Title: Synthesizing disparate data for a comprehensive view of floating kelp distribution in Washington State, USA

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Supplementary Information

Technical Considerations in Framework Development

Using vector line segments as the synthesis unit, rather than rasters or vector polygons, was chosen for this effort because of the robust history of using linear extent to describe floating kelp distribution (e.g. ShoreZone datasets, Berry et al. 2021) and the limiting resolution of the input data sources. The data sources integrated here describe kelp presence using a variety of metrics, including kelp bed perimeter, kelp canopy area, and at the coarsest spatial resolution, linear presence/absence of floating kelp along stretches of shoreline. Linear presence absence is often the highest resolution of spatial data that can be derived from historical data sources like oblique photographs, where data limitations prevent photogrammetric orthorectification, but images can still be referenced along a shoreline (Starko et al. 2024; McKenna et al. 2025a). Denoting presence/absence along a shoreline is also a rapid way to conduct *in-situ* boat-based mapping of large areas (Berry et al. 2019). While it is possible to collapse polygon or raster data to linear units, the reverse would lead to inaccuracies. To maximize the amount of viable data we could include in our dataset, linear extent was the only appropriate option. In addition, relying on spatial units associated with existing geometries used for marine vegetation mapping in other monitoring programs (Dowty et al. 2022) makes future multi-species data integration possible.

In order to reduce the spatial information loss resulting from the upscaling process, we created the coverage category metric. The coverage category metric provides additional granularity to floating kelp presence by evaluating floating kelp presence along subdivided line segments and reporting a proportional value (1-4). This value does not correspond directly to the amount of floating kelp (e.g., bed area or canopy area) within a given segment, but rather the alongshore characteristics of the floating kelp presence in the source data. We considered

generating a series of indexes to bin the relative amount (area or extent) of kelp in each segment from each dataset, but it was impossible to create an index that could be consistently applied across our highly heterogenous datasets. However, the coverage category metric can help distinguish between shorelines with a small extent of kelp coverage from those with more continuous coverage.

A key element that enabled the automation and therefore rapid synthesis of a wide variety of spatial data to these line segments was the creation of polygons that bounded the marine habitat represented by each line segment. Using existing geometry from other marine vegetation monitoring programs (Dowty et al. 2022) in combination with deep Theissen polygons, we were able to use modern GIS tools to rapidly, automatically, and reproducibly evaluate the presence or absence of floating kelp from a wide variety of data sources for each of the 3,418 line segments that comprehensively represent the State's marine shorelines. Most previous uses of linear extent have involved manually mapping different data sources to linear units (Berry et al. 2021; Hollarsmith et al. 2024). This automated pipeline drastically increases the potential for the rapid integration of novel current and historical floating kelp surveys into this dataset.

Tables

Table S1. List of data sources integrated in the linear extent dataset at the time of publication.

