

Committee Staff Summary for July 16-17, 2025 MRC

6. Kelp Management

Today's Item	Information <input type="checkbox"/>	Action <input checked="" type="checkbox"/>
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- | | |
|-----|---|
| (A) | <i>Kelp restoration and management plan (KRMP) development</i> |
| (B) | <i>Kelp restoration tracking</i> |
| (C) | <i>Commercial bull kelp harvest regulatory sunset date extension</i> |

Summary of Previous/Future Actions**(A) KRMP development**

- | | |
|--|-------------------------------------|
| • Commission referred KRMP development to MRC | February 2022 |
| • MRC and TC received Department overview of plans and process for KRMP development | March 2022; MRC and August 2022; TC |
| • MRC received Department update on KRMP development | March 2023; MRC |
| • MRC received a comprehensive kelp report prepared by Department and California Ocean Protection Council (OPC), and an update on KRMP development | November 2023; MRC |
| • Today's update | July 16-17, 2025; MRC |

(B) Kelp restoration tracking

- | | |
|--|--|
| • Commission referred kelp recovery and restoration tracking to MRC | October 2019 |
| • MRC received overview of collaborative kelp recovery and restoration efforts | November ; MRC |
| • MRC received updates on kelp recovery and restoration | March 2021, March 2023, and November 2023; MRC |
| • Today's update | July 16-17, 2025; MRC |

(C) Commercial bull kelp harvest regulatory sunset date

- | | |
|--|------------------------------|
| • Commission adopted commercial bull kelp harvest regulatory amendments | February 2022 |
| • Today's update, Department-proposed extension, and potential MRC recommendation | July 16-17, 2025; MRC |
| • Notice hearing | August 13-14, 2025 |
| • Discussion/adoption hearing | October 8-9, 2025 |

Background

Beginning in 2014, bull kelp populations in Mendocino and Sonoma counties dramatically declined to levels outside of the range of normal variability. The decline was caused by elevated sea surface temperature, poor nutrient availability, and drastic increases in purple sea

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urchin (*Strongylocentrotus purpuratus*) populations. The altered ecosystem conditions have persisted and, in some areas, worsened in subsequent years.

In October 2019, the Commission received a Department update confirming the dramatic bull kelp declines were persisting across the northern California coastline. Based on interest in tracking kelp condition and kelp restoration strategies, the Commission referred the topic to MRC. Since then, the Department has partnered with entities throughout California to collaboratively monitor, manage, and restore kelp forests. These efforts include: (A) developing a statewide KRMP; (B) tracking kelp status and monitoring efforts; and (C) temporarily restricting commercial harvest of bull kelp as a precautionary approach.

The most recent update to MRC on these efforts was presented by the Department in November 2023, which summarized information detailed within a comprehensive report, *Status of Research and Monitoring, Restoration Efforts, and Developing Management Strategies for Kelp Canopy Forming Species in California* ([2023 kelp report](#)). The Department prepared the kelp report in collaboration with OPC. Today is the first detailed update since November 2023.

(A) **KRMP Development**

In February 2022, the Department, in partnership with OPC, initiated planning to develop a statewide, ecosystem-based, adaptive KRMP for giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*). The development of the KRMP began in earnest in October 2022, after funding was secured to and a project management team was contracted. Once adopted by the Commission, the KRMP will guide the management, protection, and restoration of California's kelp forests. The Commission referred KRMP development to MRC as a work plan topic.

KRMP development is being informed through tribal engagement and formalized groups: a community working group and a science advisory committee. The KRMP will serve as a cohesive kelp management strategy with three core components:

1. A harvest management framework and other fishery management plan elements required by the Marine Life Management Act (the harvest management framework).
2. An innovative framework for ecosystem-based management (EBM) of kelp forests (the EBM framework).
3. A restoration toolkit.

The Department has provided three KRMP development updates to MRC since February 2022, including:

- March 2022: Proposed a multi-pronged approach and process for the KRMP.
- March 2023: Provided an overview of the three core components under preparation for the KRMP (i.e., the harvest management framework, the EBM framework, and the restoration toolkit).
- November 2023: Presented accelerated initiation of kelp research and restoration efforts, along with collaborative projects to explore tools like urchin suppression

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and kelp enhancement for the KRMP restoration toolkit; summarized tribal engagement and initial meetings with the community working group and science advisory committee; and shared the [2023 kelp report](#).

For more information on KRMP development, including summaries of community working group and science advisory committee meetings, visit the Department's website at <https://wildlife.ca.gov/Conservation/Marine/Kelp/KRMP>.

Update

Today, the Department will provide an update on KRMP development, including the timeline for completion, Commission consideration and potential adoption, and implementation; an update on tribal engagement and meetings of the community working group and science advisory committee; and next steps for continued tribal, stakeholder, and community engagement (see presentation in Exhibit 1).

(B) Kelp Restoration Tracking

MRC has been tracking kelp restoration since the Commission referred the topic in 2019. The Department provided its most recent updates to MRC in March and November 2023 related to kelp canopy coverage trends and progress of kelp restoration research projects. The trends showed persistent kelp loss in the north and different patterns of kelp loss and recovery across the remainder of the state.

Today, the Department will provide updates on the status of kelp canopy throughout California by region, and will provide an update on the various kelp restoration research projects currently underway (Exhibit 1).

(C) Commercial Bull Kelp Harvest Regulatory Sunset Date

Given the dramatic reduction in the north coast bull kelp population and lack of scientific data to explain the impact of commercial harvest on the current kelp population, the Department determined that a precautionary management approach was warranted. Therefore, it recommended the Commission adopt limited-term commercial harvest restrictions for bull kelp take on the north coast to help maintain the remaining bull kelp population.

Responding to Department recommendations, at its February 2022 meeting the Commission adopted limited-term regulations to: (1) close commercial bull kelp harvest in Mendocino and Sonoma counties, where bull kelp loss was most pronounced; (2) limit annual harvest to 8,000 pounds wet weight in Humboldt and Del Norte counties; and (3) close three lease-only administrative kelp beds in Mendocino, Humboldt, and Del Norte counties. The Commission set a three-year sunset date to provide time for KRMP development and to reassess bull kelp status trends. The temporary commercial bull kelp harvest regulations (sections 165 and 165.5) were enacted January 1, 2023 and end on January 1, 2026, unless action is taken (for additional details see Exhibit 2).

Since then, in December 2024 [OPC funded research led by Woods Hole Oceanographic Institution](#) to investigate the potential impacts commercial and recreational kelp canopy harvest could have on the future resilience of kelp forests; this project is ongoing.

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Update

Today's Department update on kelp canopy area trends (Exhibit 1) will highlight that bull kelp canopy cover has not recovered in northern California and, in fact, has declined further in Del Norte County. Thus, the Department recommends extending the temporary restrictions to January 1, 2029, during which time both the OPC-funded research on harvest impacts and development of the KRMP will continue.

The proposed regulatory extension is scheduled for notice in August 2025 with a discussion and adoption hearing in October 2025 to ensure the extension is effective before January 1, 2026.

Significant Public Comments

The founder of a kelp restoration organization and petitioner for Petition 2023-23MPA, requests that the KRMP provide policy implementation of the restoration strategies and measures proposed within their MPA petition (Exhibit 3). They also share an article from April 2025 titled "*Global floating kelp forests have limited protection despite intensifying marine heatwave threats*" (Exhibit 4).

Recommendation

Commission staff: Extend temporary commercial bull kelp harvest restrictions through January 1, 2029 as recommended by the Department.

Department: Extend the current temporary commercial bull kelp harvest restrictions through January 1, 2029, including: closure in Mendocino and Sonoma counties; four ton (8,000 pounds) wet weight annual fishery quota in Humboldt and Del Norte counties, with weekly reporting; closure and lease prohibition on lease-only administrative kelp beds 308, 309, 312; and correct a typographical error in Administrative Kelp Bed 109 coordinate.

Exhibits

1. [Department presentation](#)
2. *Background document:* [Staff summary for Agenda Item 8, February 2022 Commission meeting](#)
3. [Letter from Keith Rootsart, Founder and CEO, Giant Kelp Restoration, received July 3, 2025](#)
4. [Email from Keith Rootsart, Founder and CEO, Giant Kelp Restoration, received June 25, 2025](#)

Committee Direction/Recommendation

The Marine Resources Committee recommends that the Commission support extending the regulation for commercial bull kelp harvest restrictions and correcting a typographical error in an Administrative Kelp Bed 109 coordinate as recommended by the Department and discussed today, for consideration in the rulemaking scheduled for notice at the August 2025 Commission meeting and discussion/adoption at the October 2025 Commission meeting.



Kelp Management

16 July 2025

Presented to:

Marine Resources Committee
CA Fish and Game Commission

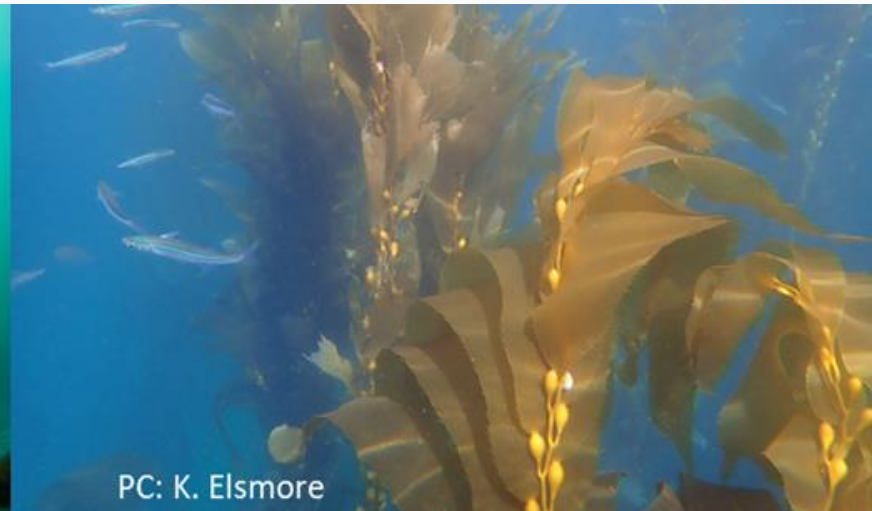
Presented by:

Dr. Kristen Elsmore
Sr. Environmental Scientist Specialist
CDFW Marine Region



Overview

- Development of the Kelp Restoration and Management Plan (KRMP)
- Kelp Restoration and Recovery Tracking
 - Kelp status statewide
 - Update on ongoing projects
- Commercial Bull Kelp Harvest Regulatory Sunset Date and Recommendations





Kelp Restoration and Management Plan



Kelp Restoration and Management Plan (KRMP)

- **Overarching Goal:**
 - To develop a robust, adaptive, climate-ready approach to managing, protecting, and restoring giant and bull kelp forest ecosystems statewide for consideration and adoption by the Fish and Game Commission
- **Core Components:**
 - Overarching ecosystem-based management framework
 - Adaptive kelp harvest framework
 - Restoration toolkit



KRMP Development Timeline



Science Advisory
Committee

Tribal
Engagement and
Consultation

Community Working
Group



2023-2026

Recommendations informing the KRMP



On the Ground
Research

2025 - 2026

KRMP Drafting, CEQA, Peer
Review, and Finalization

2026 - 2027

Management Plan and
Regulatory Process



2027

Implementation



KRMP Tribal Engagement



- Listening Sessions, Forums, and Consultations
- Representation on Community Working Group and Science Advisory Committee
- Exploration of co-management pathways



PC: K. Elsmore | CDFW



KRMP Community Working Group (CWG)



- Role and Composition:
 - Tasked with informing KRMP development, including gathering and sharing information with their communities
 - 23 Members
 - Representing regional community sectors
- Meeting Discussions to Date (6):
 - Ecosystem-based management
 - Monitoring and assessment of kelp forest ecosystems
 - Restoration approaches and success factors
 - Harvest management strategies
 - Permitting



KRMP Science Advisory Committee (SAC)



- Role and Composition:
 - To provide scientific expertise on all aspects of the KRMP
 - 12 Members
 - Representing broad scope of disciplines and geographic areas
- Meeting Discussions to Date (7):
 - Kelp Socio-ecological Conceptual Framework
 - Key indicators to assess the health of the kelp resource
 - Monitoring and existing data
 - Identifying thresholds for key indicators
 - Identify and evaluate potential management strategies
 - Spatial and temporal considerations



KRMP CWG and SAC Joint Meeting



- Purpose:
 - Provide progress updates and support interaction, questions, and discussion
- Interactive Exercises and Discussions:
 - Defining kelp ecosystem health status (qualitatively and quantitatively)
 - Identifying potential management strategies based on forest conditions and available resources
 - Integrating scientific data and community insights into monitoring and management
- Poster Session:
 - Showcased kelp-related projects
 - Supported cross-learning and statewide knowledge exchange



KRMP: Next Steps 2025-2026



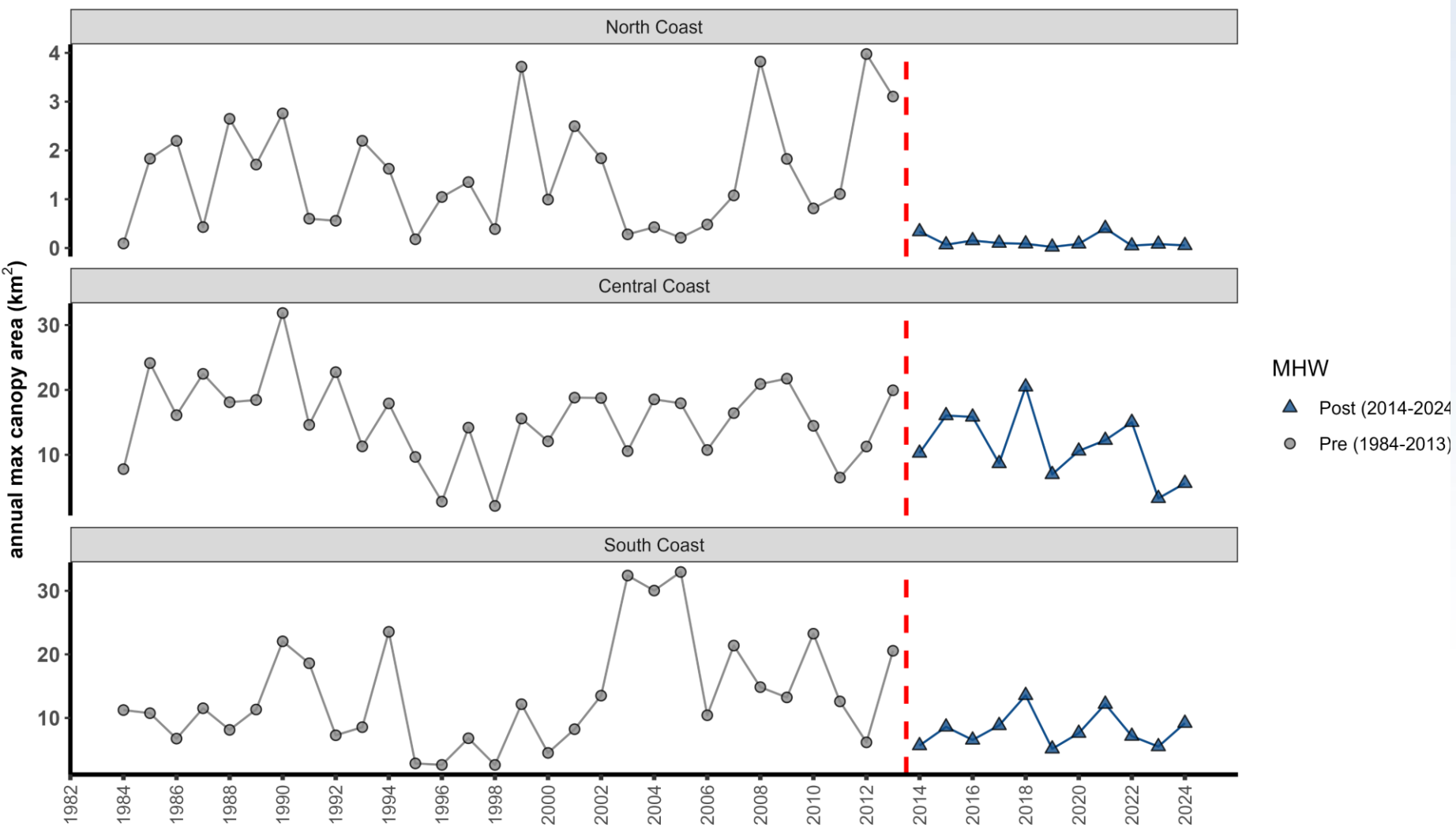
- Tribal Engagement:
 - Support additional opportunities for input and engagement
 - Consultation and co-management conversations
- Community Working Group:
 - Continue gathering community input and priorities
 - Draft and discuss recommendations
- Science Advisory Committee:
 - Integrate results from ongoing projects to inform evaluation of potential restoration tools and approaches, harvest frameworks, other considerations
 - Build out decision tree for overarching management framework



Kelp Status Overview



Kelp Canopy Status by Region



Data Source: Santa Barbara Coastal LTER et al. 2025





Kelp Recovery Research Projects Underway



Advancing Kelp Research in California



- Kelp Recovery Research Program (CASG)

2020-2022



- Accelerating Kelp Research and Restoration (CASG)

2024-2026



- Adaptive Management and Resilience of Kelp Forest Projects

2025-2027



- Other research by scientific community

Ongoing



- Ghvtlh-k'vsh shu'-srnelh-'i~ (Kelp Guardians)
 - Location: Del Norte
 - Project Leads: Tolowa Dee-ni' Nation
 - Build capacity and integrate Western and Indigenous sciences
 - Subtidal monitoring and scientific dive training
 - Pilot tumble culture for cultural practices and tribal food sovereignty
 - Engage Indigenous youth in kelp restoration workshops rooted in community-based methods



- Accelerating Bull Kelp Recovery Using Sequencing of Restoration Techniques
 - Locations: Big River, Albion, Noyo (Mendocino)
 - Project Lead: The Nature Conservancy
 - Testing novel restoration approaches:
 - Traps and commercial urchin divers to reduce grazing pressure
 - Supplementing drift to modify grazer behavior
 - Elevated kelp modules to increase spore supply
 - Testing efficacy of sequencing multiple restoration approaches





Approaches to Minimizing Grazing Pressure



- Evaluating Giant Kelp Recovery Following Localized Removal of Grazers
 - Locations: Monterey, Sonoma, and Humboldt
 - Project Lead: UC Santa Cruz
 - Testing key aspects of managing grazing pressure:
 - Modifying grazing pressure along edges of remnant kelp forests
 - Considering multiple grazer taxa (urchins, snails, etc.)
 - Grazer removal frequencies and associated costs
 - Evaluating oceanographic parameters important for restoration site selection



