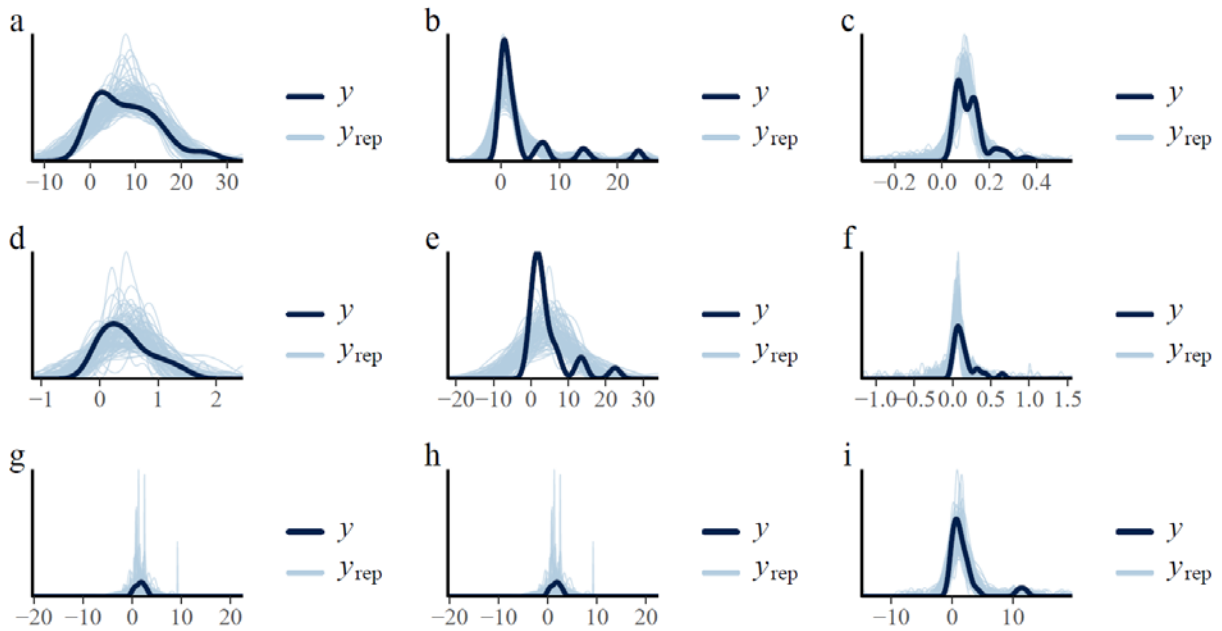
Supplementary Figure 7. Sensitivity of standing annual carbon export estimates for subsurface kelp forests to changes in kelp area (Mha) and per area rates of kelp primary production $\text{Mg C ha}^{-1} \text{ yr}^{-1}$. Red symbols indicate the estimates representing the lower (plus sign), median (square), high (triangle), and maximum (circle) extent of subsurface kelps in Canada.



Supplementary Figure 8. Distribution of observed (y) carbon stocks (Mg C Ha^{-1}) of eleven kelp species compared to simulated data from the posterior predictive distribution (y_{rep}) of the final Bayesian hierarchical models. Kelp species include: a) *Macrocystis pyrifera*, b), *Nereocystis leutkeana* c), *Costaria costata*, d) *Agarum clathratum* / *Neoagarum fimbriatum*, e) *Laminaria digitata* / *Hedophyllum nigripes*, f) *Laminaria solidungula*, g) *Pterygophera californica*, h) *Pleurophycus gardneri*, and i) *Saccharina latissima*.