Source Name	Metric	Collection Years	Spatial Extent	Method Summary
Long-term monitoring of the Coast, Strait using Aerial Photography (COSTR) (Van Wagenen 2015, Nearshore Habitat Program 2022)	kelp bed area polygon	1989-2024	Open coast and the Strait of Juan de Fuca to Point Wilson, Port Townsend (COSTR).	Near-vertical low-tide color-infrared imagery is collected from a fixed wing platform during late summer. Imagery is projected onto 1:12,000 paper maps and kelp canopies are hand-delineated. Bed area is estimated by buffering canopy data with a 20-m radius of association.
Long-term monitoring of the Aquatic Reserves using Aerial Photography (AQRES) (Van Wagenen 2015, Nearshore Habitat Program 2022)	kelp bed area polygon	2010-2024	DNR's northern Aquatic Reserves (AR): Smith and Minor Island AR, Cypress Island AR, Cherry Point AR (AQRES). Note: Protection Island AR is included in the COSTR dataset.	Near-vertical low-tide color-infrared imagery is collected from a fixed wing platform during late summer. Imagery is projected onto 1:12,000 paper maps and kelp canopies are hand-delineated. Bed area is estimated by buffering canopy data with a 20-m radius of association.
The Washington State ShoreZone Inventory (Berry et al. 2001)	qualified kelp presence within shoreline segments	1995-2001	Entirety of Washington's Coastline	Inventory information was collected from a helicopter during low tides, including videography and continuous commentary from a geomorphologist and marine ecologist. The shoreline was divided into geomorphological units and biological communities were categorized
Kelp Forest Aerial Monitoring (Nearshore Habitat Program)	kelp canopy area raster	2022	Open Coast, Strait of Juan de Fuca, Admiralty Inlet, North Puget Sound, San Juan Islands, Saratoga-Whidbey sub-basin, Tacoma Narrows, Squaxin Island, and Aquatic Reserves.	High-resolution 4-band aerial imagery collected from fixed wing platform during summer low tides and slack currents. Imagery is classified for kelp canopy area via a semi-supervised classification pipeline.
Bull Kelp Monitoring in Central Puget Sound in 2019 (Berry et al. *in prep*)	qualified kelp linear extent along -6.1m MLLW	2018	North of Tacoma Narrows and South of Admiralty Inlet	Floating kelp presence was mapped along the -6.1 m MLLW isobath from a boat using handheld GPS
Bull Kelp Monitoring in South Puget Sound in 2017 and 2018 (Berry et al. 2019)	qualified kelp linear extent along -6.1m MLLW	2017	Tacoma Narrows and waters inwards	Floating kelp presence was mapped along the -6.1 m MLLW isobath from a boat using handheld GPS

Source Name	Metric	Collection Years	Spatial Extent	Method Summary
Long-term kayak monitoring of floating kelp in Puget Sound (Ledbetter and Berry 2025)	kelp bed area polygon	2013-2024	N sites distributed throughout Puget Sound	Kayak-based delineation of bed perimeter with handheld GPS in summer low tides and calm currents. Minimum abundance for inclusion: single bulb. Maximum distance among individuals for inclusion in a single bed: 25 m.
UAS surveys of floating kelp in the central basin of Puget Sound (McClure et al. *in prep*)	kelp bed area polygon	2023-2024	N sites throughout Puget Sound	Ultra-high resolution 5-band imagery collected from an Uncrewed Aircraft System platform as part of Intergovernmental Agreement 93-105196 between DNR and the Suquamish Indian Tribe of the Port Madison Reservation. Bed perimeters were manually delineated from continuous orthomosaics following methods in Cowdry and Claar 2024.
Northwest Straits Commission Floating Kelp Monitoring (Bishop 2014, updated 2023)	kelp bed area polygon	2015-2023	N sites distributed through North Puget Sound, San Juan Islands, and Strait of Juan de Fuca	Kayak-based delineation of bed perimeter with handheld GPS in summer low tides and calm currents collected by volunteers from Clallam MRC, Island MRC, Jefferson MRC, Skagit MRC, Snohomish MRC, Whatcom MRC. Minimum thresholds for inclusion: canopy width >5 m. Maximum distance among individuals (fronds or bulbs) for inclusion: 8 m between individuals
Samish Indian Nation Department of Natural Resources Kelp Forest Aerial Monitoring (Samish Indian Nation GIS, *unpublished*)	kelp bed area polygon	2004/2006, 2016, 2019, 2022, 2023	San Juan Islands	Kelp beds manually delineated from aerial photography
South Puget Sound Historical Data: Long-term changes in kelp forests in an inner basin of the Salish Sea (Berry et al. 2021)	kelp presence/absence within -6.1m MLLW linear segments	Periodic years between 1873 and 2018	South Puget Sound	Analysis of 48 historical and modern Nereocystis surveys for presence/absence in 1-km shoreline segments
Mapping floating kelp presence along Seattle shorelines in 1984 using historical aerial imagery (McKenna et al. 2025)	qualified kelp linear extent along -6.1m MLLW	1984	Elliott Bay and West Seattle	Manual delineation of kelp extent from CIR aerial 35-mm slide photographs of kelp beds in West Seattle and Magnolia from 1984