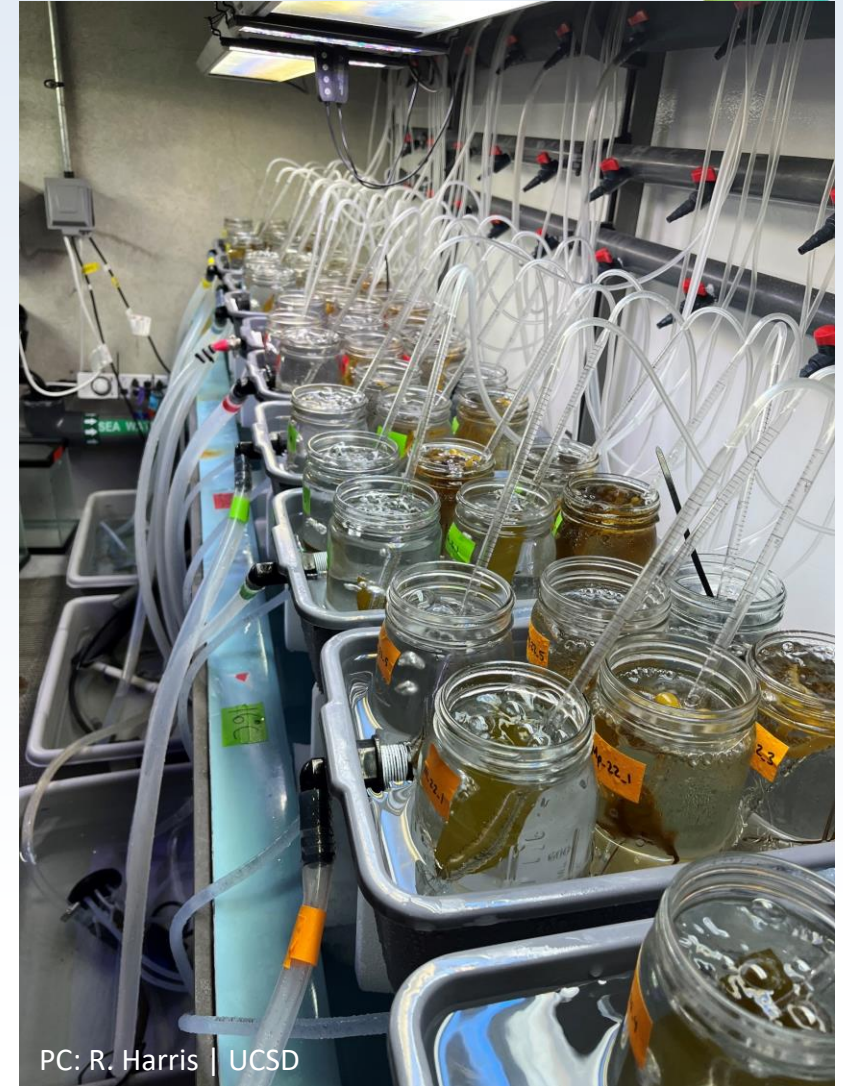
Forecasting to Inform Restoration

- A Proactive Approach to Help Restoration in California: Forecasting Kelp Loss and Optimal Restoration Times
 - Location: Statewide
 - Project Lead: UC Santa Barbara
 - Modeling long-term survival under different climate scenarios
 - Incorporate tool to evaluate seasonal drivers to inform decisions around timing and locations for kelp restoration
 - Informing climate-readiness and resilience within the KRMP



Thermal Tolerance

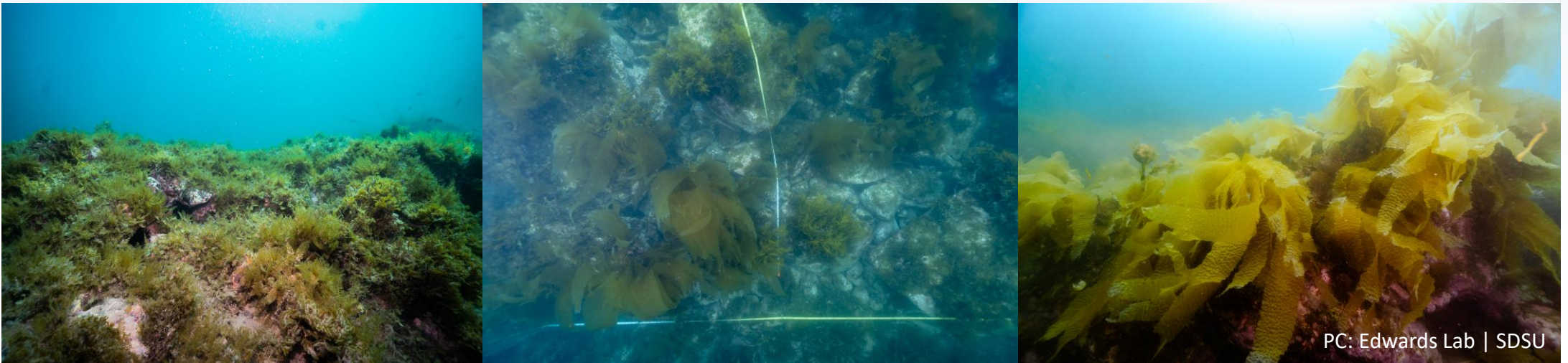
- Thermal Tolerance, Population Variability and Experimental Restoration in Southern California
 - Location: San Diego
 - Project Lead: UC San Diego
 - Investigating thermal tolerance of giant kelp, bull kelp, and a suite of key understory algae
 - Evaluating linkages across genetics, thermal tolerance, growth and survival
 - Informing climate-readiness and resilience within the KRMP





Experimental *Sargassum horneri* Removal

- Evaluating giant kelp recovery following localized removal of invasive algae (*Sargassum horneri*) and perennial turf algae
 - Locations: Catalina Island
 - Project Lead: San Diego State University
 - Evaluating efficacy of localized removal of competitive species and conditions under which spore supplementation is important





Greater Farallones Association/GFNMS

- Evaluating Bull Kelp Restoration Approaches Along the Sonoma Coast
 - Locations: Ft. Ross, Timber Cove, Sea Ranch (Sonoma)
 - Project Leads: Greater Farallones Association, Greater Farallones National Marine Sanctuary; Kashia Band of Pomo Indians
 - Evaluating efficacy of urchin grazer suppression and kelp outplanting



PC: K. Elsmore | CDFW



Palos Verdes Kelp Restoration Project

- Evaluating giant kelp recovery following localized removal of grazers
 - Locations: Palos Verdes Peninsula (Los Angeles)
 - Project Lead: The Bay Foundation
 - Ongoing effort over past 12 years
 - Spans 78 acres to date
 - Reducing grazing pressure via crushing urchins in situ
 - Minimal maintenance of restoration sites
 - Increase in giant kelp, inverts, fish diversity and biomass, and red urchin gonad weight
 - Partnership with commercial urchin divers and recently launched volunteer program





Temporary Regulations for Urchin Take

- Assessing the efficacy of urchin culling by recreational divers under temporary regulations
 - Locations: Caspar Cove (Mendocino) and Tanker Reef (Monterey)
 - Caspar Cove:
 - Temporary regulations in place through April 2029
 - Increase in diver participation
 - Commercial urchin harvest on north portion of cove
 - Tanker Reef:
 - Temporary regulations sunset April 2024
 - Urchin densities reduced
 - Initial kelp regrowth, with canopy persisting through spring 2025 surveys

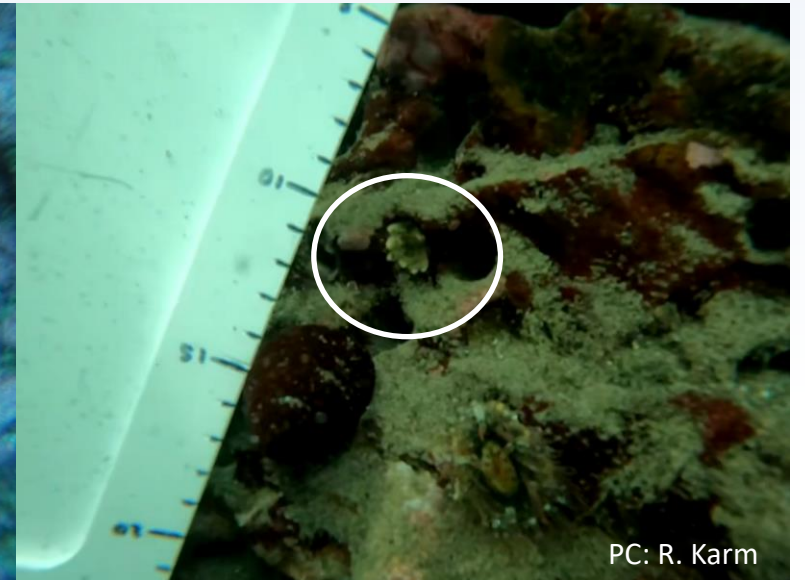


PC: T.A. McHugh | The Nature Conservancy



Sunflower Star (Pycnopodia)

- Subtidal and intertidal sightings in Northern California
- Advances in eDNA as potential monitoring tool
- Advances in disease research
- Advances in captive breeding research



- Strategic Mapping of Giant and Bull Kelp Genomic Diversity
 - Location: Statewide
 - Project Lead: UC Santa Cruz
 - Map giant and bull kelp genomic diversity in California
 - Identify where genetics may be driving patterns of loss and persistence
 - Informing climate-readiness and resilience within the KRMP



Kelp Biomass and Harvest Assessment

- Assessment of Biomass, Production, and Harvest Impact for Canopy-forming Kelps in California
 - Location: Statewide
 - Project Lead: Woods Hole Oceanographic Institution
 - Providing quantitative metrics for giant and bull kelp biomass and production
 - Partnership with commercial harvesters in Northern, Central and Southern California
 - Informing the adaptive harvest framework within the KRMP





Commercial Bull Kelp Harvest Regulatory Sunset Date



Background, Outreach, and Engagement

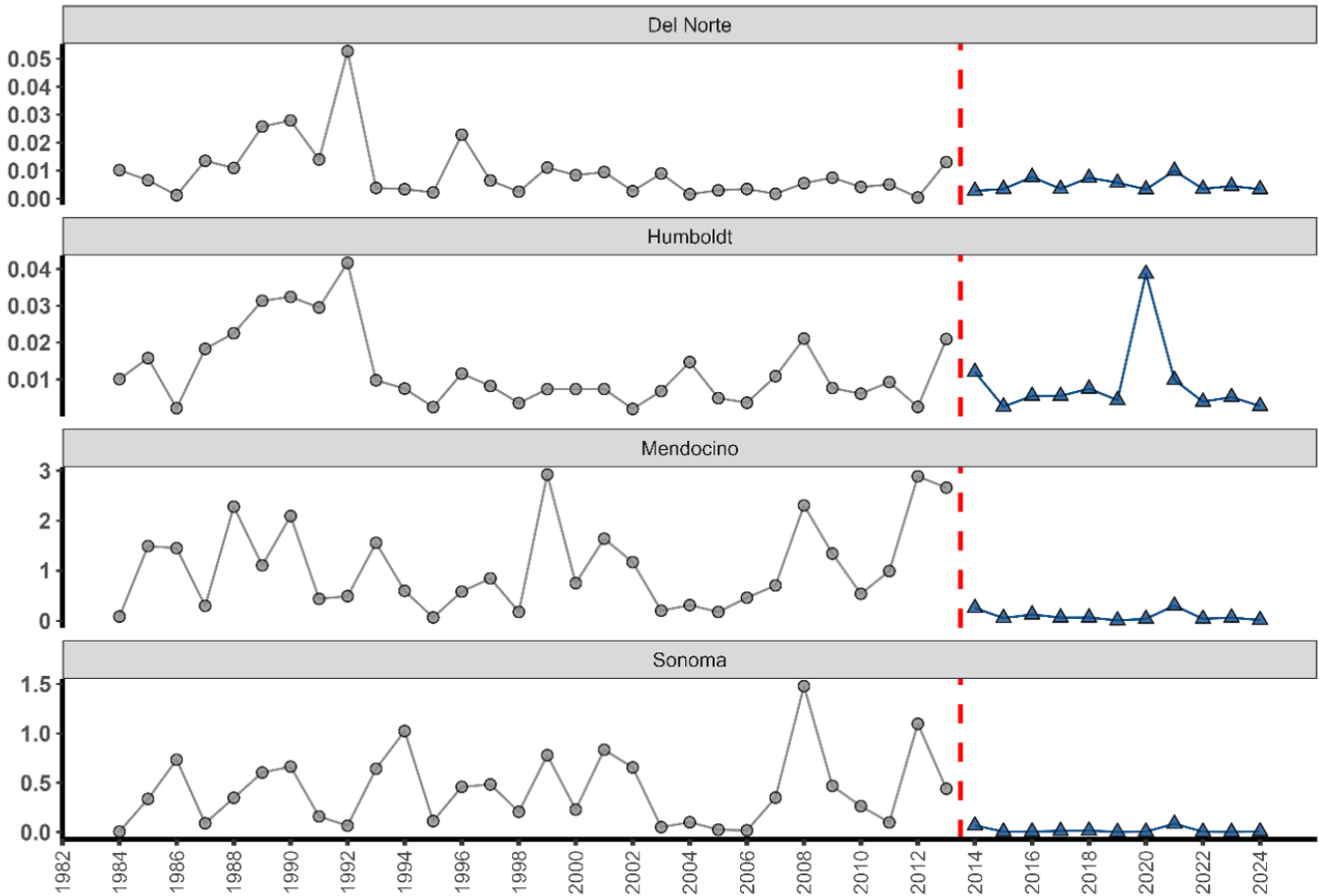
- Background
 - Commercial bull kelp harvest temporary regulations CCR, Title 14, Sections 165 and 165.5
 - January 1, 2023 - January 1, 2026
 - Enacted as a precautionary approach
 - Allow development of the KRMP
- Outreach and Engagement
 - May 28, 2025 – Tribal Notification
 - July 1, 2025 – Stakeholder informational meeting
 - Today's MRC meeting



Bull Kelp Canopy Area

County	2022 Pre-Adoption Statement of Reasons 2014 – Third Quarter 2021 Percent Change Time Frame (Compared to 1984-2013)	Updated 2014 – Fourth Quarter 2024 Percent Change Time Frame (Compared to 1984-2013)
Mendocino	90% decline	91% decline
Sonoma	95% decline	96% decline
Humboldt	20% increase	29% decline
Del Norte	5% decline	48% decline

Max canopy area (km²)



Timeframe

- ▲ Post (2014-2024)
- Pre (1984-2013)



Proposed Bull Kelp Regulations

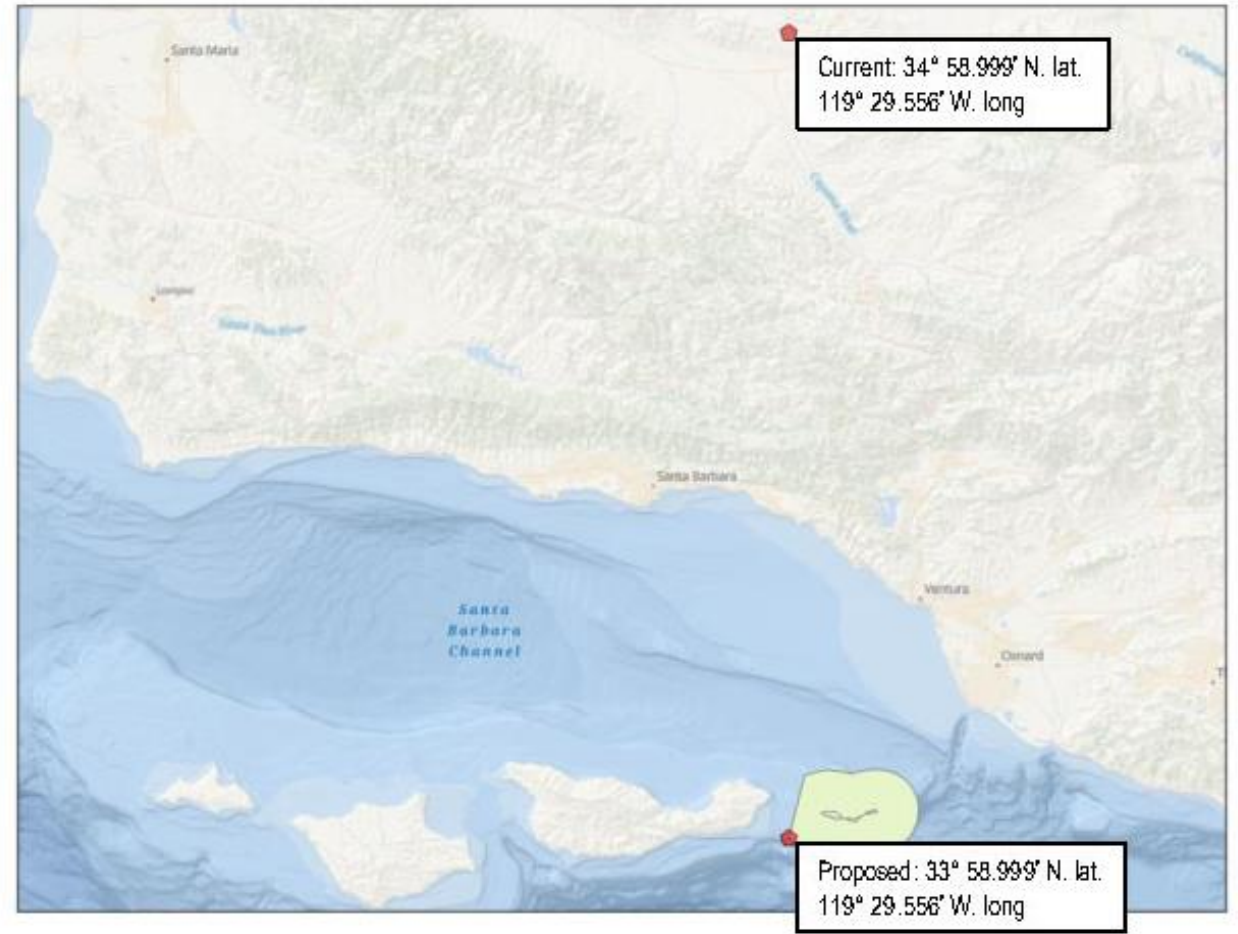
- Recommend extending temporary restrictions through January 1, 2029
 - Closure in Mendocino and Sonoma counties
 - Four ton (8,000 lbs.) wet weight annual fishery quota in Humboldt and Del Norte counties, weekly reporting
 - Closure and lease prohibition on lease only administrative kelp beds 308, 309, 312
 - Availability to lease the lease only beds amended to on or after January 2, 2029





Proposed Kelp Bed Regulation

- Correct typographical error in administrative kelp bed 109 coordinate





Proposed Commerical Harvest Timeline/Next Steps

- Notice: August 2025
- Discussion and Adoption: October 2025
 - Effective January 1, 2026
 - Sunset January 1, 2029
- Continue to work with researchers and stakeholders to fill priority research gaps and complete the development of the Kelp Restoration and Management Plan



Recap

- Development of the Kelp Restoration and Management Plan (KRMP)
- Kelp Recovery and Restoration Research Tracking
 - Kelp status statewide
 - Ongoing projects
- Proposed Commercial Bull Kelp Harvest Regulatory Sunset Date Extended to January 1, 2029
- Correct coordinate error for administrative kelp bed