Supplementary Figure 9. Distribution of observed (y) carbon production rates ($\text{Mg C Ha}^{-1} \text{Yr}^{-1}$) of eleven kelp species compared to simulated data from the posterior predictive distribution (y_{rep}) of the final Bayesian hierarchical models. Kelp species include: a) *Macrocystis pyrifera*, b) *Nereocystis leutkeana* c) *Costaria costata*, d) *Agarum clathratum*, e) *Laminaria digitata* / *Hedophyllum nigripes*, f) *Laminaria solidungula*, g) *Pterygophora californica*, h) *Pleurophycus gardneri*, and i) *Saccharina latissima*.



Supplementary Tables

Supplementary Table 1. Full summary table of data types and sources to used to identify data gaps across regions and species.

Scientific name	Aerial Extent	Canopy Cover	Canopy Biomass	Net Primary Production
<u>Agarum clathratum</u>	This study	1,2	2–7	4,8
<u>Alaria esculenta</u>		2	2	
<u>Costaria costata</u>			6	6
<u>Cymathaere triplicata</u>			6	6
<u>Egregia menziesii</u>				
<u>Eisenia arborea</u>			7,9	
<u>Hedophyllum nigripes</u>	This study	2,10	2,4,11	11
<u>Laminaria digitata</u>	This study	1–3,10	3–5,12	12–15
<u>Laminaria longipes</u>				
<u>Laminaria setchellii</u>			6	
<u>Laminaria solidungula</u>	This study	2,10	2	16–20
<u>Laminaria longipes</u>				
<u>Macrocystis pyrifera</u>	21,22	30	7,11,23,24	11,25–29
<u>Neoagarum fimbriatum</u>			11	11
<u>Nereocystis luetkeana</u>	21,22	30	4,24,31,32	4,24,31–33
<u>Pleurophycus gardneri</u>	This study		4,6	4
<u>Pterygophora californica</u>	This study		6	34
<u>Saccharina latissima</u>	This study	1–3,10	2–5,7,12,35–37	4,13,20,35,36,38

Supplementary References 2:

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Supplementary Table 2. Summary table of kelp species with sufficient data on abundance (i.e., biomass and/or density) and net primary productivity across species and coasts to be included in the assessment. Kelp icons indicate there is at least one data record for a given species and data type for a given coast. Colors of kelp icons indicate the coast from which the data was originally collected (Pacific= purple, Arctic= blue, and Atlantic = green).

Scientific name	Abundance	Net Primary Productivity
<i>Agarum clathratum</i>		
<i>Costaria costata</i>		
<i>Hedophyllum nigripes</i>		
<i>Laminaria digitata</i>		
<i>Laminaria solidungula</i>		
<i>Macrocystis pyrifera</i>		
<i>Neoagarum fimbriatum</i>		
<i>Nereocystis luetkeana</i>		
<i>Pleurophycus gardneri</i>		
<i>Pterygophora californica</i>		
<i>Saccharina latissima</i>		

Supplementary Table 3. Full summary table of data types and sources available for estimating the percentage of exported kelp-derived carbon entering the three main pathways for kelp carbon sequestration.

Coast	Marine Ecoregions	Pathway 1 – Refractory dissolved organic carbon (rDOC)	Pathway 2 – Shelf burial in marine sediments	Pathway 3 – Export fluxes to the deep ocean (waters > 200m depth) ¹
Arctic	Baffin Bay - Davis Strait	No Data	No Data	13.07 ± 15.91
Arctic	Beaufort-Amundsen-Viscount Melville-Queen Maud	No Data	No Data	5.64 ± 11.92
Arctic	Hudson Complex	No Data	No Data	0.90 ± 1.83
Arctic	Lancaster Sound	No Data	No Data	7.91 ± 15.03
Arctic	Northern Labrador	No Data	No Data	16.41 ± 17.95
Pacific	North American Pacific Fjordland	No Data	No Data	22.29 ± 13.91
Pacific	Puget Trough/Georgia Basin	No Data	No Data	10.04 ± 6.41
Pacific	Oregon, Washington, Vancouver Coast and Shelf	No Data	No Data	33.62 ± 15.73
Atlantic	Gulf of Maine/Bay of Fundy	No Data	No Data	8.00 ± 3.11
Atlantic	Gulf of St. Lawrence - Eastern Scotian Shelf	No Data	No Data	8.17 ± 5.41
Atlantic	Northern Labrador	No Data	No Data	16.41 ± 17.93
Atlantic	Northern Grand Banks - Southern Labrador	No Data	No Data	8.43 ± 2.81
Atlantic	Scotian Shelf	No Data	No Data	9.04 ± 3.40
Atlantic	Southern Grand Banks - South Newfoundland	No Data	No Data	14.79 ± 7.81

