A century of loss & resilience: Understanding the spatio-temporal drivers of Haida Gwaii kelp forests

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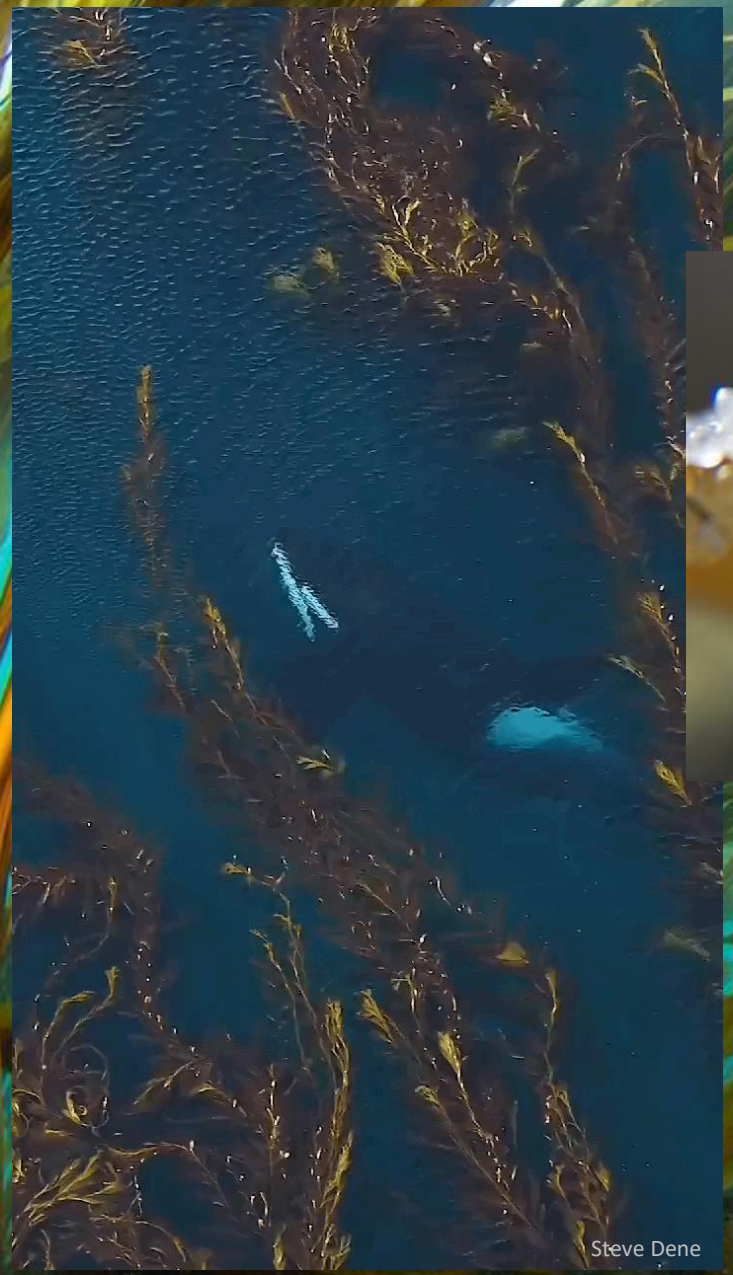
We would like to acknowledge with respect the Muwinina peoples, on whose traditional land we are on.

We acknowledge and respect the lək̓ʷəŋən peoples, the Songhees, Esquimalt and W̱SÁNEĆ Nations on whose traditional territory the University of Victoria stands.

We also acknowledge the Haida peoples on whose territory this research takes place and whose relationship and stewardship of the land and sea continues to this day.