Thank You

Dr. Kristen Elsmore

Senior Environmental Scientist Specialist

State Managed Finfish and Nearshore Ecosystems Program

Department of Fish and Wildlife

Marine Region

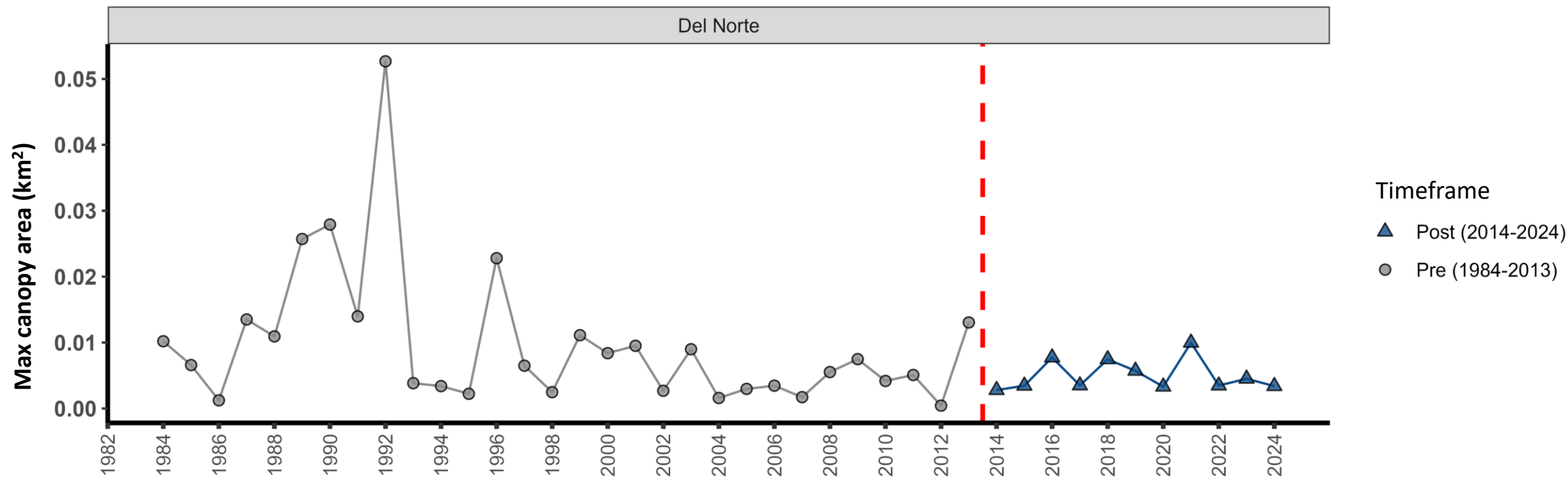
Email: kelp@Wildlife.ca.gov



Kelp Canopy Data By County



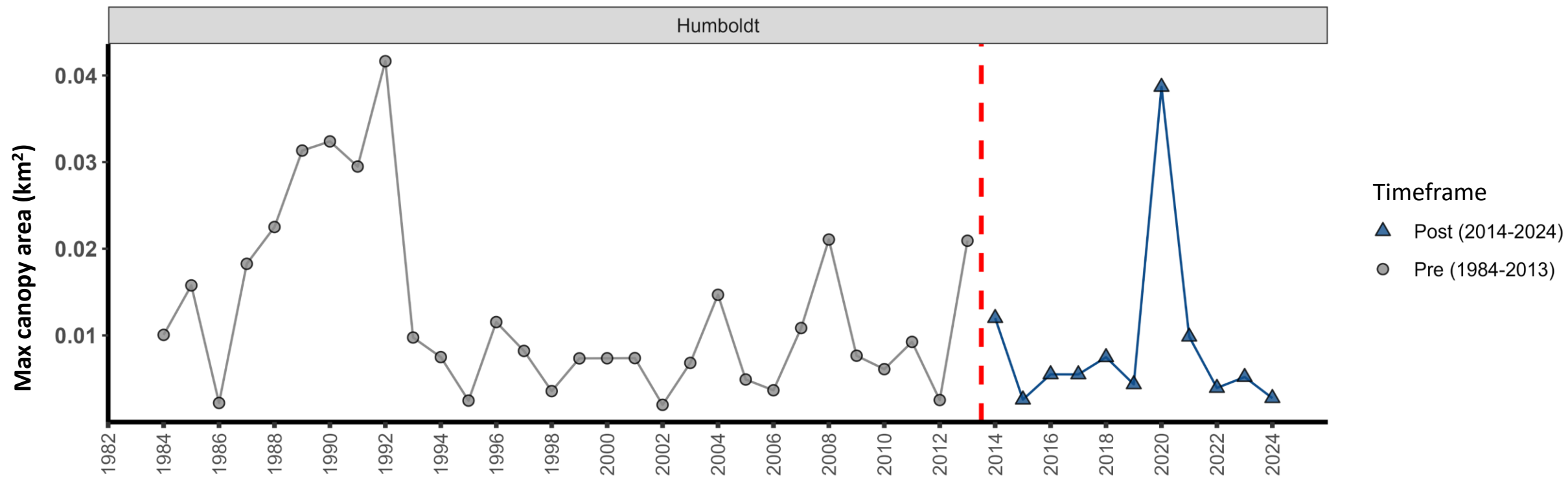
Kelp Canopy Status: Del Norte County



Data Source: Santa Barbara Coastal LTER et al. 2025



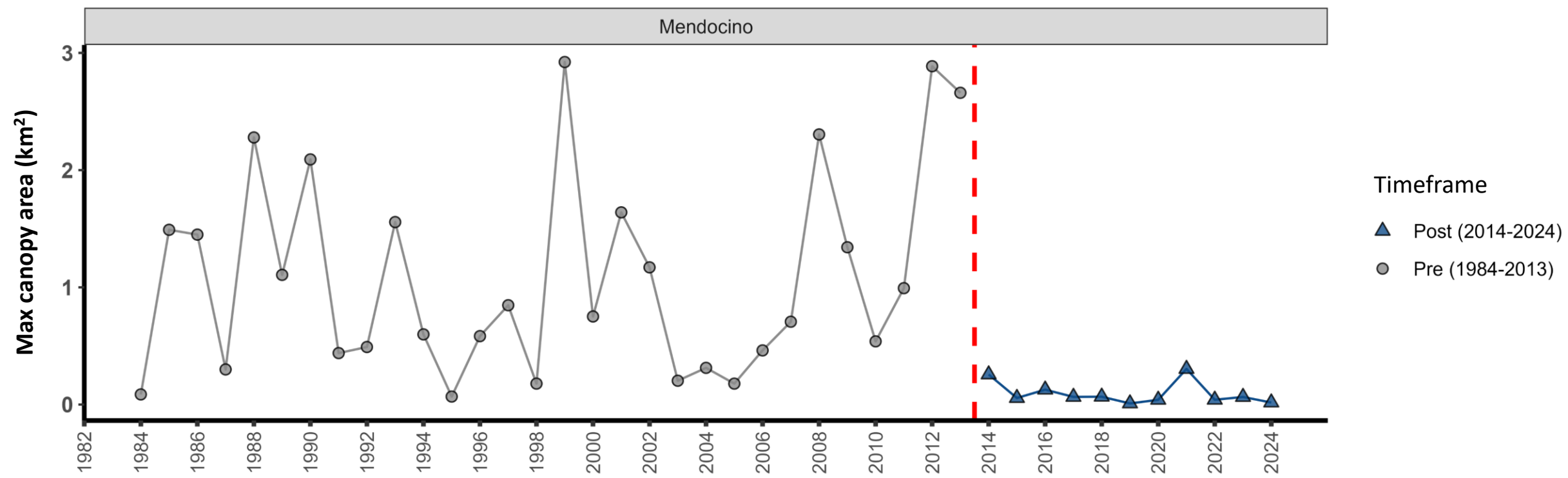
Kelp Canopy Status: Humboldt County



Data Source: Santa Barbara Coastal LTER et al. 2025



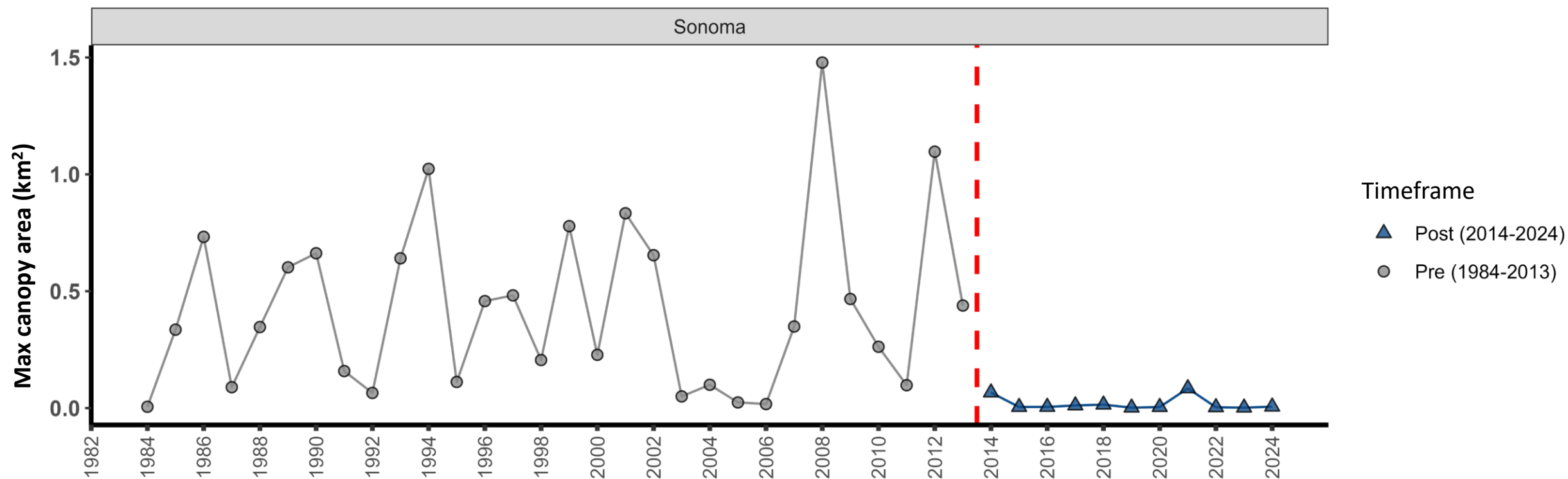
Kelp Canopy Status: Mendocino County



Data Source: Santa Barbara Coastal LTER et al. 2025



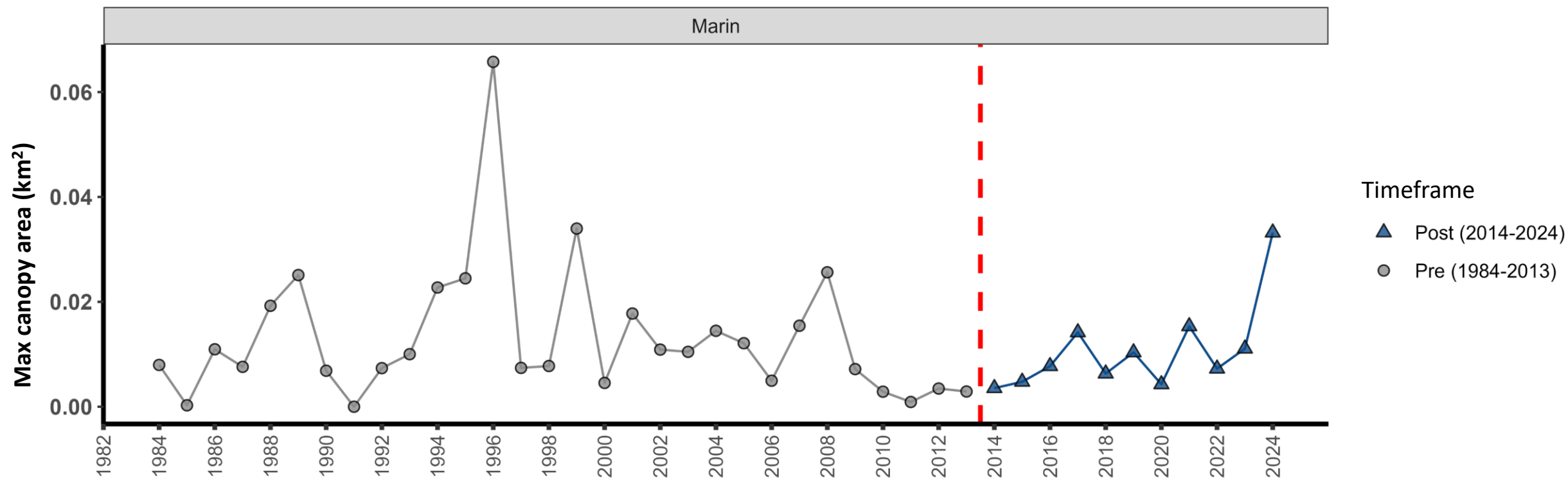
Kelp Canopy Status: Sonoma County



Data Source: Santa Barbara Coastal LTER et al. 2025



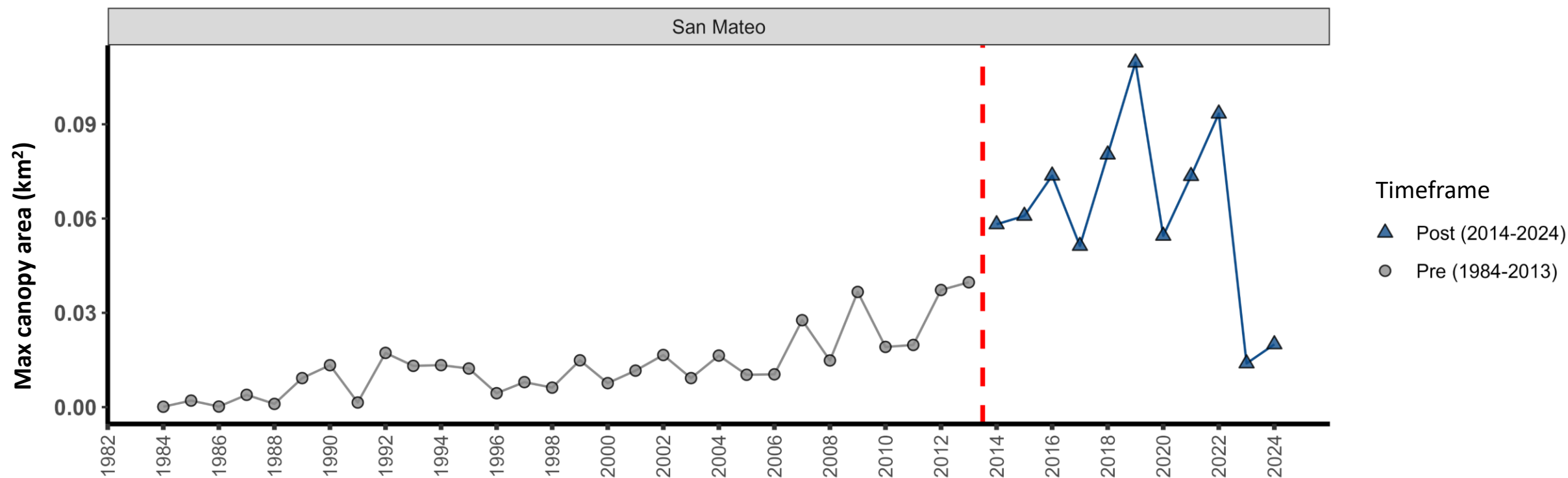
Kelp Canopy Status: Marin County



Data Source: Santa Barbara Coastal LTER et al. 2025



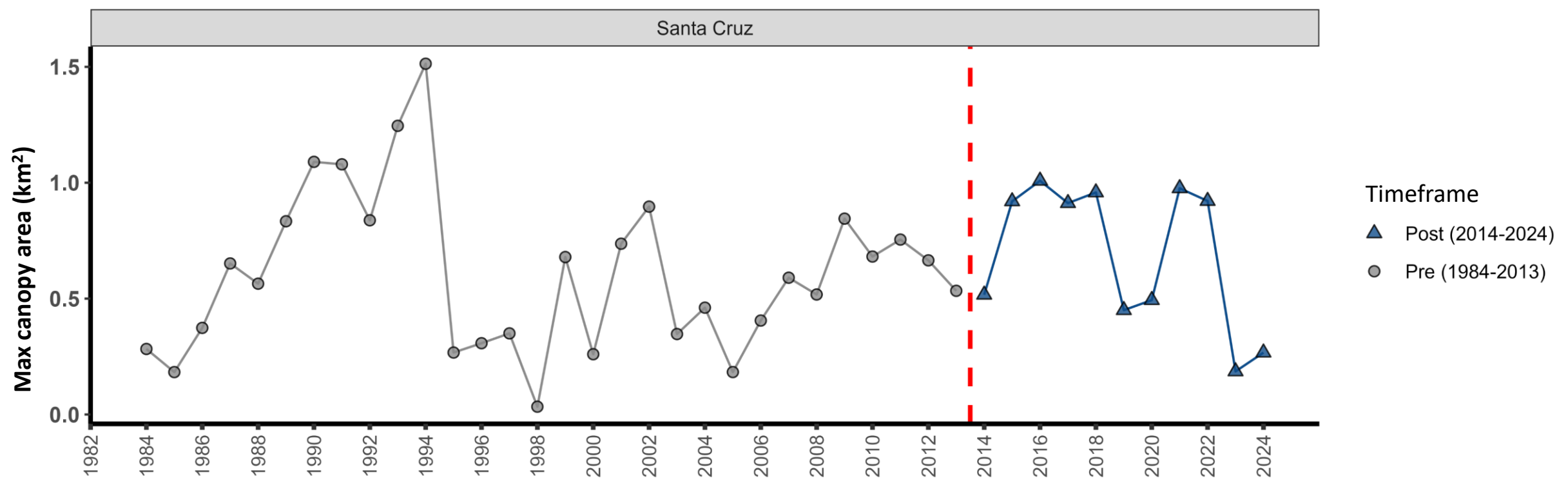
Kelp Canopy Status: San Mateo County



Data Source: Santa Barbara Coastal LTER et al. 2025



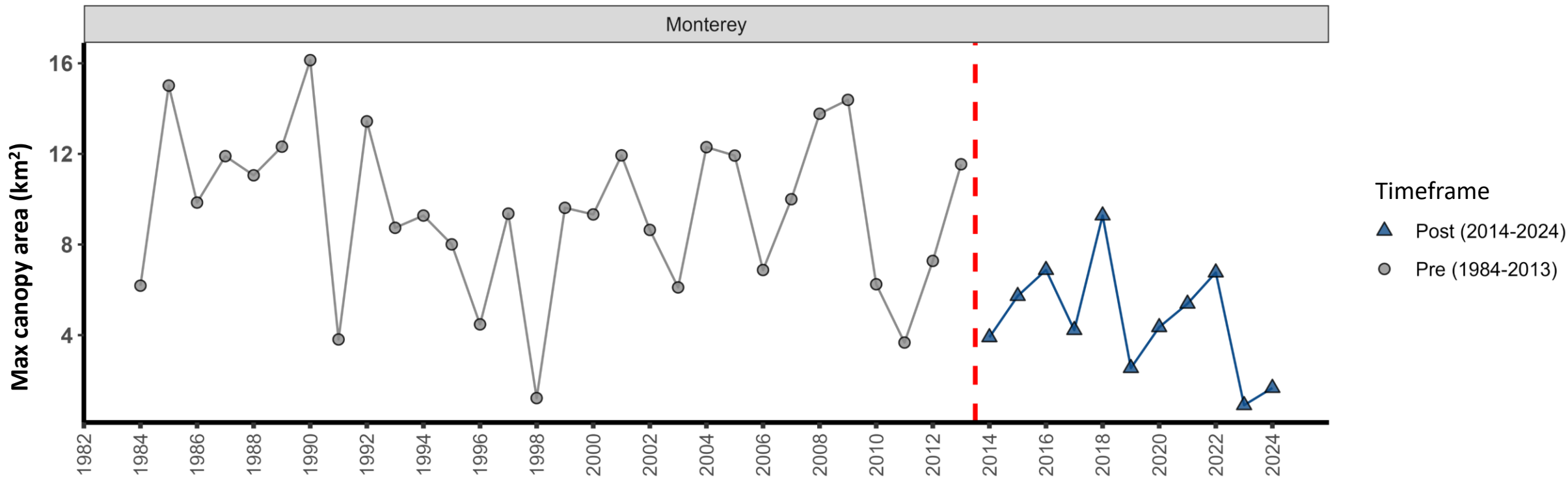
Kelp Canopy Status: Santa Cruz County



Data Source: Santa Barbara Coastal LTER et al. 2025



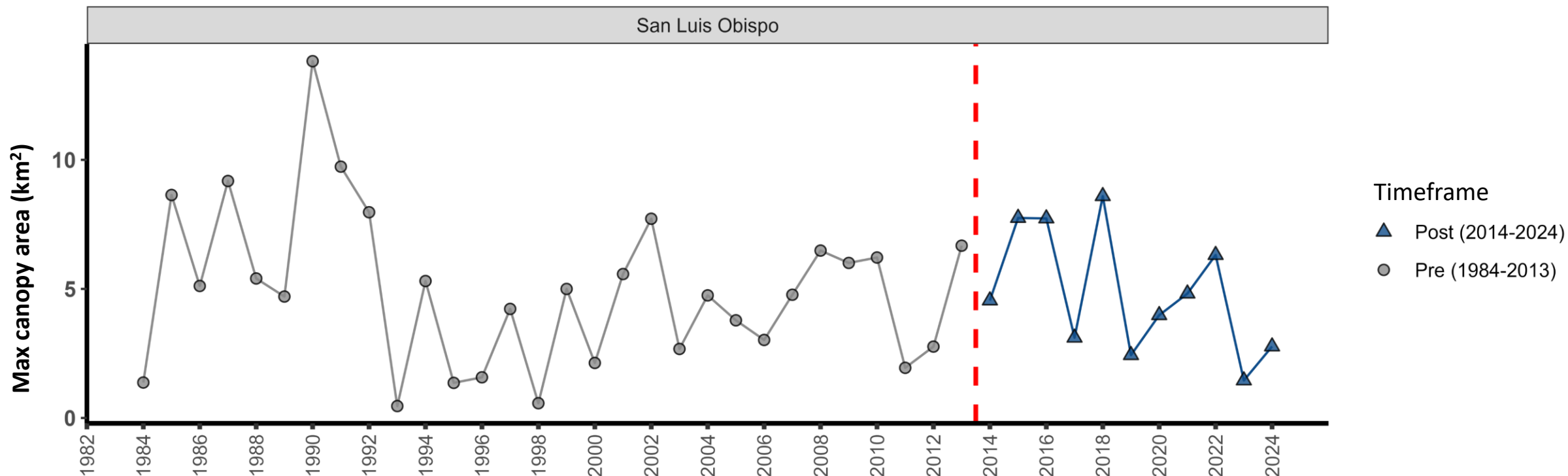
Kelp Canopy Status: Monterey County



Data Source: Santa Barbara Coastal LTER et al. 2025



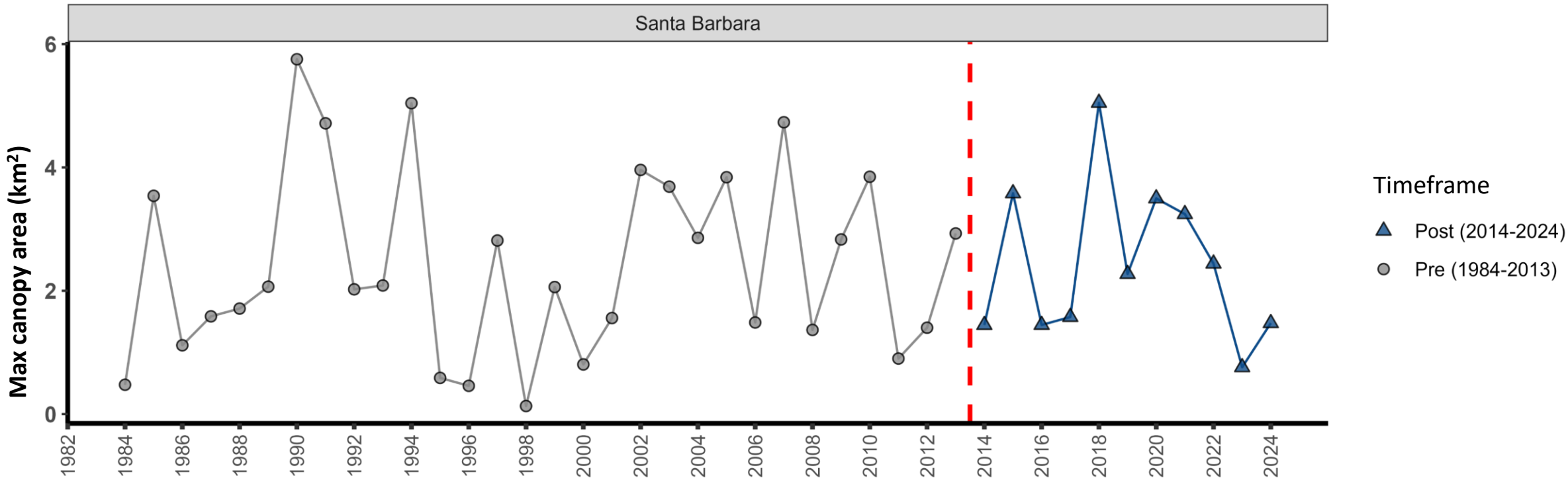
Kelp Canopy Status: San Luis Obispo County



Data Source: Santa Barbara Coastal LTER et al. 2025



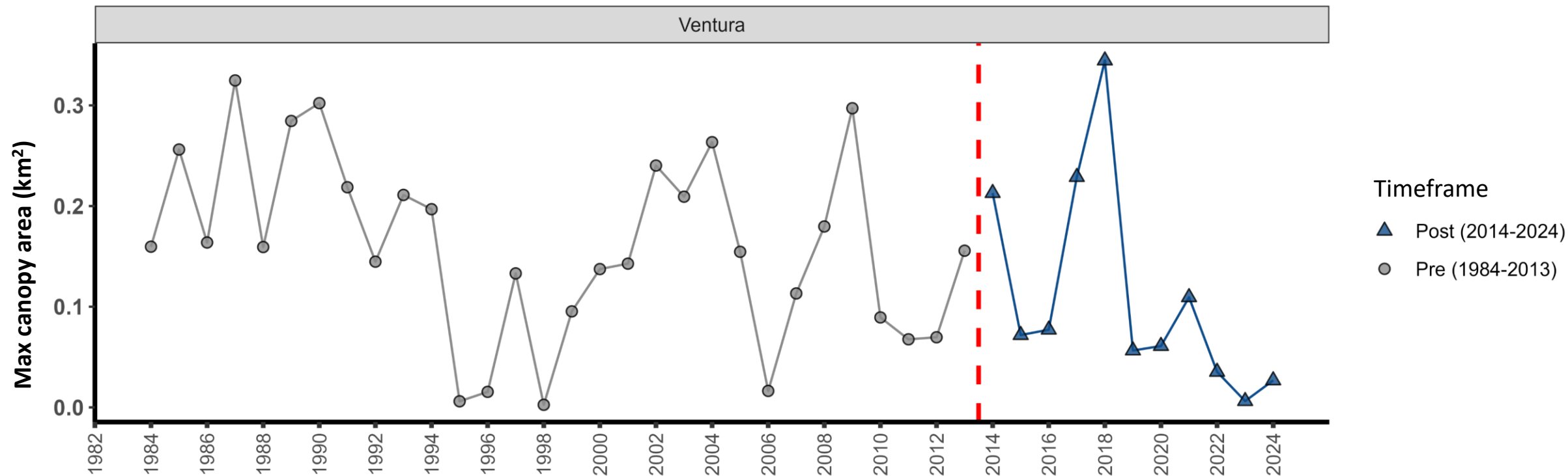
Kelp Canopy Status: Santa Barbara County