¹ Sourced from Filbee-Dexter et al. Carbon export from seaweed forests to deep ocean sinks. *Nat. Geosci.* (2024).

Supplementary Table 4: Potential extent (Mha) of kelp forests in Canada. All estimates are presented as the potential low, high, and maximum potential area of kelp forests on each coast.

Ocean	Extent Estimates (Mha)		Source
Pacific			
Surface kelp forests	Maximum	0.29	Rocky reef above 10m
	High	0.11	Rocky reef above 10 m intersecting historic surface canopy maps compiled from the BC Shore Zone oblique shoreline aerial survey (Howes et al., 1994)
	Low	0.005	Recent surface canopy maps determined by detections at peak biomass from Sentinel-2 satellite imagery between 2015 and 2017 (Mora-Soto et al., 2020)
Subsurface kelp forests	Maximum	0.49	Rocky reef above 20 m (maximum kelp cover)
	High	0.19	Rocky reef above 20m (75 th percentile kelp cover)
	Lower	0.02	Rocky reef above 20m (25 th percentile kelp cover)
Arctic			
Subsurface kelp forests	Maximum	4.55	Rocky reef above 20m (maximum kelp cover)
	High	3.2	Rocky reef above 20m (75 th percentile kelp cover)
	Lower	0.75	Rocky reef above 20m (25 th percentile kelp cover)
Atlantic			
Subsurface kelp forests	Maximum	1.31	Rocky reef above 20m (maximum kelp cover)
	High	0.52	Rocky reef above 20m (75 th percentile kelp cover)
	Lower	0.02	Rocky reef above 20m (25 th percentile of kelp cover)
Canada			
All kelp forests	Maximum	6.34	Summed across coasts
	High	3.90	Summed across coasts
	Lower	0.70	Summed across coasts

Supplementary Table 5. Pairwise conditional support for significant differences between the posterior mean estimates for kelp species in Canada. Estimates of a) carbon stocks (Mg C Ha⁻¹) and b) carbon production rates (Mg C ha⁻¹ yr⁻¹) of kelp species are shown separately. Cells show the percent probability support that row species are significantly different from column species. Species names are abbreviated as followed: *Agarum clathratum* / *Neoagarum fimbriatum* (Ac / Nf), *Costaria costata* (Cc), *Laminaria digitata* / *Hedophyllum nigripes* (Ld / Hn), *Laminaria solidungula* (Ls), *Macrocystis pyrifera* (Mp), *Nereocystis luetkeana* (Nl), *Pterygophora californica* (Pc), *Pleurophycus gardneri* (Pg), and *Saccharina latissima* (Sl).