Figures

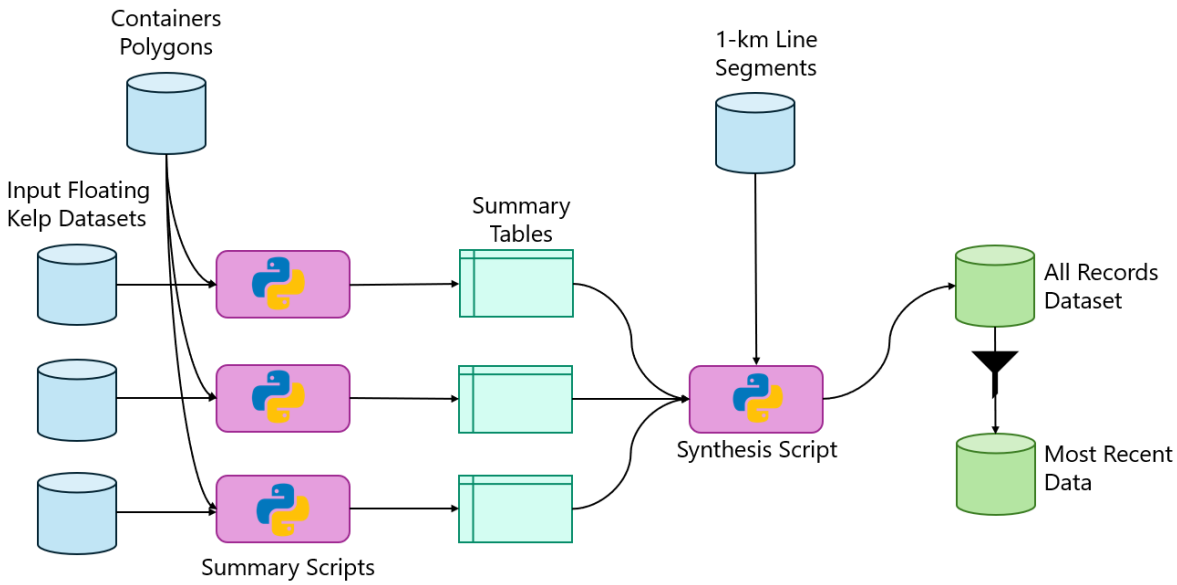

Fig. S1. Generalized analysis pathway for floating kelp linear extent data synthesis.