Data Source: Santa Barbara Coastal LTER et al. 2025



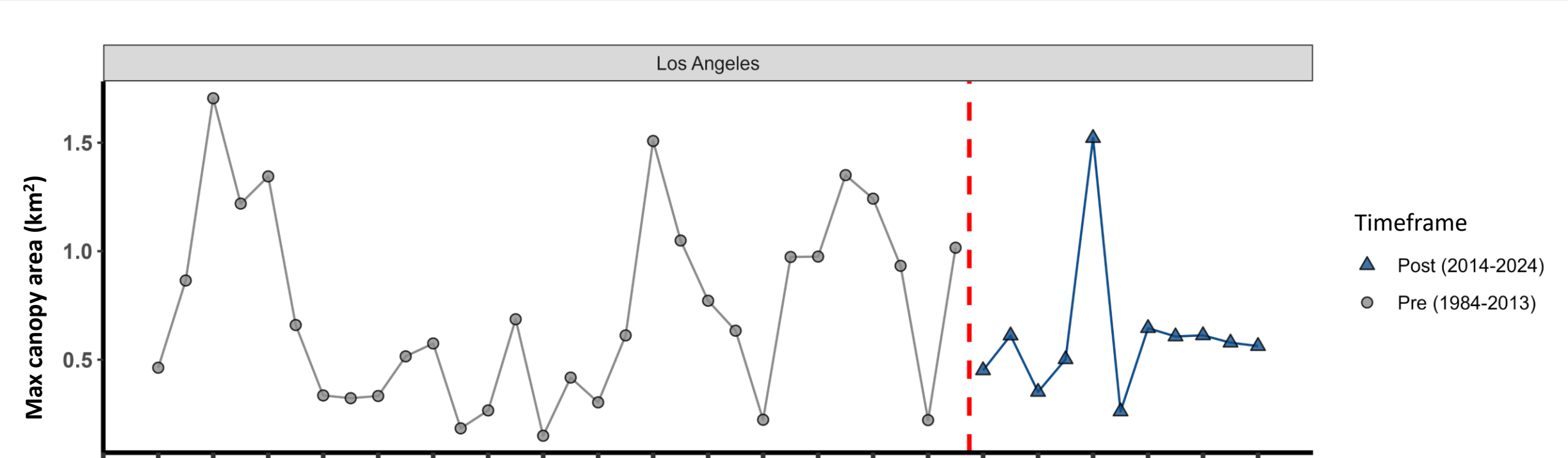
Kelp Canopy Status: Ventura County



Data Source: Santa Barbara Coastal LTER et al. 2025



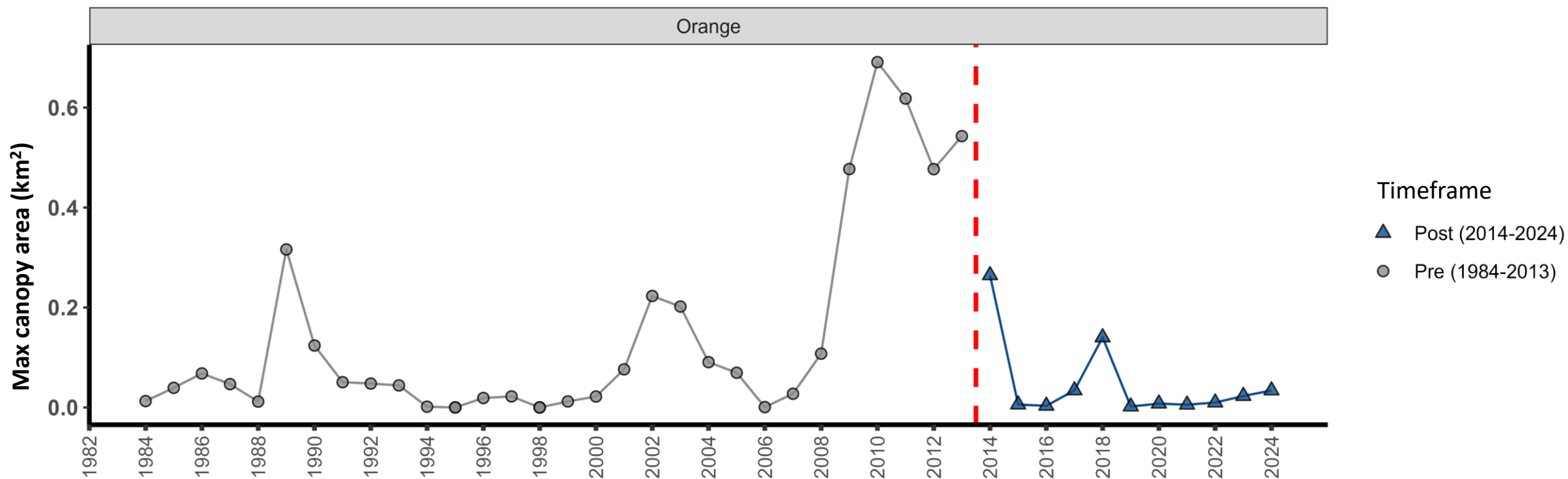
Kelp Canopy Status: Los Angeles County



Data Source: Santa Barbara Coastal LTER et al. 2025



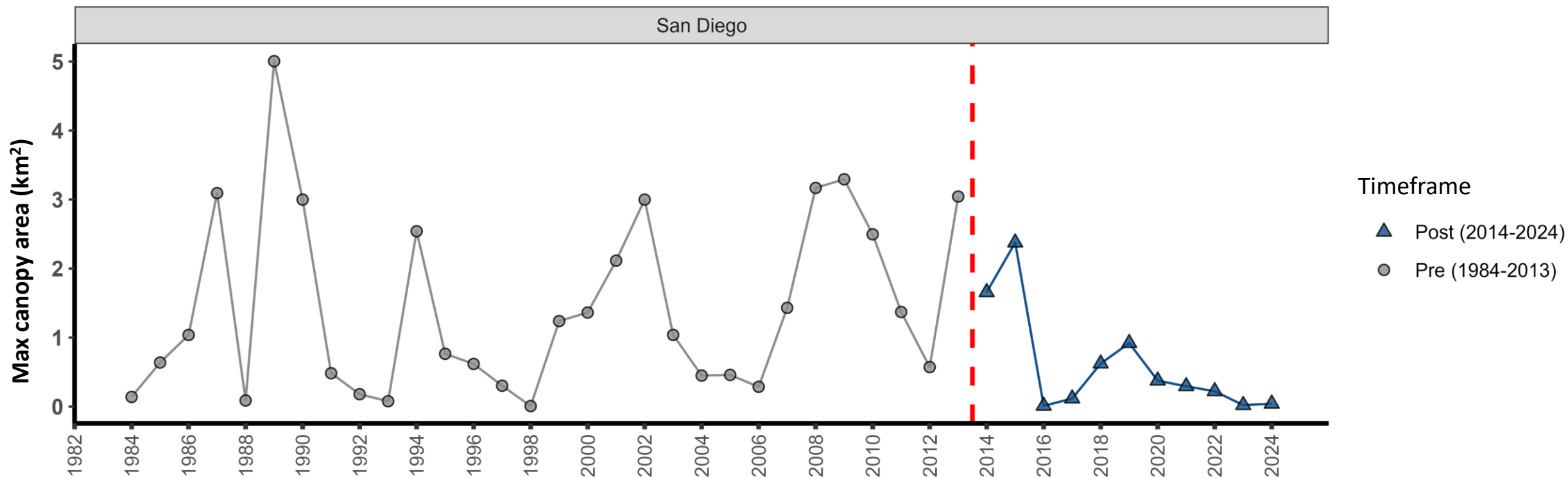
Kelp Canopy Status: Orange County



Data Source: Santa Barbara Coastal LTER et al. 2025



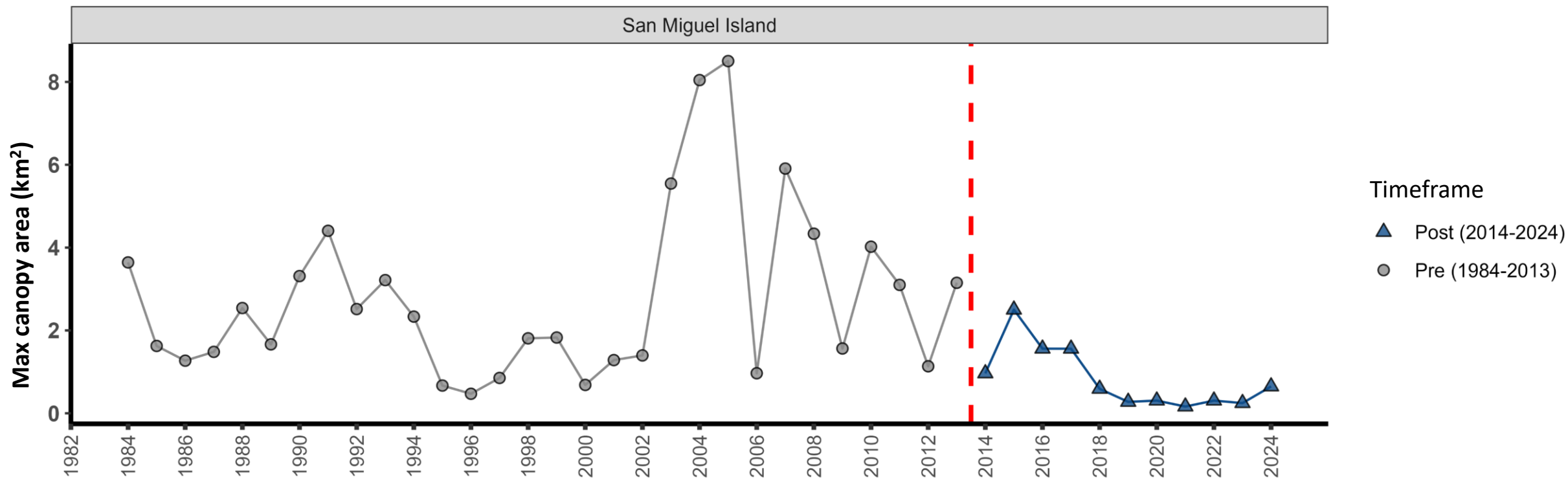
Kelp Canopy Status: San Diego County



Data Source: Santa Barbara Coastal LTER et al. 2025



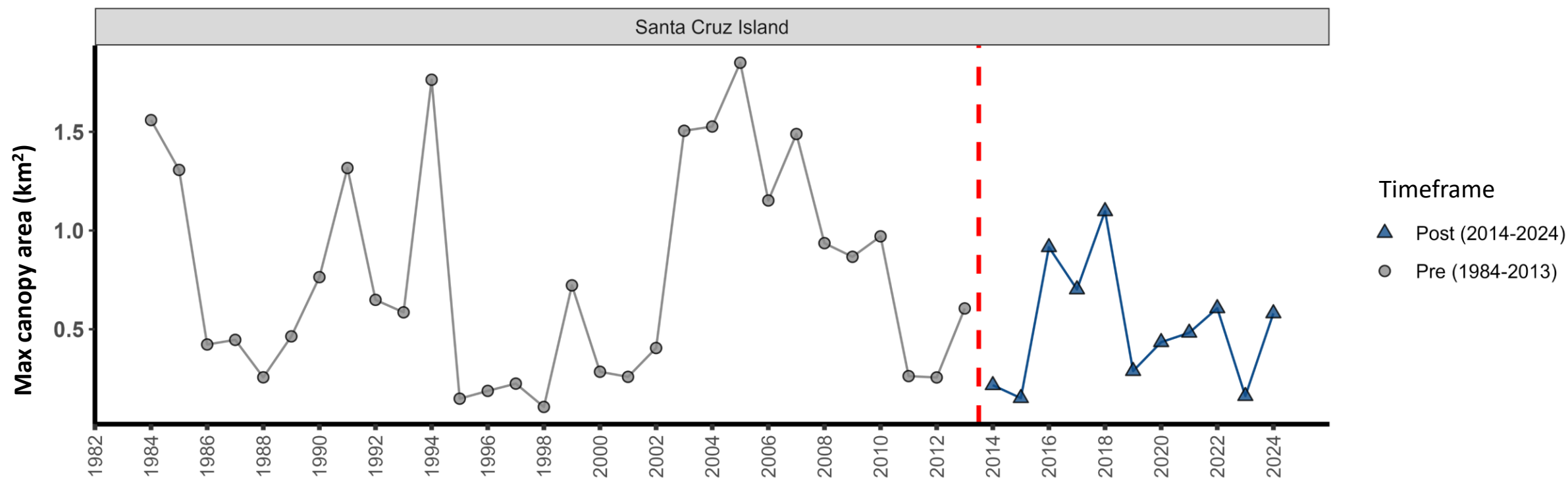
Kelp Canopy Status: San Miguel Island



Data Source: Santa Barbara Coastal LTER et al. 2025



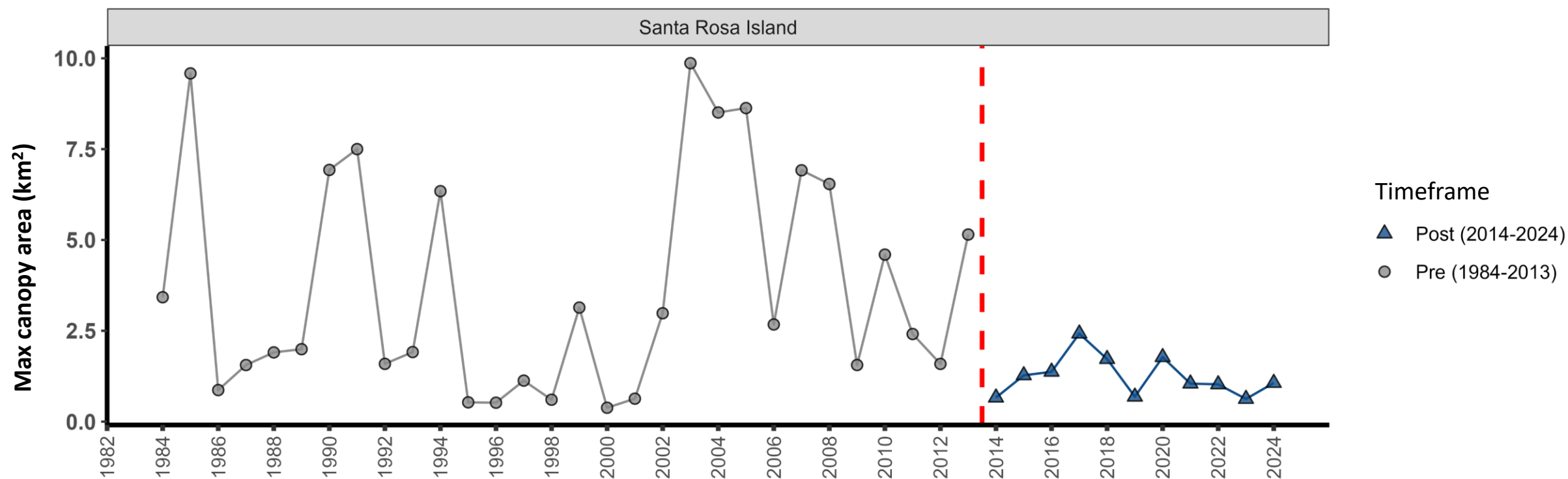
Kelp Canopy Status: Santa Cruz Island



Data Source: Santa Barbara Coastal LTER et al. 2025



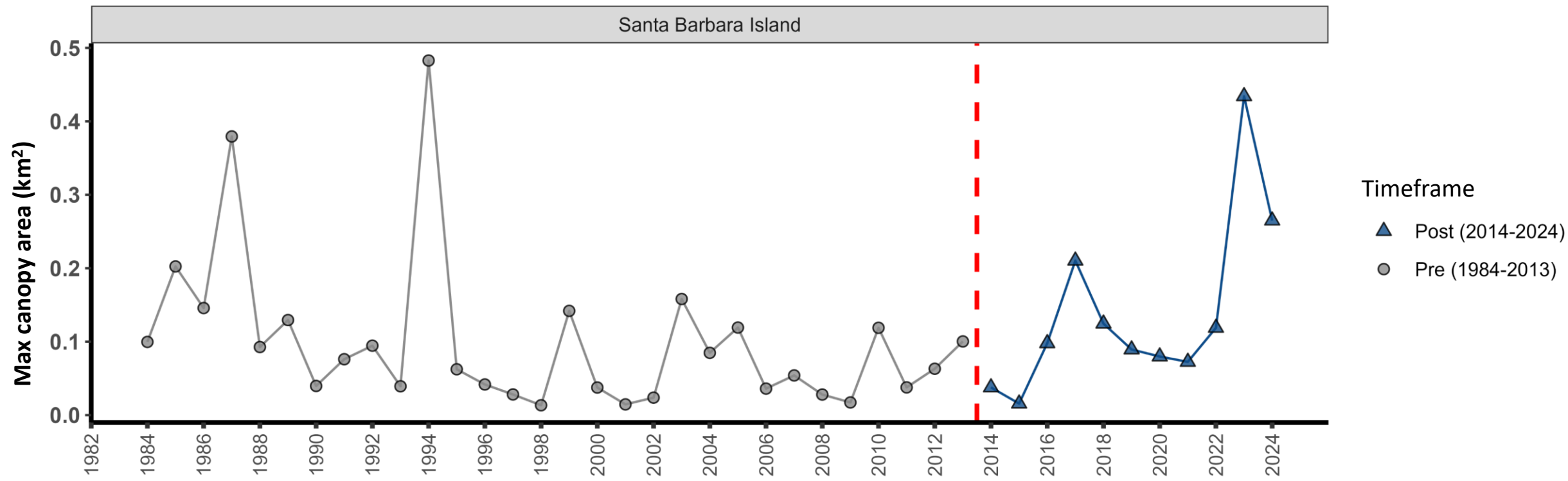
Kelp Canopy Status: Santa Rosa Island



Data Source: Santa Barbara Coastal LTER et al. 2025



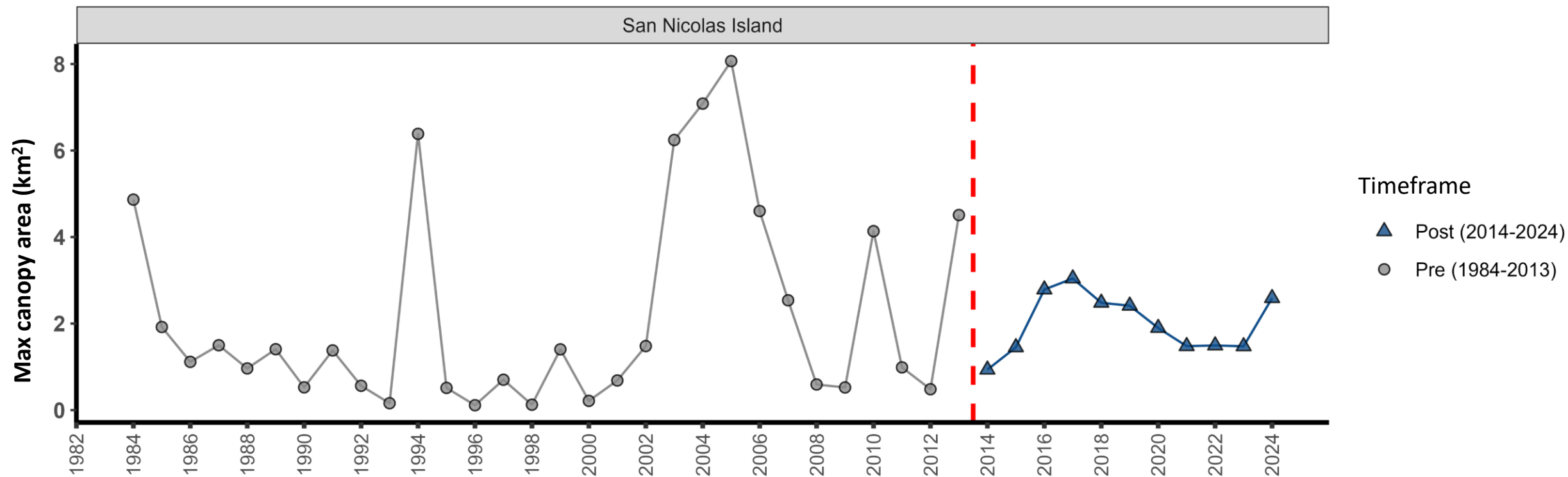
Kelp Canopy Status: Santa Barbara Island



Data Source: Santa Barbara Coastal LTER et al. 2025



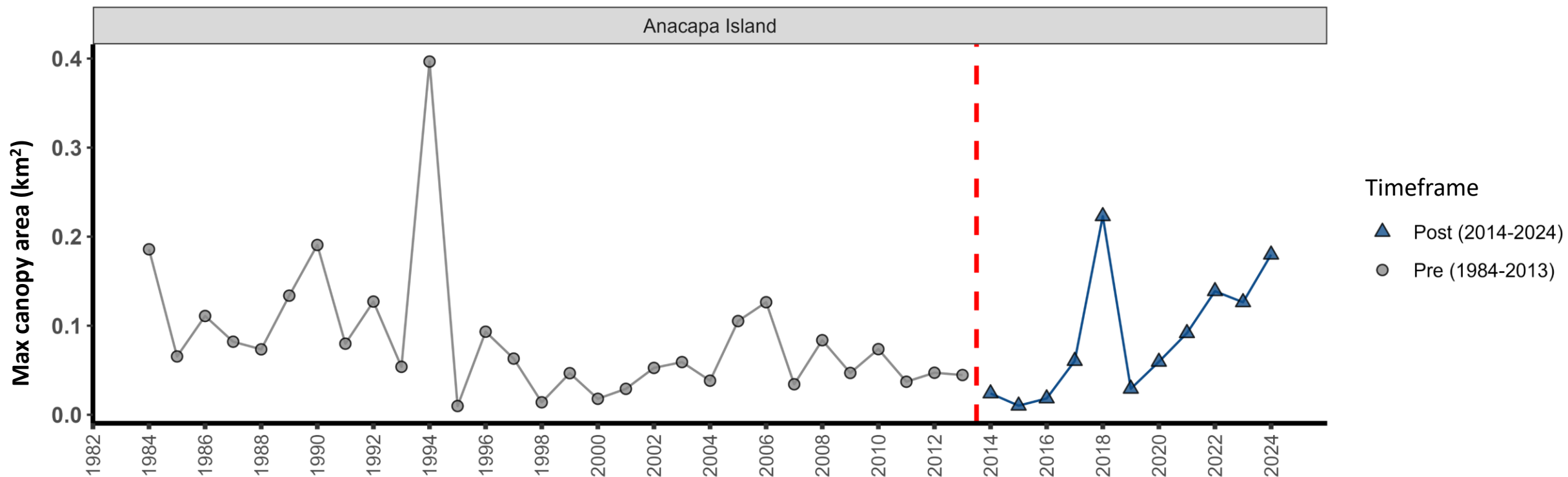
Kelp Canopy Status: San Nicolas Island



Data Source: Santa Barbara Coastal LTER et al. 2025



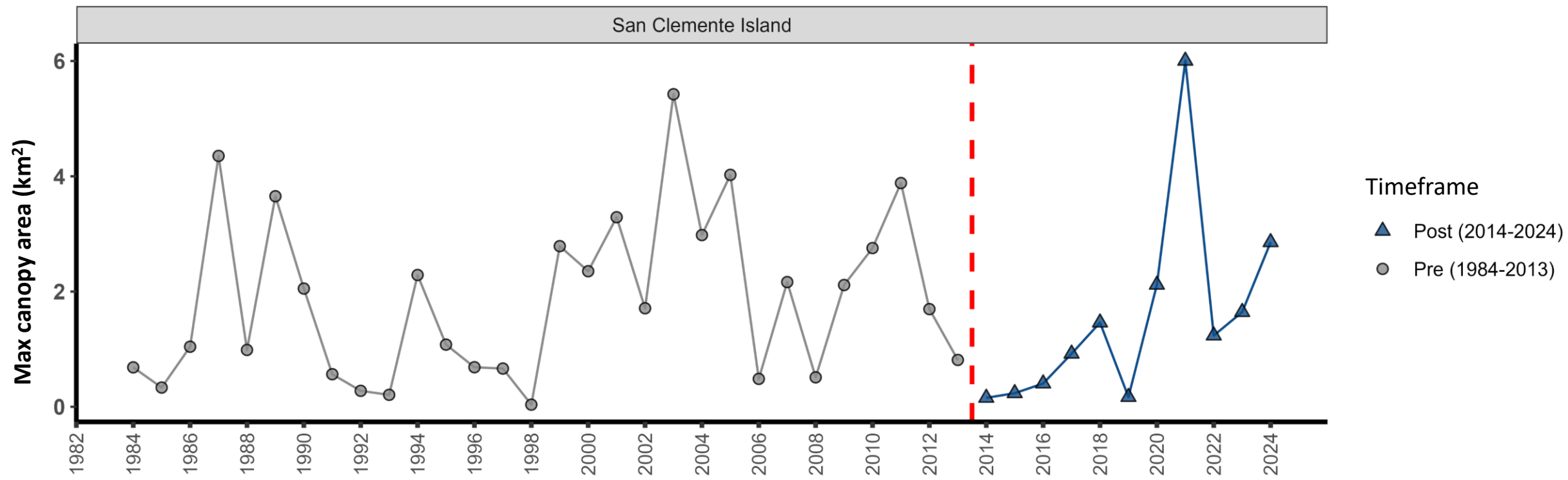
Kelp Canopy Status: Anacapa Island



Data Source: Santa Barbara Coastal LTER et al. 2025



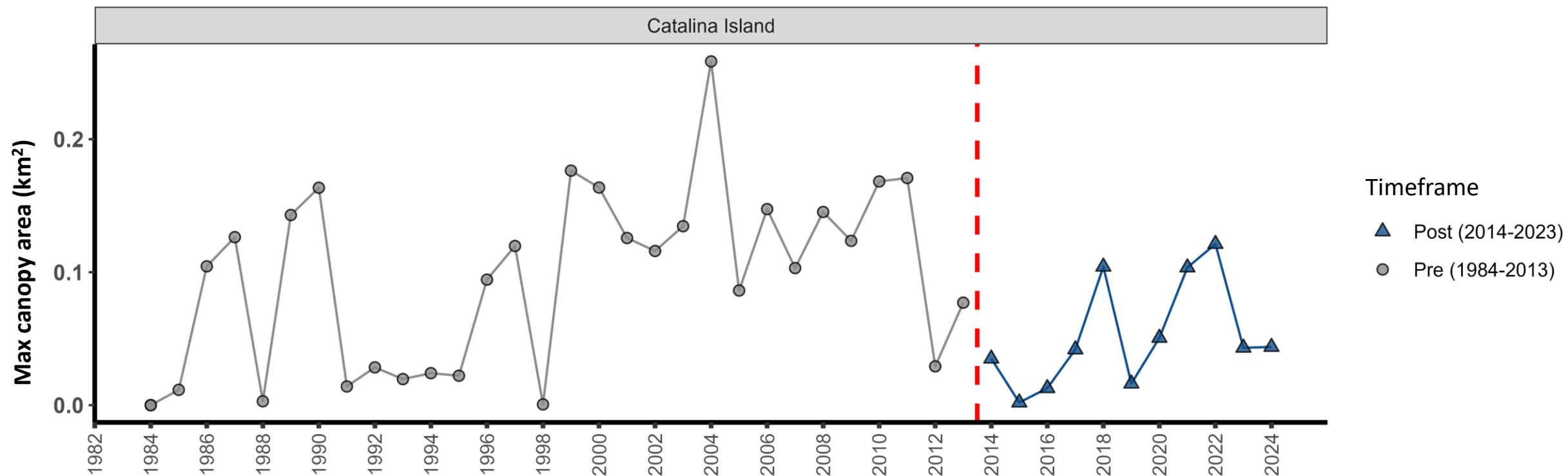
Kelp Canopy Status: San Clemente Island



Data Source: Santa Barbara Coastal LTER et al. 2025



Kelp Canopy Status: Catalina Island



Data Source: Santa Barbara Coastal LTER et al. 2025

From: Keith Rootsart <[REDACTED]>
Sent: Thursday, July 3, 2025 4:31:03 PM
To: FGC <FGC@fgc.ca.gov>
Subject: MRC Meeting Agenda Item 6A

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FGC Staff,

Please find attached our written Comments for the Marine Resources Meeting prior to the written comment deadline of 7/3/25 at 5:00.

Thank you,

Keith Rootsart

Giant Giant Kelp Restoration

[REDACTED]



Giant Giant Kelp
Restoration Project

Agenda Item 6A

When we first gave public comments to the Fish and Game Commission in 2017 about kelp loss it seemed like nobody was listening, and here we are 8 years later and there is an enormous volume of interest in kelp restoration. It seems the problem became apparent to more and more people.

Coming to commission meetings over the years I found that I'm the only person there applying for a fictional Kelp Restoration Management Permit we dreamed up in our Decadal Management Review Petition 2023-23MPA. I was not selected to be on the Kelp Restoration Management Plan working group, which is fair because I am the subject of their recommendations on how to do my work.