a) Carbon Stocks (Mg Ha ⁻¹)	Pacific								Arctic				Atlantic		
	Ac / Nf	Cc	Ld / Hn	Mp	Nl	Pc	Pg	Sl	Ac / Nf	Ld / Hn	Ls	Sl	Ac / Nf	Ld / Hn	Sl
Pacific															
Ac / Nf	NA	52.2	18.1	0.0	2.7	0.1	61.5	21.6	0.0	1.9	6.1	0.1	47.5	26.0	22.6
Cc	47.8	NA	17.4	0.0	2.7	0.1	64.1	21.1	0.0	1.8	2.5	0.1	46.7	25.6	22.4
Ld / Hn	81.9	82.6	NA	1.8	6.0	11.3	83.2	49.4	33.1	16.3	65.1	1.7	76.2	48.1	31.5
Mp	100.0	100.0	98.2	NA	28.5	89.9	100.0	98.3	100.0	82.2	100.0	22.1	100.0	95.2	60.1
Nl	97.3	97.3	94.0	71.4	NA	86.2	97.4	93.8	93.9	83.4	96.2	50.0	96.9	92.3	68.7
Pc	99.9	99.9	88.7	10.2	13.8	NA	99.9	86.3	91.9	51.6	99.1	6.9	98.9	81.3	47.0
Pg	38.6	35.8	16.8	0.0	2.6	0.1	NA	20.2	0.1	1.8	6.3	0.1	43.5	24.9	22.1
Sl	78.4	79.0	50.6	1.7	6.2	13.7	79.7	NA	36.8	18.2	63.6	1.7	74.1	48.9	31.7
Arctic															
Ac / Nf	100.0	100.0	66.9	0.0	6.1	8.1	99.9	63.2	NA	17.2	96.9	0.9	95.5	58.2	34.9
Ld / Hn	98.1	98.2	83.7	17.7	16.6	48.4	98.2	81.8	82.8	NA	94.9	10.8	96.1	77.7	47.2
Ls	93.9	97.5	34.9	0.0	3.8	0.9	93.7	36.4	3.1	5.1	NA	0.2	74.1	37.0	27.0
Sl	99.9	99.9	98.3	77.9	50.0	93.1	99.9	98.3	99.1	89.2	99.8	NA	99.8	96.6	70.2
Atlantic															
Ac / Nf	52.5	53.3	23.8	0.0	3.1	1.1	56.5	25.9	4.5	3.9	25.9	0.2	NA	29.0	23.4
Ld / Hn	74.0	74.4	51.9	4.8	7.7	18.7	75.1	51.1	41.8	22.3	63.1	3.4	71.0	NA	32.5
Sl	77.4	77.6	68.5	39.9	31.3	53.1	77.9	68.2	65.1	52.8	73.0	29.8	76.6	67.5	NA

b) Carbon Production (Mg Ha ⁻¹ Yr ⁻¹)	Pacific								Arctic				Atlantic		
	Ac / Nf	Cc	Ld / Hn	Mp	Nc	Pc	Pg	Sl	Ac / Nf	Ld / Hn	Ls	Sl	Ac / Nf	Ld / Hn	Sl
Pacific															
Ac / Nf	NA	52.4	10.9	0.3	7.0	31.1	14.3	3.2	28.8	NA	53.8	24.3	47.1	29.8	37.0
Cc	47.6	NA	9.4	0.1	6.7	30.3	8.6	1.7	24.5	NA	77.0	23.0	43.9	29.6	37.0
Ld / Hn	89.1	90.6	NA	8.3	22.3	61.8	75.0	39.1	77.7	NA	90.8	67.7	86.0	48.3	54.7
Mp	99.7	99.9	91.6	NA	57.0	87.9	98.8	84.7	98.1	NA	99.9	96.5	99.1	72.4	76.0
Nc	93.0	93.3	77.7	43.0	NA	79.0	88.2	70.8	88.8	NA	93.3	85.2	91.9	65.9	70.2
Pc	68.9	69.6	38.1	12.0	21.0	NA	55.7	30.3	59.1	NA	69.8	51.3	67.0	41.5	46.8
Pg	85.7	91.4	25.0	1.2	11.8	44.3	NA	13.3	61.9	NA	91.6	47.1	78.4	37.6	45.5
Sl	96.8	98.3	60.9	15.3	29.2	69.7	86.7	NA	87.5	NA	98.3	77.7	93.7	54.2	60.3
Arctic															
Ac / Nf	71.2	75.5	22.2	1.9	11.2	40.9	38.1	12.5	NA	NA	76.0	40.0	66.1	35.6	42.9
Ld / Hn	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ls	46.2	23.0	9.2	0.1	6.6	30.2	8.4	1.6	24.0	NA	NA	22.6	43.1	29.5	36.9
Sl	75.7	77.0	32.3	3.5	14.8	48.8	52.9	22.3	60.0	NA	77.3	NA	72.4	40.0	47.0
Atlantic															
Ac / Nf	53.0	56.1	14.0	0.9	8.1	33.0	21.6	6.3	33.9	NA	56.9	27.7	NA	30.6	37.3
Ld / Hn	70.2	70.4	51.7	27.6	34.1	58.4	62.4	45.8	64.4	NA	70.6	60.0	69.4	NA	54.1
Sl	63.1	63.0	45.3	24.0	29.8	53.3	54.5	39.7	57.1	NA	63.1	53.0	62.7	45.9	NA