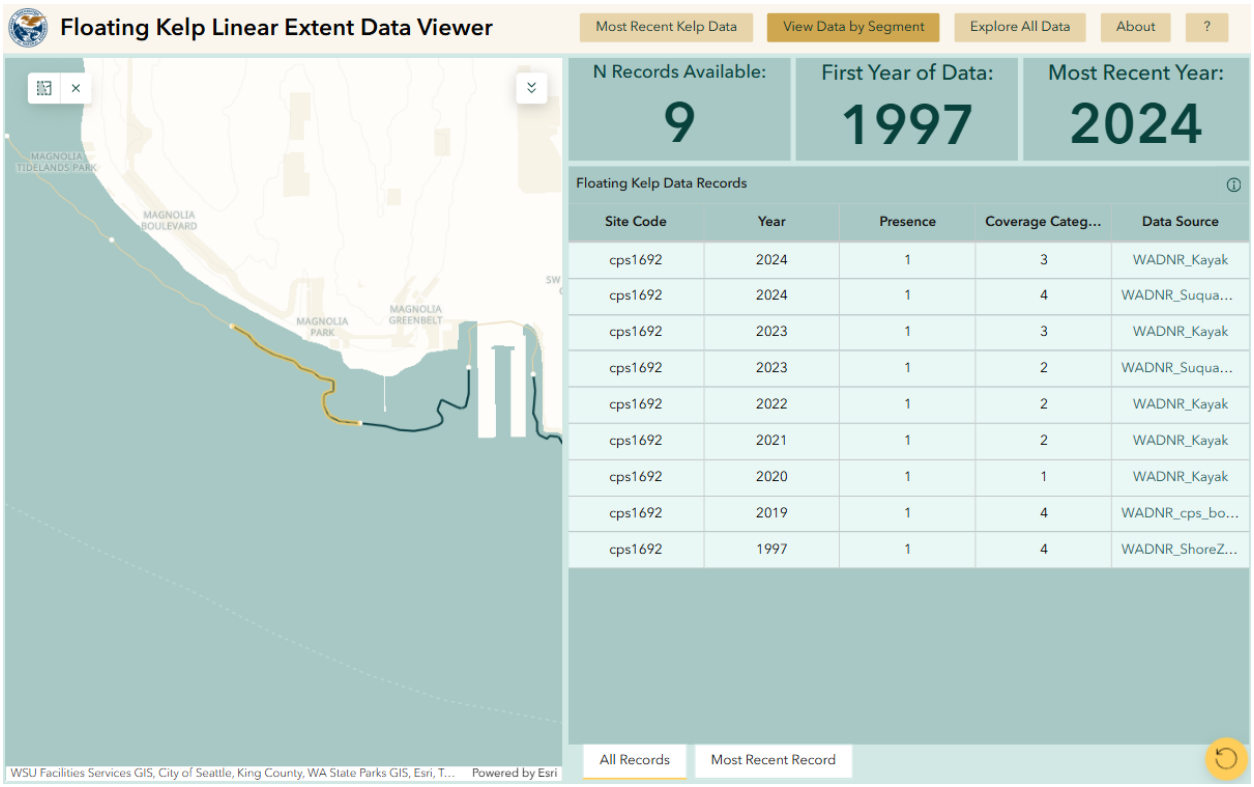

Fig. S2. Screenshot of one page of the web-based Floating Kelp Linear Extent Data Viewer platform. Selected segment in map on left populates records table right.