The KRMP presentation looks like solid progress on kelp restoration without really allowing any kelp restoration for a couple years. G2KR is uncertain what the recommendations will be for governing our activities when we are practicing kelp restoration presently as recreational and commercial fishing. We can legally do kelp restoration under existing regulations on 84% of the coast. KRMP is not about *good management practices*, this is about *control*. We are relieved that the state is delaying rulemaking a couple years while we develop a Regenerative Purple Urchin Fishery on the Central Coast without them.

As the only applicant, we ask the KRMP to advise on policy implementation needed by our DMR Petition 2023-23MPA to allow our recommended kelp restoration strategies in 5 of 125 Marine Protected Areas while the KRMP is further developed and implemented California-wide. We anticipate the timeline of the state will slip, but the kelp crisis is an urgent concern, especially in the presence of endangered southern sea otters. Our Giant Kelp Restoration Project will provide more information and research, develop better methods and strategies that would enrich the KRMP development.

We look forward to a healthy discussion when recommendations are published.

The MPA Statewide Leadership Team work plan 25-30 was published on July 1:
<https://opc.ca.gov/wp-content/uploads/2025/07/MSLT-Workplan-2025-508.pdf>

Page 22 has a section on restoring kelp forests:

18 Utilize OPC's Restoration and Mitigation Policy to develop a framework to evaluate and approve appropriate restoration and mitigation actions within MPAs and MMAs	1) Identify circumstances under which restoration would be appropriate to consider in an MPA and the types of MPAs in which restoration may be considered	CDFW, CFGC, OST, OPC, CCC
	2) Develop a structured decision-making approach for case-by-case determinations regarding restoration in MPAs	CDFW, OPC, CFGC, CCC
	3) Determine appropriate permitting pathways, assess capacity challenges, and fund gaps to ensure efficient permitting	CDFW, OPC, CCC

Statewide Leadership made a plan to make a plan. How will the Statewide Leadership Team influence or overlap with the development of the KRMP?

Keith Rootsart,
Executive Director



Giant Kelp
Restoration Project

From: Keith Rootsart <[REDACTED]>
Sent: Wednesday, June 25, 2025 12:22 PM
To: FGC <FGC@fgc.ca.gov>
Cc: Aaron Eger <[REDACTED]>
Subject: MRC Written Comments

FGC Staff,

We would like to submit this article published April 3, 2025 for reference:

Global floating kelp forests have limited protection despite intensifying marine heatwave threats.

As the ocean continues to warm, Marine Heat Waves are growing more intense and are happening more often. California is more vulnerable than other places around the world to these stressors on kelp forests as the ocean continues to warm.