Supplementary Table 6. National estimates of the total carbon stock, production, and export capacity of kelp forests in Canada. Estimates are shown here using a) species-specific verses and b) species-independent approach.

a) Coasts	Maximum Carbon Stock in Living Biomass (Tg C)	Maximum Annual Carbon Production (Tg C Yr-1)	Maximum Annual Carbon Export (Tg C Yr-1)
Arctic	3.51	5.81	0.16
Pacific	0.40	2.23	0.50
Atlantic	0.50	3.51	0.34
Canada	4.42	11.55	1.00

b) Coasts	Maximum Carbon Stock in Living Biomass (Tg C)	Maximum Annual Carbon Production (Tg C Yr-1)	Maximum Annual Carbon Export (Tg C Yr-1)
Arctic	3.41	14.40	0.39
Pacific	0.37	1.55	0.34
Atlantic	0.98	4.14	0.41
Canada	4.76	20.09	1.14

Supplementary Table 7. Model definitions for carbon standing stocks and annual accumulation rates associated with kelp forest found. All models include site and source ID as random effects.

Model	Model definition
<i>Carbon standing stocks (CS)</i>	
CS.1	carbon stock ~ 1
CS.2	carbon stock ~ ocean temperature
CS.3	carbon stock ~ ocean [*]
CS.4	carbon stock ~ ocean temperature + ocean [*]
<i>Carbon accumulation rates (CP)</i>	
CP.1	carbon accumulation ~ 1
CP.2	carbon accumulation ~ ocean temperature
CP.3	carbon accumulation ~ ocean [*]
CP.4	carbon accumulation ~ ocean temperature + ocean [*]

^{*}*Included only for species that occur across multiple oceans.*

Supplementary Table 8. Prior definitions for all carbon stock and carbon accumulation rate models.

Coefficient	Prior	Notes
Intercept	Student_t(3,0,9)	Scaled to the range of observed carbon stocks and accumulation rates found in Canadian kelp species
Slope	Student_t(3,0,9)	For fixed effects
Sigma	Student_t(3,0,9)	For random effects

Supplementary Table 9. Results of leave-one-out pareto-smoothed importance sampling (LOO-PSIS) model evaluation for carbon stocks of kelp forest-forming species. All models include site and source identity as random effects. Elpd_diff is the difference in the expected log predictive density between model structures; se_diff is the difference in standard error explained between models. Guidelines for interpreting these criteria are available at <https://mc-stan.org/loo/reference/loo-glossary.html>.