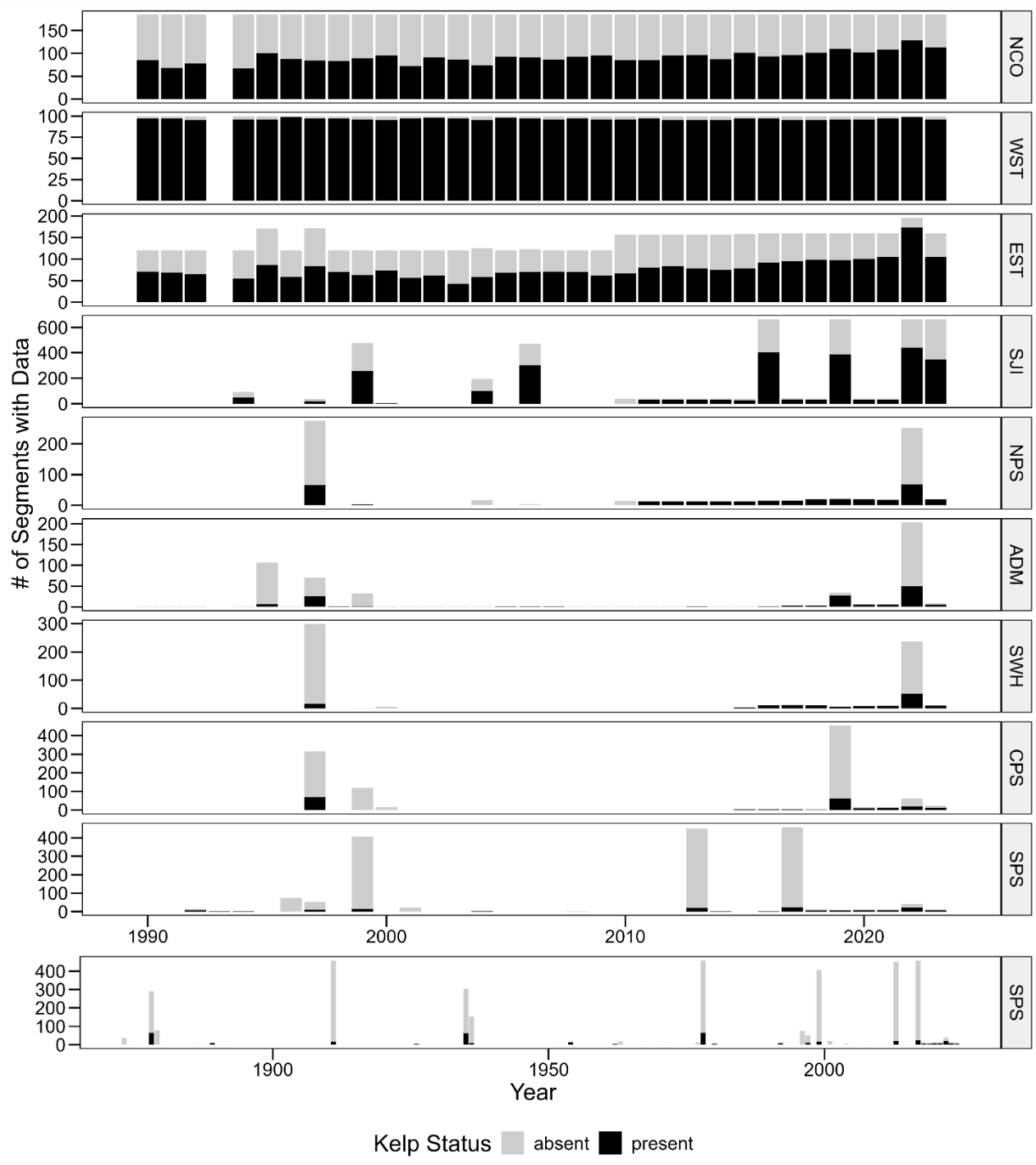

Fig. S3. Number of segments with at least one floating kelp data record for each year between 1989 (earliest long-term monitoring program) and 2024, split by sub-basin. Bar fill shows whether kelp was present (black) or absent (grey). Two facets are shown for SPS: SPS data records 1989-2024 (second from bottom) and SPS entire time series (bottom). The South Coast and Hood Canal are not displayed as no floating kelp was detected in those sub-basins.

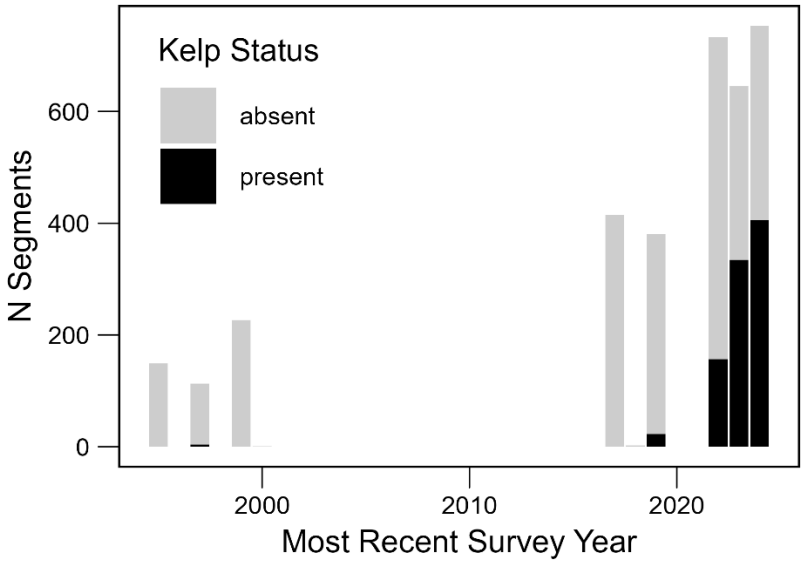

Fig. S4. Most recent survey year and presence/absence of floating kelp for line segments across the entire state within the Most Recent linear extent dataset. Stacked bars show count of segments and which year was most recent, colors indicate whether kelp was present (black) or absent (grey).