We often reference “the Blob” in 2014-2016 as the tipping point for the decline of California kelp forests and the rise of urchin barrens. Kelp forests could be subject to >6 to >16 times higher cumulative MHW intensities in the mid and long term.

Thank you,

Keith Rootsart

Giant Giant Kelp Restoration




Giant Giant Kelp
Restoration Project


Global floating kelp forests have limited protection despite intensifying marine heatwave threats

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 Check for updates


Nur Arafah-Dalmau^{1,2,3,4,5} , Juan Carlos Villaseñor-Derbez^{1,6,7}, David S. Schoeman^{8,9}, Alejandra Mora-Soto^{5,10}, Tom W. Bell¹¹, Claire L. Butler¹², Maycira Costa¹⁰, Loyiso V. Dunga^{5,13,14,15}, Henry F. Houskeeper¹¹, Cristian Lager^{16,17}, Carolina Pantano¹⁸, Daniela Laínez del Pozo¹⁹, Kerry J. Sink^{14,15}, Jennifer Sletten²⁰, Timothe Vincent²⁰, Fiorenza Micheli^{1,21} & Kyle C. Cavanaugh²

Kelp forests are one of the earth's most productive ecosystems and are at great risk from climate change, yet little is known regarding their current conservation status and global future threats. Here, by combining a global remote sensing dataset of floating kelp forests with climate data and projections, we find that exposure to projected marine heatwaves will increase ~6 to ~16 times in the long term (2081–2100) compared to contemporary (2001–2020) exposure. While exposure will intensify across all regions, some southern hemisphere areas which have lower exposure to contemporary and projected marine heatwaves may provide climate refugia for floating kelp forests. Under these escalating threats, less than 3% of global floating kelp forests are currently within highly restrictive marine protected areas (MPAs), the most effective MPAs for protecting biodiversity. Our findings emphasize the urgent need to increase the global protection of floating kelp forests and set bolder climate adaptation goals.

Marine protected areas (MPAs) are a cornerstone of marine conservation¹. Promoted by international agreements, such as the Convention on Biological Diversity (CBD) Aichi Target 11², the area of marine ecosystems under some form of protection has increased since the turn of the century³. Because climate change is a major long-term threat to biodiversity^{4–6}, the newly agreed Global Biodiversity Framework at COP15⁷ calls for effectively protecting 30% of the oceans by 2030. A central component of the post-2020 targets is increasing the representation of different habitats under effective protection while adapting to climate change. Although many studies report the protection of critical habitat-forming species, such as corals, seagrass, and mangroves³, other essential marine habitats, such as kelp forests, remain largely neglected⁸ (but see refs. 9,10). Comprehensive maps on kelp forest distribution, threats associated with climate change,

extreme events, and protection status are urgently needed to guide ongoing local and global protection efforts.

Kelp forests dominate >30% of the world's rocky reefs and are among the most productive ecosystems on earth—comparable to terrestrial forests^{11–14}. However, marine heatwaves (MHWs) and anthropogenic activities threaten kelp forests^{15–18} and their capacity to provide ecosystem services worth billions of dollars^{19–22}. The IPCC Sixth Assessment Report identified kelp forests as the second most at-risk marine ecosystem from MHWs⁶, after coral reefs, which is concerning given that MHWs are projected to become more frequent and severe in the next decades²³. In addition, kelp forests are facing other stressors (e.g., pollution, overgrazing) that can reduce their ability to recover from heatwaves. For example, northern California has lost >90% of its kelp forests due to the combined effects of severe marine

A full list of affiliations appears at the end of the paper.  e-mail: n.arafehdalmau@uq.net.au

heatwaves and overgrazing by sea urchins^{24,25}. Climate adaptation strategies—including MPAs—are urgently needed to halt and reverse this loss^{16,26,27}. While MPAs cannot directly counter the impacts of climate change that can surpass a species' physiological tolerance²⁸, MPAs can mitigate non-climatic stressors like overfishing and habitat destruction, which can enhance ecosystem resilience^{29,30}, supporting ecological functioning and providing societal benefits^{31–33}.

Well-managed and highly restrictive MPAs—no-take marine reserves where all fishing activities are prohibited—are the most effective type of MPA for rebuilding fished populations³¹, supporting the stability of kelp forest ecosystems³⁴ and, in some documented cases, providing resilience to MHW impacts^{35–38}. For example, in regions where urchin predators are protected from fishing and where trophic cascades are a driver of food-web dynamics, MPAs can facilitate the recovery of higher-trophic-level organisms, which helps control kelp grazer populations and prevent overgrazing of kelp^{30,39,40}. This mechanism has been found to support resistance to and recovery from MHWs in a network of 39 MPAs in southern California³⁰. In addition, MPAs can provide climate resilience for kelp forests ecosystems through other mechanisms^{35–37,41–43}. For example, a recent global analysis found that fish communities were more stable to MHW in highly restrictive MPAs than unprotected sites³⁷, and abalone populations in two MPAs in Mexico were more resilient to a hypoxia event and MHWs through increased body size and reproductive output^{36,42}.

Monitoring subtidal kelp populations over large spatial and temporal scales can be challenging. However, the largest species (i.e., *Macrocystis pyrifera*, *Nereocystis leutkeana*, *Ecklonia maxima*) can be mapped by remote sensing because they create extensive canopies that float on the water surface. Recent advances in satellite imaging of surface-canopy-forming kelp species provide an opportunity to map the distribution of kelp forest habitats, quantify the threats posed by MHWs, and assess their protection status⁴⁴. Floating kelp forests are a globally distributed foundation species that co-exist with other sub-canopy kelp species that structure one of Earth's most biodiverse ecosystems⁴². These forests can cover thousands of hectares (e.g., 28,500 hectares in the Southern California Bight ecoregion¹⁰) and sustain hundreds to thousands of species, some of which are economically and culturally significant. For example, in the Channel Islands in Southern California, studies found 716 species associated with giant kelp forest ecosystems⁴⁵ and in Patagonia, Chile and Argentina, similar studies found between 150 and 250 species^{46–48}. In addition, in the northeast Pacific Ocean, 17 species of sub-canopy kelp coexist with floating kelp forests (www.algaebase.org/) from Alaska to Baja California, Mexico. Since remote sensing is the only available method to detect kelp forest ecosystems comprehensively (i.e., using standardized methods at large temporal and spatial scales), maps of floating kelps are good indicators of the broader ecosystem and associated biodiversity. These data can also inform other climate-adaptation strategies such as identifying and protecting climate refugia^{49,50}—areas less impacted by or more resilient to climate change—for kelp forests. Effectively protecting climate refugia for kelp forest ecosystems is a priority for conservation⁵¹ because, in these areas, biodiversity can persist⁴⁹ and may enhance the resilience of other kelp forests, depending on local and regional connectivity and life history-traits, by maintaining a source of recovery for impacted kelp habitats²⁶.

Here, we compile a comprehensive global map of floating kelp forest habitats (henceforth “kelp forests”) and leverage these datasets to project the global exposure of kelp forests to MHWs and assess their protection status within MPAs. To develop the global kelp forest map, we assemble existing regional and national remote-sensing datasets from Landsat observations (1984–present), supplemented with Sentinel-2 satellite imagery (2015–2019⁵²) (Supplementary Table 1; see methods). To project threats to kelp forests from climate change, we estimate future cumulative annual MHW intensities from an ensemble of sea surface temperature (SST) from 11 Earth System models, using

three climate scenarios generated under the IPCC Shared Socio-Economic Pathways (SSPs)⁵³ (see methods). We then quantify the global protection status and the representation of kelp forests at both country and biogeographic levels (i.e., realm, ecoregions⁵⁴) within MPAs categorized as highly, moderately, or less protected based on restrictions to extractive activities obtained from ProtectedSeas⁵⁵ (see methods). Our findings reveal increasing threats to all floating kelp forests from future MHWs, although some southern hemisphere forests may act as climate refuges. We also found that kelp forests remain largely unprotected within restrictive MPAs, the most effective type of MPA, which are poorly represented globally. These findings emphasize the urgent need to increase the global protection and effective representation of kelp forests and, given the scale of the threat posed by future MHWs, for bolder climate adaptation goals for kelp forests.

Results

Global distribution of kelp forests

We found floating kelp forest habitats in only 12 nations distributed across 6 biogeographic realms and 32 ecoregions, mostly in mid-latitudes in the Pacific, Atlantic, and Indian Oceans (Fig. 1a). Most of the kelp forests are located in five ecoregions, with 23.7% in Malvinas/Falklands, 20.9% in Channels and Fjords of Southern Chile, 12.8% in Southern California Bight, 10.3% in Kerguelen Islands, and 9.2% in Northern California; while 17 ecoregions combined account for only 1% of the distribution of kelp forests (Supplementary Fig. 1).

In the northern hemisphere, kelp forests can be found at their highest latitudes, overall, in the USA (– 61.4 °N), extending southward to their warm-distribution limit in Mexico (– 27 °N). In the southern hemisphere, kelp forests can be found at their lowest latitudes, overall, in Peru (– 13.6 °S), extending southwards to their cool-distribution limit in Chile (– 56 °S). Other warm-distribution limits of kelp forests in the southern hemisphere are located in Argentina, Namibia, South Africa, Australia, and New Zealand.

Contemporary and Future exposure of kelp forests to marine heatwaves

Projected future MHWs for kelp forests increase for each realm, ecoregion, climate scenario, and time (Figs. 1b and 2 and Supplementary Figs. 2 and 3). In the near term (2021–2040), kelp forests are projected to be subject to > 2 times higher exposure to cumulative MHW intensities compared to contemporary exposure, with similar values across climate scenarios (Supplementary Table 2–5). Projections suggest that these magnitudes will continue to intensify, and under SSP5-8.5, kelp forests could be subject to >6 to >16 times higher cumulative MHW intensities in the mid (2041–2060) and long term (2081–2100), respectively, compared to contemporary exposure (Supplementary Table 6). These magnitudes are ~2 to ~3 times higher than corresponding projections under SSP1-2.6 and SSP2-4.5, respectively. In the long term, even under SSP1-2.6 and SSP2-4.5, magnitudes are ~5.6 and ~9.6 times higher than contemporary exposure, respectively. Note that these estimations were derived from the mean cumulative MHW intensities ($n = 2156$ pixels) for each climate scenario and time frame, and then divided by the corresponding mean contemporary values.

The Arctic and the Temperate North Pacific realms are projected to be the most exposed to future MHWs under all climate scenarios, while Temperate South America and Temperate South Africa will be the least exposed (Fig. 1b), matching the general spatial patterns in contemporary exposure. Overall, the pattern is very similar across SSP scenarios, with the northern hemisphere experiencing nearly twice the exposure to future MHWs than the southern hemisphere (Fig. 2b). However, some differences emerge. We found a difference in the latitudinal pattern of exposure between the northern and southern hemisphere. Specifically, projections suggest a latitudinal pattern of increasing exposure to future MHWs from lower to higher latitudes in

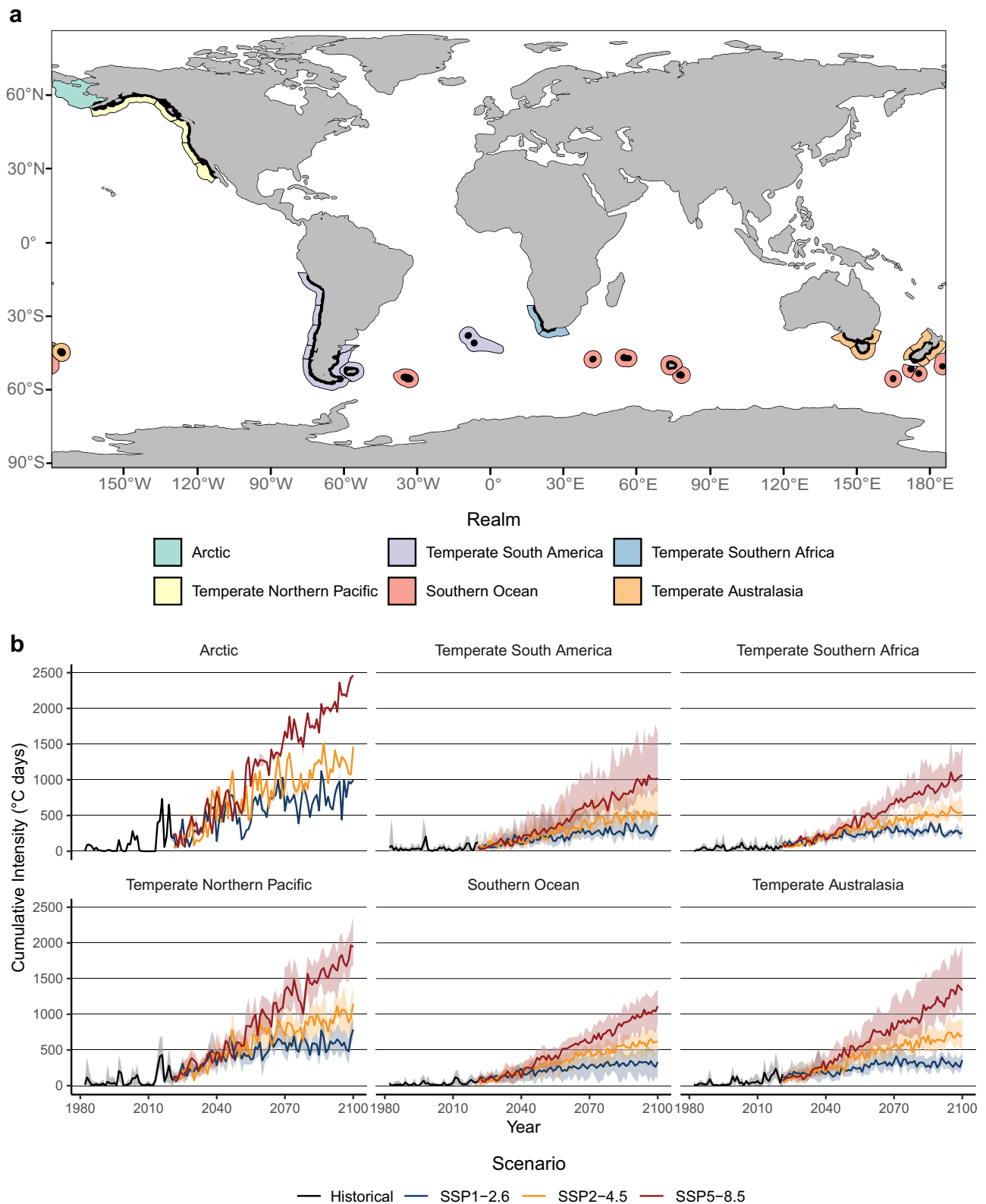


Fig. 1 | Global distribution of floating kelp forests and exposure to contemporary and future marine heatwaves. Panel (a) map of kelp distribution (black lines) across 32 biogeographic ecoregions (census⁵⁴) (polygons; the color indicates the realm to which they belong), (b) realm-specific exposure of kelp forest to historical (1982–2020) and future cumulative annual marine heatwave

intensities (2021–2100) across three climate scenarios under IPCC Shared Socio-Economic Pathways (SSP1-2.6, SSP2-4.5, SSP5-8.5). The solid line shows the mean across ensemble medians for all pixels, and the shaded area represents the 5th and 95th percentiles.

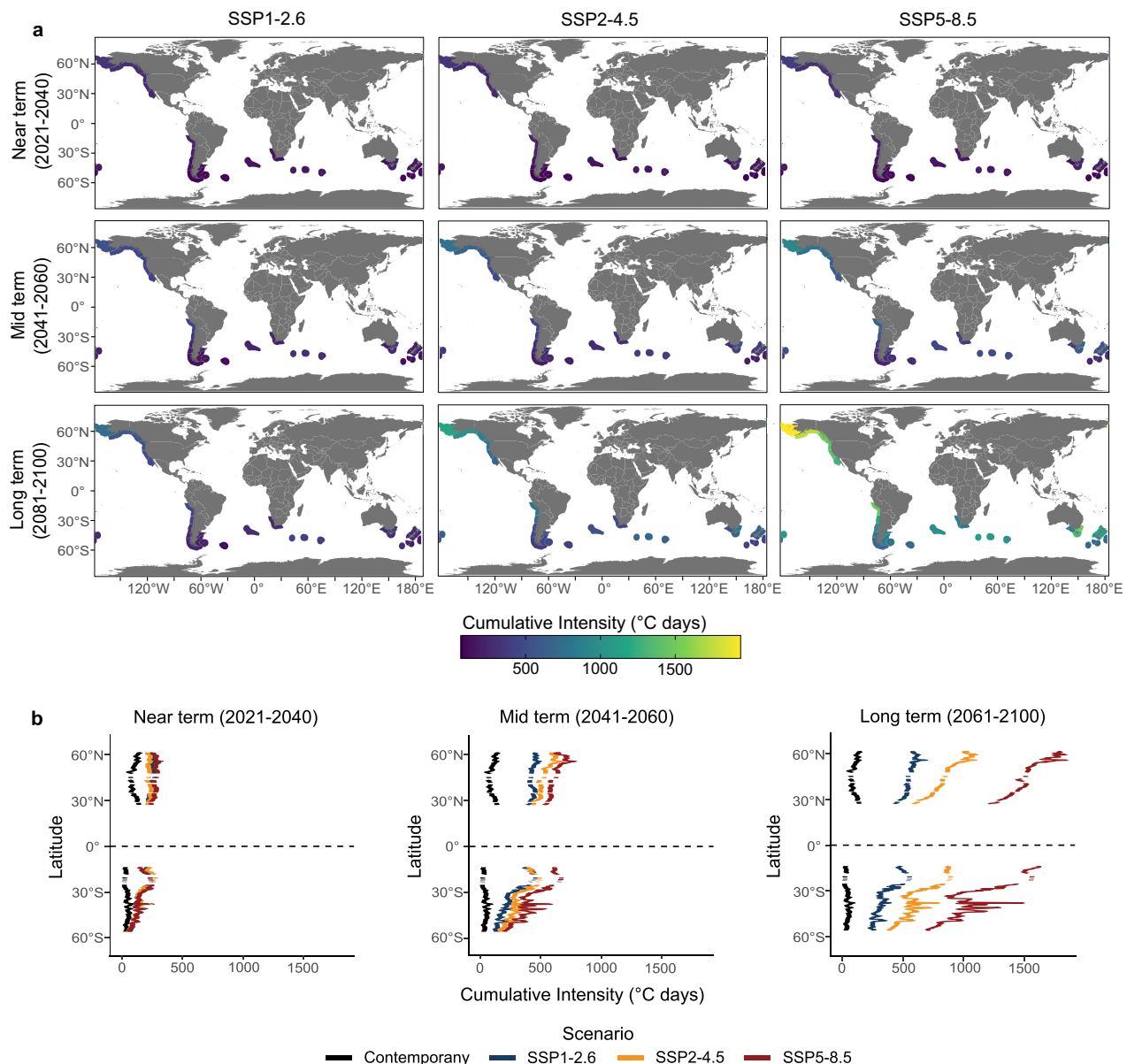


Fig. 2 | Ecoregional exposure of floating kelp forests to contemporary and future marine heatwaves. Panel (a) mean future cumulative annual marine heatwave intensity for all pixels in each of 32 ecoregions across three climate scenarios under IPCC Shared Socio-Economic Pathways (SSP1-2.6, SSP2-4.5, SSP5-8.5) and

three-time frames (near, mid, and long term). **b** Latitudinal plots representing mean cumulative annual marine heatwave intensities by 1° of latitude under contemporary (2001–2020) and climate scenarios for each time.

the northern hemisphere, whereas in the southern hemisphere, this pattern is reversed (Fig. 2b). For example, in the mid and long term and under all future scenarios for the northern hemisphere, the Eastern Bering Sea and the Gulf of Alaska are projected to become the most exposed ecoregions, while the southern California Bight becomes the least exposed (Fig. 2a and Supplementary Fig. 3), albeit with elevated levels of MHW exposure relative to the present. In contrast, in the southern hemisphere lower latitude ecoregions such as Cape Howe and Humboldtian are projected to be the most exposed to future MHWs while remote islands in high latitudes and ecoregions such as the Channels and Fjords of Southern Chile will be the least exposed.