a) Carbon Standing Stocks (Mg Ha-1)				
Taxa	Model	Effects tested	elpd_diff	se_diff
<i>Macrocystis pyrifera</i>	CS.1	carbon stock ~ 1	0	0
	CS.2	carbon stock ~ ocean temperature	-0.1	0.5
<i>Nereocystis leutkeana</i>	CS.2	carbon stock ~ ocean temperature	0	0
	CS.1	carbon stock ~ 1	-0.7	0.4
<i>A. clathratum</i> / <i>N. fimbriatum</i>	CS.2	carbon stock ~ ocean temperature	0	0
	CS.3	carbon stock ~ ocean	-0.8	1.8
	CS.1	carbon stock ~ 1	-1.5	1.7
	CS.4	carbon stock ~ ocean temperature + ocean	-2.3	1.17
<i>Costaria costata</i>	CS.1	carbon stock ~ 1	0	0
	CS.2	carbon stock ~ ocean temperature	-0.9	0.6
<i>L. digitata</i> / <i>H. nigripes</i>	CS.2	carbon stock ~ ocean temperature	0	0
	CS.3	carbon stock ~ ocean	-0.4	0.7
	CS.4	carbon stock ~ ocean temperature + ocean	-0.4	0.7
	CS.1	carbon stock ~ 1	-0.7	1.1
<i>Laminaria solidungula</i>	CS.1	carbon stock ~ 1	0	0
	CS.2	carbon stock ~ ocean temperature	-0.9	0.2
<i>Pleurophycus gardneri</i>	CS.1	carbon stock ~ 1	0	0
	CS.2	carbon stock ~ ocean temperature	-0.8	0.8
<i>Pterygophora californica</i>	CS.1	carbon stock ~ 1	0	0
	CS.2	carbon stock ~ ocean temperature	-0.3	1.2
<i>Saccharina latissima</i>	CS.4	carbon stock ~ ocean temperature + ocean	0	0
	CS.1	carbon stock ~ 1	-1.2	1
	CS.3	carbon stock ~ ocean	-3.6	1.7
	CS.2	carbon stock ~ ocean temperature	-3.7	2.1
b) Carbon Accumulation Rates (Mg Ha-1 Yr-1)				

Taxa	Model	Effects tested	elpd_diff	se_diff
<i>Macrocystis pyrifera</i>	CP.1	carbon accumulation ~ 1	0	0
	CP.2	carbon accumulation ~ ocean temperature	-0.5	0.3
<i>Nereocystis leutkeana</i>	CP.2	carbon accumulation ~ ocean temperature	0	0
	CP.1	carbon accumulation ~ 1	-0.1	0.4
<i>A. clathratum</i> / <i>N. fimbriatum</i>	CP.1	carbon accumulation ~ 1	0	0
	CP.2	carbon accumulation ~ ocean temperature	-0.2	0.6
	CP.3	carbon accumulation ~ ocean	-0.6	0.4
	CP.4	carbon accumulation ~ ocean temperature + ocean	-0.7	0.5
<i>Costaria costata</i>	CP.1	carbon accumulation ~ 1	0	0
	CP.2	carbon accumulation ~ ocean temperature	-0.9	0.4
<i>L. digitata</i> / <i>H. nigripes</i>	CP.2	carbon accumulation ~ ocean temperature	0	0
	CP.1	carbon accumulation ~ 1	-0.1	0.6
	CP.3	carbon accumulation ~ ocean	-0.5	0.6
	CP.4	carbon accumulation ~ ocean temperature + ocean	-0.6	0.4
<i>Laminaria solidungula</i>	CP.1	carbon accumulation ~ 1	0	0
	CP.2	carbon accumulation ~ ocean temperature	1.2	0.4
<i>Pleurophycus gardneri</i>	CP.1	carbon accumulation ~ 1	0	0
	CP.2	carbon accumulation ~ ocean temperature	-1.2	0.4
<i>Pterygophora californica</i>	CP.1	carbon accumulation ~ 1	0	0
<i>Saccharina latissima</i>	CP.4	carbon accumulation ~ ocean temperature + ocean	0	0
	CP.2	carbon accumulation ~ ocean temperature	-2.1	2.5
	CP.3	carbon accumulation ~ ocean	-3.6	2.3
	CP.1	carbon accumulation ~ 1	-3.8	2.4