Global protection status of kelp forests

Globally, more than 33.1% of floating kelp forest habitats are protected by MPAs, of which 13.7% are highly protected (the most effective type of MPA), 4.6% are moderately protected, and 14.8% are in less-

protected MPAs (Figs. 3a, b and 4a). However, most of the effective protection for kelp forests is in remote islands in the Southern Ocean realm (24,319.8 ha), and when excluding these areas, only 2.8% (5,870.9 ha) of the global kelp forests are highly protected from fishing activities (Fig. 3c). At the country level, France has placed all their floating kelp forests within highly protected MPAs (Fig. 4a, b) and is the only country that meets the current 30% effective representation target⁷. New Zealand, South Africa, Canada, Australia, and the USA have at least 10% of their kelp forests highly protected (Fig. 4a, b). However, this protection is in overseas territories in remote islands for all of France (23,007.1 ha, there is no floating kelp forests in mainland France) and much of New Zealand (145.1 ha), South Africa (285.1 ha), and Australia (78.7 ha). Australia has only 2.7% (23.0 ha), New Zealand 2.0% (14.1 ha), and South Africa (400.6 ha) 8.9% of their continental kelp forests highly protected. Mexico and the UK have provided

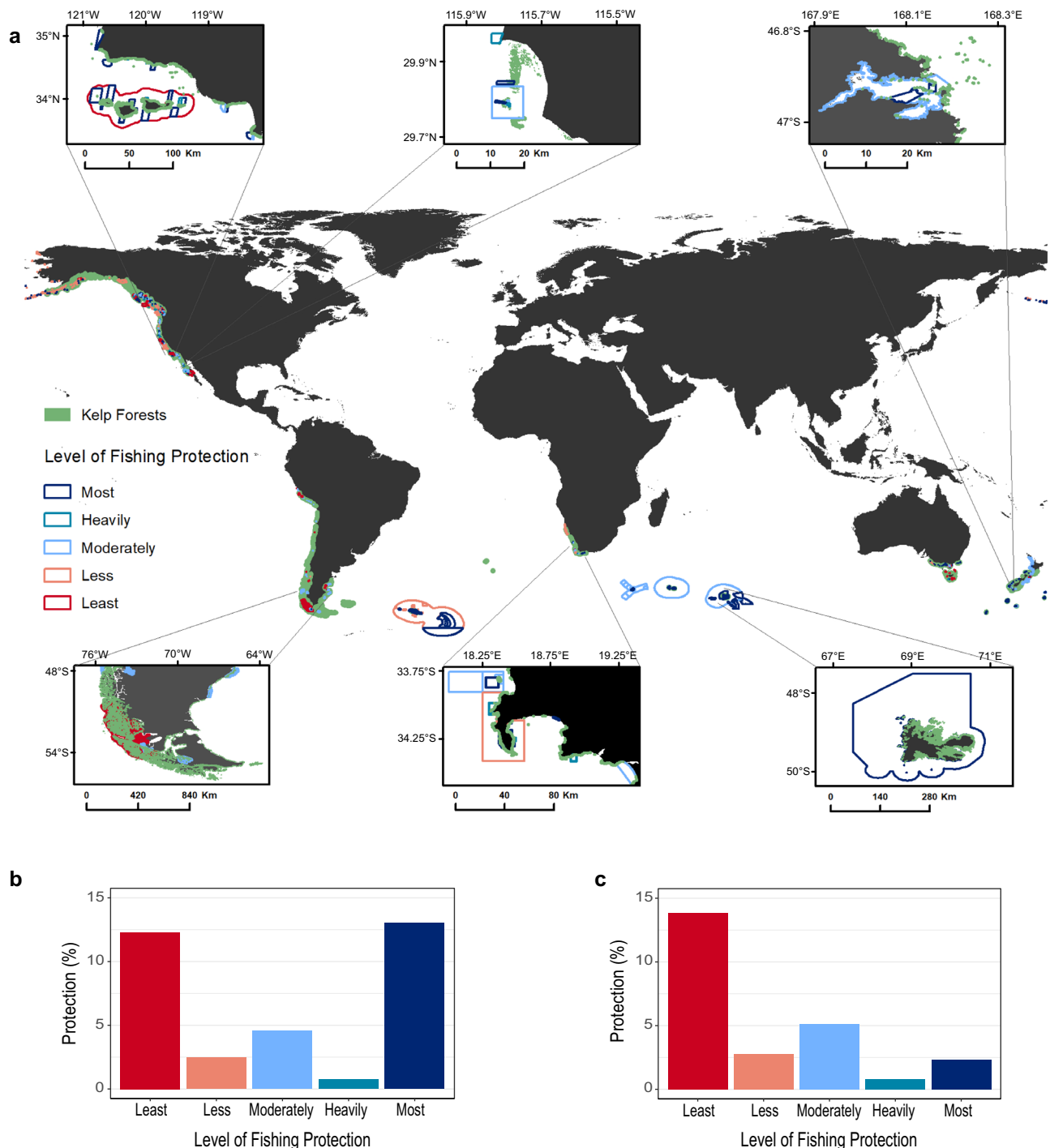


Fig. 3 | Global distribution of floating kelp forests and marine protected areas by categories of protection. a Global map of kelp forests and marine protected areas, we provide six fine-scale views. Starting from the top-left and moving clockwise: USA, Mexico, New Zealand, France (Kerguelen and Crozet Islands), South Africa, and Chile and Argentina. Global protection (%) of kelp by category of protection **(b)** including all realms and **(c)** excluding the Southern Ocean realm.

Protection categories are based on the Level of Fishing Protection (LFP)⁵⁵ score assigned to each marine protected area. The scores are divided in three categories: Lightly protected (LFP score of “Least” and “Less”), moderately protected, and highly protected (LFP score of “Heavily” and “Most”). Global basemap boundaries were derived from the ESRI ArcGIS World Countries Generalized shapefile.

effective protection for less than 2% of their kelp forests, Chile less than 0.02%, and Peru, Argentina, and Namibia none.

Of the world’s biogeographic realms, the Southern Ocean realm has 99.9% of its kelp forests within highly protected MPAs (which represents 11% of the global distribution, see Figs. 3c and 4), while all other realms have less than 10%. However, at least 10% of kelp forests are protected in some form of MPA in all realms, except for the Arctic,

where the area of surface-canopy forming kelp is minimal and no kelp forests are protected under any category (Fig. 4c). At the ecoregional level, only 9 ecoregions have met the old 10% effective representation targets² for kelp forests within highly protected MPAs, all in remote islands except for the Northern California ecoregion (Supplementary Fig. 4). Overall, 47.2% of ecoregions have less than 10% of their kelp forests protected, regardless of the MPA type. Only one nation, one

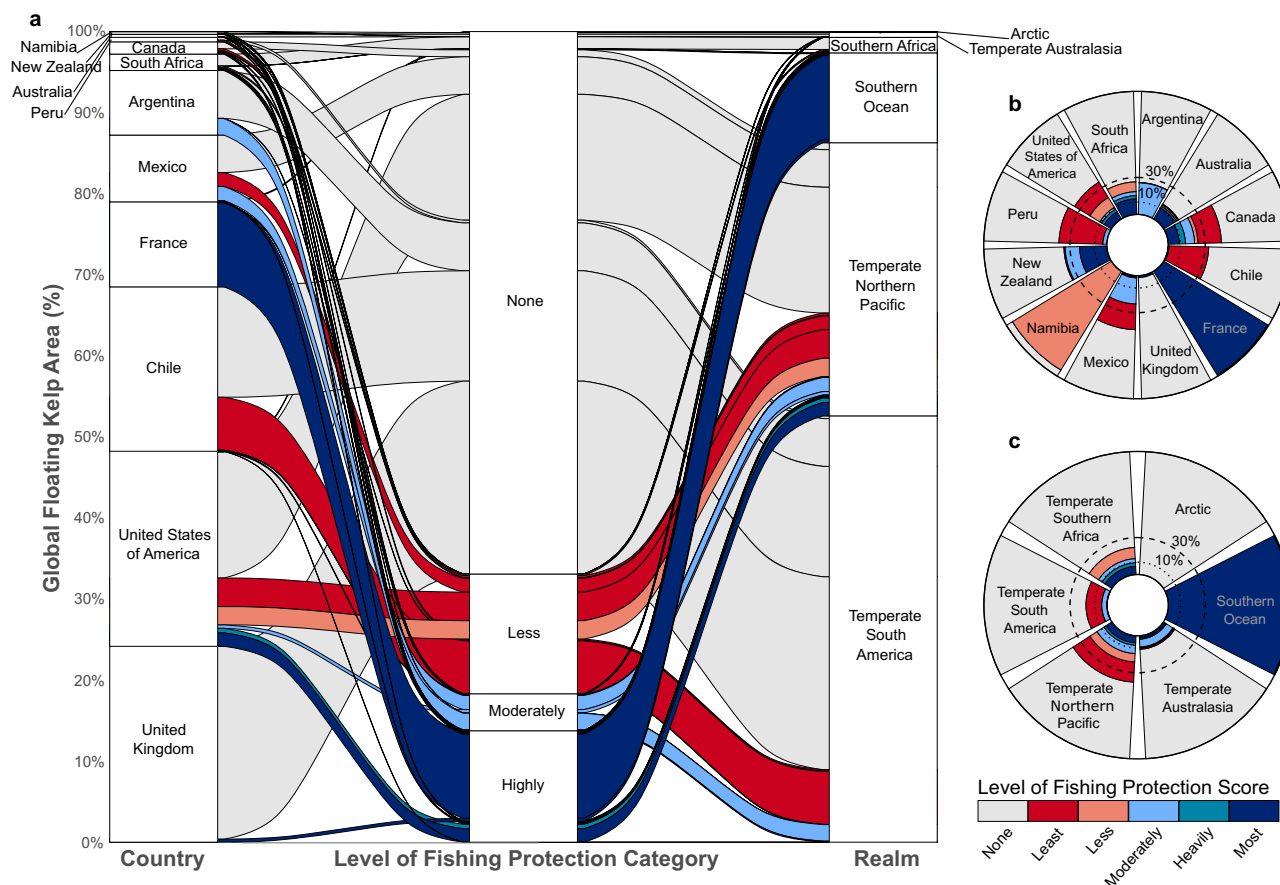


Fig. 4 | Global status and distribution of floating kelp forest protection.

a Alluvial diagram with the distribution and protection of kelp by country and realm (% of total area), and radial plots showing percentage protection of kelp at the level of **(b)** country and **(c)** biogeographic realm. Protection categories are based on the Level of Fishing Protection (LFP)³⁵ score assigned to each marine protected area. The dotted and dashed lines show the old 10%² and the current 30%⁷ effective

protection targets. Note that France and the United Kingdom have no floating kelp forests in their mainland and are all in their overseas territories in the Southern Ocean realm. We included the Malvinas/Falkland Islands as part of the United Kingdom territory, although we acknowledge that Argentina has ongoing legal claims for their sovereignty.

realm, and 25% of ecoregions (all remote islands) meet the new 30% target for effective representation⁷ for kelp forests.

Ecoregional future marine heatwave threats and protection status

Kelp forests within the ecoregions that are most threatened by projected MHWs and currently have low levels of effective protection (highly protected) include the Bering Sea (none protected), the Gulf of Alaska (0.6%), the North American Fjordlands (2.5%), the Puget Trough (0.09%), and the Oregon to Vancouver ecoregions (2.4%) (Fig. 5a, b and Supplementary Figs. 5 and 6). Northern California is the only ecoregion projected to be highly threatened by MHWs where at least 10% of kelp forests are inside highly protected MPAs. In contrast, eight ecoregions that have all their kelp forests inside highly protected MPAs will face low to intermediate threats from projected MHWs under the SSP2-4.5 scenario. These ecoregions are all located in remote islands of the Southern Ocean realm. When combining highly and moderately protected MPAs, the Patagonian Shelf and North Patagonian Gulfs ecoregions have at least 30% of their kelp forests protected and low exposure to MHWs (Fig. 5b).

Discussion

We present a global map of the protection status of floating kelp forest habitats, which allowed us to identify escalating climate change threats and important conservation gaps for kelp forest ecosystems globally. Although one nation and a few ecoregions are meeting current

international protection targets⁷ for kelp forests, many of these MPAs are in remote islands with low levels of exposure to contemporary and projected MHWs and few non-climatic threats⁵⁶. When kelp forests in remote islands are excluded, less than 3% of kelp forests are inside highly restrictive MPAs—no-take marine reserves—the most effective type of MPA for conserving biodiversity^{1,31} and for enhancing climate resilience^{29,30,35–37,39,42}. Thus, current global protection does not adequately account for anthropogenic pressures on kelp forest ecosystems. It is concerning that the kelp forests most exposed to current and projected MHWs have minimal protection, which suggests that their resilience is likely being compromised. Therefore, to achieve international conservation commitments and climate adaptation goals, most countries and ecoregions require additional investments to increase the area of kelp forest habitats that are effectively protected. This presents a unique opportunity for designing and implementing climate-smart MPAs²⁶.

Our study reveals that marine heatwaves will increasingly threaten kelp forests under all projected SSP scenarios and time frames. If greenhouse emissions are not mitigated, kelp forests could be exposed to >16 times the magnitude of contemporary exposure under extreme scenarios by the end of the century. That represents an increase of 2–5 °C in average ocean temperatures, which in some regions may permanently surpass physiological tolerances of kelp forests, impact their distribution, restructure associated ecological communities and impact the livelihood of local human communities^{4,15,17,19,20,57–60}. Note that our study assessed the exposure to

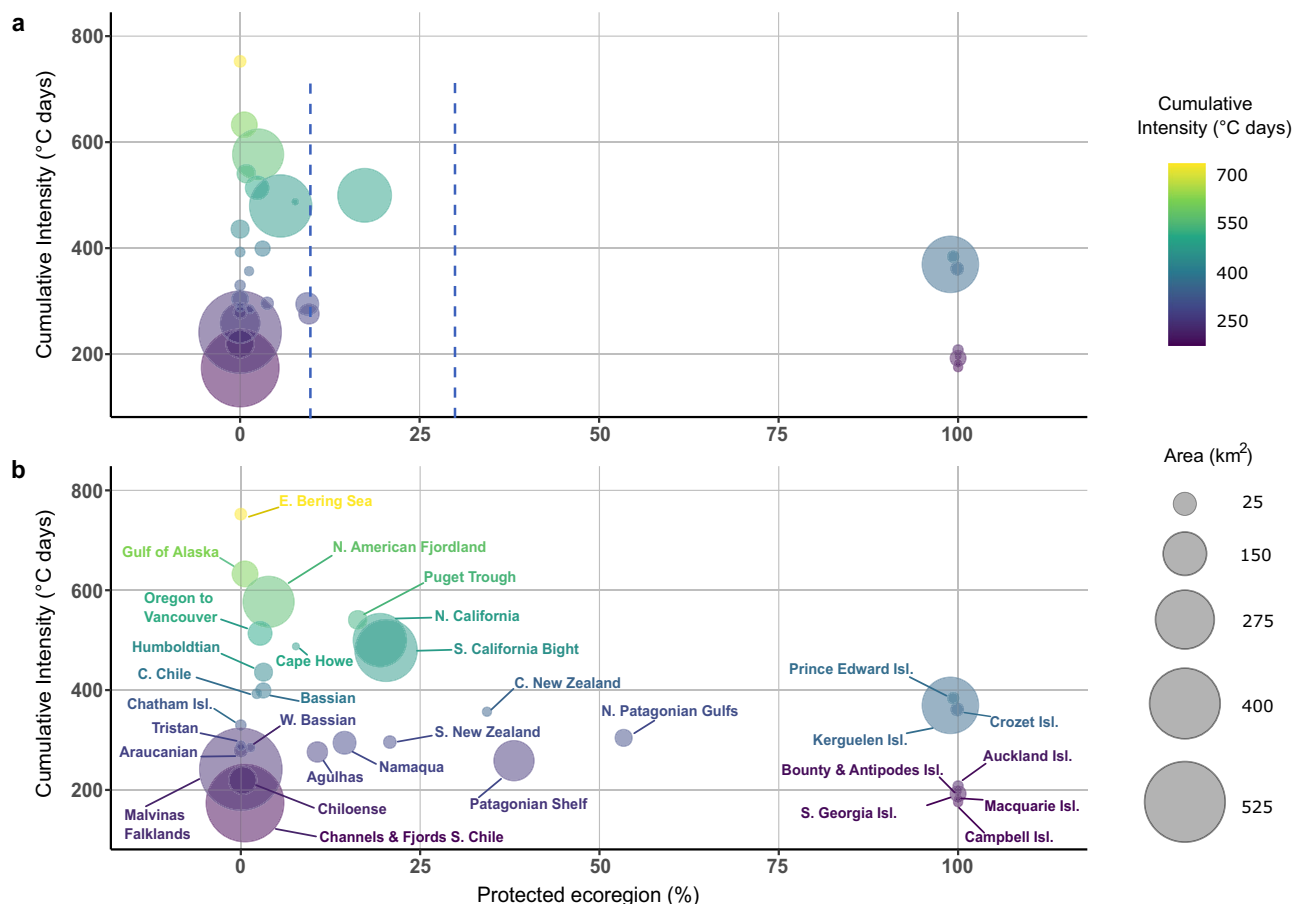


Fig. 5 | Relationship between threat posed by future marine heatwaves and level of protection for floating kelp forests. a Scatterplots of mean future cumulative annual marine heatwave intensities for the mid-term (2041–2060) under an intermediate IPCC Shared Socio-Economic Pathway (SSP2-4.5) climate scenario

and the amount of kelp forests highly protected, **(b)** highly and moderately protected combined. The size of the bubble indicates the amount of kelp in each ecoregion. The dashed blue vertical lines represent the old 10% and the current 30%⁷ targets for effective protection.

projected MHWs, not the vulnerability of kelp forests. While kelp forests near their current warm distribution limit will likely be the most affected and subject to range contractions^{15,58,61,62}, populations living further from their thermal tolerance limit may be less threatened, and novel climates may favor kelp expansion^{58,59}. However, cold-range populations subject to extreme MHWs could also be threatened because these populations may be less adapted to extreme temperatures⁶³. Moreover, the persistence of kelp forest ecosystems is not driven solely by available substratum and suitable temperatures but also by biotic interactions⁶⁴, and not all components of these ecosystems will necessarily respond in the same way. Predicting whether MPAs can provide resilience to kelp forest ecosystems under such extreme and persistent changes is therefore challenging on multiple fronts. However, for less-extreme emission scenarios that track current mitigation policies^{65,66}, the magnitude of exposure to future MHWs will be two times lower than for extreme scenarios. Under these conditions, it is more likely that marine reserves can support the resilience of kelp forest ecosystems.

MPAs cannot directly mitigate the impacts of MHWs that surpass the physiological thresholds of kelp forests; however, they can minimize other non-climatic threats, such as overfishing and habitat destruction, thereby promoting the recovery of kelp forests following MHWs. For example, after the 2014–2016 MHWs in the northeast Pacific Ocean, urchins overgrazed kelp forests and caused many of them to collapse into less biodiverse ecosystems^{16,25}. Studies in the Channel islands have shown that urchin barrens reduced sessile invertebrate diversity by 40% and almost completely lost canopy fish

assemblage⁴⁵. However, highly protected MPAs have promoted the resilience of kelp forests following MHWs by facilitating recovery of overfished predators that control urchin populations^{30,40}. Because the magnitude of future warming may cause the loss of kelp forests in some regions, MPAs will likely not be enough on their own to support the persistence of kelp forests. In these cases, supplementary climate-adaptation strategies will be necessary, particularly for areas of high exposure to future MHWs, such as regions in North America and especially areas near-warm distribution limits. These strategies include identifying and protecting climate refugia, restoring degraded kelp, identifying genetically resilient kelp stocks, and managing other anthropogenic impacts (e.g., land-based pollution) not mitigated by MPAs^{16,67}.

We identified areas that will likely act as climate refugia—projected to be less exposed to future MHWs—where kelp forests are likely to persist^{9,10,26,68}. We found that although many ecoregions with potential climate refugia have all their kelp forests protected inside MPAs, the Southern Fjordlands of Chile and the Malvinas/Falklands ecoregions have no protection and account for >40% of the global distribution of kelp forests. These ecoregions emerge as priority areas for global conservation of kelp forests, and efforts are needed to secure their effective protection and representation⁵⁶ before other non-climatic threats intensify and erode their resilience.

It is important to note that our analysis maps floating kelp forests, thus our method will not detect other kelp forest ecosystems when they do not co-occur with floating kelps. There are > 120

laminarian kelp species (many are intertidal), of which three of the largest kelp species form extensive floating canopies that can be detected by remote sensing, including the globally distributed *M. pyrifera*. Our estimates likely represent overall kelp forest distribution and ecosystem protection in regions where floating kelps co-exist with other sub-canopy kelp species (e.g., the west coast of North America, South America, and remote southern hemisphere islands, among others). However, some other nations and regions not included here have extensive kelp forest ecosystems that do not co-occur with floating kelp forests (the east coast of North America, northern Europe, and parts of Australia, among others). Given the limitations in detecting subsurface canopy kelp forests, they are likely less-well represented here than those detected by remote sensing. This is a substantial gap for kelp conservation and an avenue for novel technologies and research⁶⁹ to address associated needs for these kelp ecosystems that do not overlap with floating kelps, which also support diverse and productive ecosystems^{13,70} and human livelihoods²¹.

We also note that our compiled map may underestimate floating kelp habitat for those regions where regional maps are not yet available (e.g., Canada, Chile, New Zealand) because the global map covers a shorter time period than the regional Landsat data and so may miss kelp habitat that was not present between 2015 and 2019⁵². Therefore, the coverage of floating kelp reported here should be updated as new information becomes available. Nonetheless, the compilation of maps presented here represents the most thorough global satellite assessment of kelp forest extent to date.

Our analysis uses the distribution of present surface canopy kelp, and it does not account for range contractions or expansions of kelp forests that are projected under climate scenarios^{38,59}. Integrating future range shifts of kelp species and associated biodiversity under climate scenarios could guide the identification of climate-smart priority areas for kelp forest conservation²⁶. Finally, the MPA dataset used here has some limitations regarding the quantification of protection. For example, it does not account for other human activities that MPAs can manage (e.g., mining, dredging) or indicators of management efficiency (e.g., budget, capacity, stage of establishment)¹ that need to be included to ensure MPAs are effectively protecting ecosystems⁷¹. Therefore, including such information will likely decrease the coverage of kelp forests within MPAs with high levels of effective protection because many lack effective governance, enforcement, or community involvement⁷². However, a comprehensive dataset of protection effectiveness is currently unavailable for all countries and MPAs (e.g., <https://mpatlas.org/>), and to date, ProtectedSeas⁵⁵ is the most complete database available to assess the level of restriction inside MPAs.

Kelp forests remain largely excluded from most international conservation policies^{8,73}, despite their enormous contribution to earth's biodiversity^{12,13} and provisioning of ecosystem services²¹. Nations have an opportunity to harness, protect, and restore kelp forests^{27,74}, not only for their function as biogenic habitats and biodiversity hot spots¹³, but also to support their role in carbon sequestration and mitigation of climate change⁷⁵. In addition, kelp forests provide food and support the livelihoods of millions of people worldwide^{13,21}. As part of efforts to protect 30% of the oceans by 2030⁷, nations have an opportunity to explicitly include the representation of kelp forests in their national conservation policies²⁷. Where nations share ecoregions, transboundary management and coordination may also be needed²⁶. However, given the immediate and escalating threats posed by climate change^{15,17,57} and other anthropogenic stressors, representation, though essential, may not be enough to safeguard the persistence of kelp forests. It is paramount that kelp forests are protected in each ecoregion through representative, adequate, and well-connected networks of climate-smart MPAs that consider additional climate adaptation strategies²⁶.

Methods

Mapping kelp forests

We compiled existing published regional and national datasets of surface-canopy forming kelp derived using remote sensing observations (Supplementary Table 1). We accessed quality-controlled estimates of kelp canopy derived from individually classified scenes observed by up to four Landsat sensors: Landsat 5 Thematic Mapper (1984–2011), Landsat 7 Enhanced Thematic Mapper+ (1999–present), Landsat 8 Operational Land Imager (2013–present), and Landsat 9 Operational Land Imager-2 (2021–present). The applicable Landsat observations have pixel resolutions of 30 × 30 m and repeat times of 16 days (8 days since 1999 in most years because two Landsat sensors were operational). Classification of floating kelp canopy was derived by applying a globally robust random forest classifier to individual Landsat scenes⁷⁶. The compiled datasets include minor differences in methodologies and time periods, but they all cover approximately over 30 years (1984 onwards) (Supplementary Table 1). Kelp maps were created by compositing observations of kelp presence across this time series. The maps include most of the USA (California, Oregon, parts of Washington, and parts of Alaska) and all of Mexico, Peru, and Argentina (available at <https://kelpwatch.org/>)⁷⁶, most of the United Kingdom⁷⁷ (Malvinas/Falkland Islands), and most of Australia⁷⁸ (Tasmania). We included the Malvinas/Falkland Islands as part of the United Kingdom territory, although we acknowledge that Argentina has ongoing legal claims for their sovereignty.

For areas where the Landsat maps are not available, we supplemented the Landsat time series using available maps derived using empirical thresholding of Sentinel-2 satellite imagery. For the empirical Sentinel maps, kelp area was calculated using band-difference³² or band-ratio⁷⁹ relationships and released for global and South African extents, respectively. The method for the empirical map applied to global waters averages all the available images from the Sentinel-2 satellite sensor from 26 June 2015 to 23 June 2019 to create a cloud-free mosaic. It then applies band-difference thresholds to identify pixels likely containing floating kelp canopy and a land mask using global digital elevation models (ALOS and SRTM), discarding topography with elevation >0 m. This dataset was validated across 14 in situ sites in South America that cover a variety of coastlines and ecoregions, and with existing data at 151 locations that cover four continents⁵². To ameliorate some potential detection caveats, we excluded pixels that fell within a 30-m buffer relative to the coastline because the global map does not distinguish between intertidal green algae and floating kelp forests and estuaries can also be a source of false positives. See Supplementary Table 1 for the coastlines used to apply the 30-m buffer. All kelp datasets were converted from coordinates to shapefiles with ArcMap10.8 using the World Geodetic System 1984 (WGS84). Our final floating kelp habitat map includes any pixel the satellite detected kelp in the time series and represents the known presence of floating kelp habitat in the timeseries. We included all observations to avoid arbitrarily choosing a period to map the distribution of floating kelp forests because these ecosystems are highly dynamic⁷⁶ and we were interested in detecting potential kelp habitat. For example, in some places kelps may be expanding their distribution (cold-edges)^{58,59}, while in others places kelps may be in alternative stable states dominated by urchin barrens²⁴ (degraded kelp ecosystems) or by more heat tolerant subcanopy kelp species (competing with floating kelps) near warm-edges⁸⁰. These alternative stable states can shift, even after decades^{81,82}.

Exposure of kelp forests to contemporary and future marine heatwaves

We estimated the expected threat of climate change to kelp forests by calculating historical and projected cumulative annual MHW intensities for each kelp pixel using a baseline climatology of 1983–2012. Marine heatwaves are periods during which temperature exceeds the

90th percentile of temperatures seasonally during a baseline period and last for at least five consecutive days⁸³. To quantify the magnitude of present-day MHWs, we used the NOAA 0.25°-resolution Optimum Interpolation Sea-Surface Temperatures (OISST)⁸⁴ dataset (1982-present). Note that cumulative MHW intensities are an indicator of exposure^{23,26}, but they are not a measure of the vulnerability of species or ecosystems to MHWs.

We also considered MHW characteristics using SST outputs from each of 11 Coupled Model Intercomparison Project Phase 6 (CMIP6; Supplementary Table 6) Earth System models (ESMs) re-gridded to 0.25° resolution using bilinear interpolation in CDO (Climate Data Operators). For each ESM, we selected the Historical run to represent the recent past (1983–2014), and selected three future (2015–2100) climate scenarios generated under the IPCC Shared Socio-Economic Pathways (SPPs)⁵³: SSP1-2.6, SSP2-4.5, SSP5-8.5. SSP1-2.6 represents an optimistic scenario with a peak in radiative forcing at -3 W m^{-2} by 2100 (approximating a future with 1.8°C of warming relative to the pre-industrial temperatures, in line with the Paris Agreement). SSP2-4.5 represents an intermediate mitigation scenario with radiative forcing stabilized at -4.5 W m^{-2} by 2100 (approximating implementation of current climate policies, resulting in 2.7°C of warming by 2100). SSP5-8.5 represents an extreme counterfactual climate scenario with a continued rapid increase in greenhouse gas emissions resulting in radiative forcing reaching 8.5 W m^{-2} (and 4.4°C of warming) by 2100 and rising after that. We bias-corrected the SST dataset from each ESM relative to the corresponding ensemble mean of the Historical runs using the delta method (see⁸⁵). This method ensures that projections for each ESM blend smoothly to the end of the Historical runs for the reference period 1983–2014. We then determined which grid cells overlaid with kelp forests, and when the kelp cell had no corresponding SST data for the ESM models (because ESMs have relatively coarse resolution), we filled the cell using the inverse-distance-weighted mean of surrounding cells.

We then used the R package *heatwaveR*⁸⁶ to estimate historical (1983–2020) and projected (2021–2100) cumulative annual MHW intensity ($^\circ\text{C}$ days) for each pixel. Note that although we used OISST data to quantify contemporary MHW intensities, we used corresponding data from each ESM's historical run for the period 1983–2014 when quantifying projected MHW intensities. This was necessary because using ESM data in the baseline period for projections instead of the OISST data ensures like-for-like comparisons (i.e., modeled data vs modeled data), avoiding issues associated with variation in inter-ESM skill in representing daily variability in SST. We used annual cumulative intensities because they are a good indicator of the exposure of kelp forests to warm anomalies^{23,26}. We then estimated the median cumulative annual MHW intensity for each grid cell for the contemporary (2001–2020) period and across the 11 ESMs for the near- (2021–2040), mid- (2041–2060), and long-term (2081–2100) for each SSP and grid cell. Finally, we summarized trends in MHWs at the level of biogeographic realms and ecoregions⁵⁴ by conducting a spatial overlay (following the same approach as in the next sections).

Marine protected areas: level of fishing restriction

We obtained the spatial boundaries of MPAs using two different sources of information for the countries that have surface-canopy forming kelp forests. First, we downloaded MPA boundaries from official country-level agencies (Supplementary Table 1). We undertook extensive searches to ensure that we used the most updated official information, as global datasets can be less comprehensive at the country-level. We then categorized each MPA based on the level of restrictions to extractive activities (recreational, subsistence, and commercial fishing). We used the Level of Fishing Protection (LFP) score obtained from ProtectedSeas⁵⁵ (<https://protectedseas.net/>). This database scores MPAs based on fishing restrictions on a scale of 1–5 scale (1 = Least restricted: no known restriction to the removal of

life, 2 = Less restricted: at least one species-or gear-specific restrictions apply, 3 = Moderately restricted: several species -or gear-specific restrictions apply, 4 = Heavily restricted: marine life removal is mostly prohibited with a few exceptions, 5 = Most restricted: marine life removal is prohibited). ProtectedSeas further divides the scores into categories: an LFP score of 1–2 is categorized as less protected, 3 as moderately protected, and 4–5 as highly protected areas, the most effective type of MPA⁵⁵. Finally, we reviewed both country-level and ProtectedSeas datasets and, when needed, consulted country-level experts to ensure that all MPAs were included. We did not include other area-based measures not categorized as an MPA in the national dataset (e.g., fishery management areas). For a few MPAs (34 of 817) that had no LFP score, we reviewed existing information on restrictions on the removal of life and assigned a LFP score of less protected, moderately protected, or highly protected. We did not include other regulatory activities that MPAs can manage (e.g., mining, dredging, anchoring) or indicators of management efficiency (e.g., enforcement capacity, budget capacity, implementing management plan)¹ because such datasets are not comprehensively available for all countries.

Global kelp distribution and protection

To estimate the amount of kelp within each level of protection, we performed a spatial intersection of MPA types (LFP classification; 817 spatial features) and the global kelp forest distribution (428,400 spatial features). Spatial intersection is a computationally expensive operation, so avoiding trivial calculations can significantly improve performance. We therefore developed and implemented a nested, parallelized, and hierarchical intersection algorithm. The approach is “nested” because spatial layers are split based on national jurisdiction before performing the spatial intersection. The approach is “parallelized” because the country-level intersection operations can be performed across parallel computer cores. Finally, the approach is “hierarchical” because, even within a country, not all kelp forests may lie within an MPA and not all MPAs may contain kelp. We first use a simple and less computationally expensive spatial join to identify kelp forests and MPAs that do not overlap with each other and exclude them from the expensive intersection calculation. Kelp forests excluded in this step are categorized as “not protected”. Finally, we perform the spatial intersection between the kelp forests and MPAs that overlap. We then repeated this approach at the biogeographic realms and ecoregions as outlined by ref. 54. For all operations, we used unprojected coordinates (EPSG code 4326) that uses WGS84 datum and a spherical geometry engine (s2)⁸⁷ via the sf package⁸⁸ in R. Parallelization was done using the furr and future⁸⁹ package in R. We validated geometries throughout the pipeline using st_make_valid in sf; any invalid geometries were removed.

Knowing the location and amount of kelp protected, we proceeded to calculate the total extent of kelp by country, biogeographic realm, and ecoregion, and by MPA category and LFP score. We also determined how much kelp was outside any protection. All spatial analyses were performed in R version 4.3.1 (2023-06-16)⁹⁰ using a x86_64-apple-darwin20 platform running macOS Ventura 13.4.1 and using the sf package v1.0^{88,91} with GEOS 3.11.0, GDAL 3.5.3, and PROJ 9.1.0.

Ecoregional marine heatwave threats under SSP2.4-5 and kelp representation

Our final analysis assessed the relationship between the threats posed by projected future MHWs to kelp forests and the amount (% area) protected in each ecoregion. We conducted this analysis at the ecoregional scale because, ideally, networks of MPAs should be established to protect the underlying biophysical processes that maintain species distribution and composition²⁶. Areas with low values of projected future MHW intensities are potential climate refugia for kelp forests. For simplicity, our measure of threat is focused only on the average

cumulative MHW intensity under one SSP for each timeframe. We used SSP2-4.5 as an intermediate climate scenario that reflects less extreme outcomes and has been proposed to inform climate adaptation and policy^{65,66}. Because the patterns of threat for each ecoregion are similar across time frames (i.e., magnitude is the largest difference across times), we focus in the main text on the mid-term and include results of the other times in the Supplementary information. We report results most conservatively for highly protected kelp, and then also for highly and moderately protected kelp combined. We did not include less protected MPAs in this analysis because this type of MPA provides minimal to no protection to marine ecosystems from extractive activities¹.

Data availability

The remote-sensing kelp forest dataset is available at <https://portal.edirepository.org/nis/mapbrowse?packageid=knbn-lter-sbc.74.13>, <https://kelpwatch.org/map>, and <https://biogeoscienceslaboxford.users.earthengine.app/view/kelpforests>. The marine protected area database is available at <https://protectedseas.net/> upon request. The marine ecoregions of the world dataset is available at <https://databasin.org/datasets/3b6b12e7bcc419990c9081c0af254a2/>. The compiled global floating kelp forest map and the processed marine protected area layer is available at Zenodo under the identifier <https://doi.org/10.5281/zenodo.14796879>. The raw data from figures and tables in this study are provided in the Source Data file. Source data are provided with this paper.

Code availability

The codes used for this project is available at zenodo repository: <https://doi.org/10.5281/zenodo.14796879>⁹².

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Author contributions

N.A.-D. conceived the study with inputs from J.V.-D., D.S., F.M., and K.C. A.M.-S., T.B., H.H., L.D., C.B., and K.C. provided remote-sensing floating kelp forest datasets. J.S., and T.V. provided marine protected area

datasets. N.A.-D., J.V.-D., and D.S. conducted analyses. N.A.-D. led reviewing nation-level marine protected area database with the support of A.M.-S., L.D., K.S., C.P., D.P., and C.L. N.A.-D. led the writing of the manuscript with the support of D.S., J.V.-D., F.M., and K.C. A.M.-S., T.B., C.B., M.C., L.D., H.H., C.L., C.P., D.P., K.S., J.S., and T.V. contributed to reviewing and editing of the manuscript.

Competing interests

All other authors declare they have no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Nur Arafeh-Dalmau.

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¹Oceans Department, Hopkins Marine Station, Stanford University, Pacific Grove California, USA. ²Department of Geography, University of California Los Angeles, Los Angeles California, USA. ³Centre for Biodiversity Conservation, School of the Environment, University of Queensland, St. Lucia, QLD, Australia. ⁴MasKelp Foundation, Monterey California, USA. ⁵IUCN Species Survival Commission, Seaweed Specialist Group, Gland, Switzerland. ⁶Department of Environmental Science and Policy, Rosenstiel School of Marine, Atmospheric & Earth Science, University of Miami, Miami, FL, USA. ⁷Frost Institute of Data Science & Computing, University of Miami, Miami, FL, USA. ⁸Ocean Futures Research Cluster, School of Science, Technology and Engineering, University of the Sunshine Coast, Maroochydore, QLD, Australia. ⁹Department of Zoology, Centre for African Conservation Ecology, Nelson Mandela University, Gqeberha, South Africa. ¹⁰Department of Geography, University of Victoria, Victoria, British Columbia, Canada. ¹¹Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, Woods Hole, MA Massachusetts, USA. ¹²Institute of Marine and Antarctic Studies, University of Tasmania, Tasmania, Australia. ¹³University of Cape Town, Cape Town, South Africa. ¹⁴South African National Biodiversity Institute, Kirstenbosch Cape Town, South Africa. ¹⁵Institute for Coastal and Marine Research, Nelson Mandela University, Gqeberha, South Africa. ¹⁶Universidad Nacional de Córdoba, Facultad de Ciencias Exactas, Físicas y Naturales, Ecología Marina, Córdoba, Argentina. ¹⁷Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Instituto de Diversidad y Ecología Animal (IDEA), Córdoba, Argentina. ¹⁸Fundación Por El Mar (PEM), Buenos Aires, Argentina. ¹⁹Sociedad, Ecología y Cultura, Lima, Perú. ²⁰ProtectedSeas, Anthropocene Institute, Palo Alto California, USA. ²¹Stanford Center for Ocean Solutions, Stanford University, Pacific Grove California, USA. ✉ e-mail: n.arafehdalmau@uq.net.au