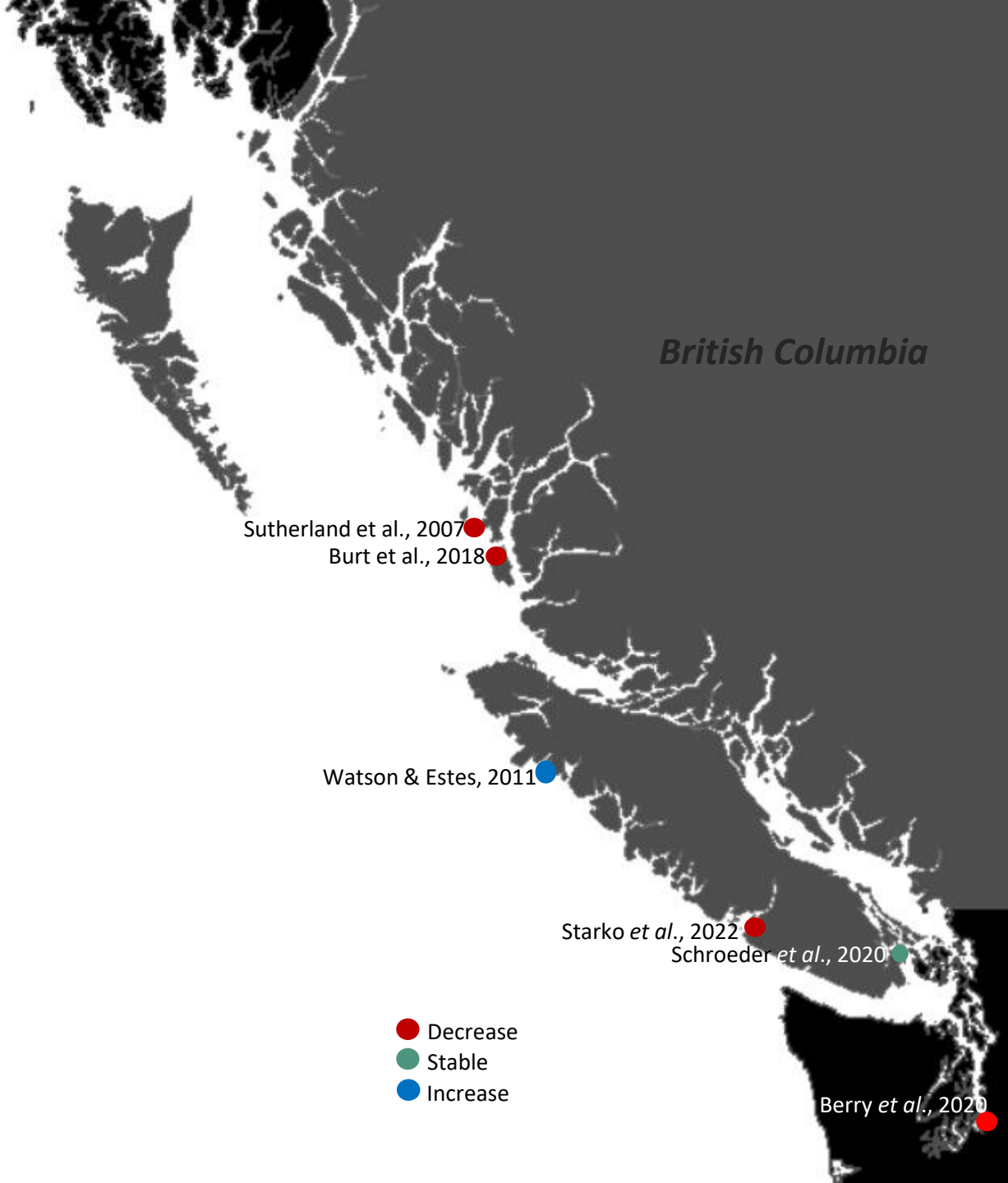
Steve Dene

MILLERMARINE
DIVINGSERVICES

Only some areas of the British Columbia have been mapped meaning…

Research Context

The large-scale trends of kelp distribution and drivers of change still remain largely unknown.

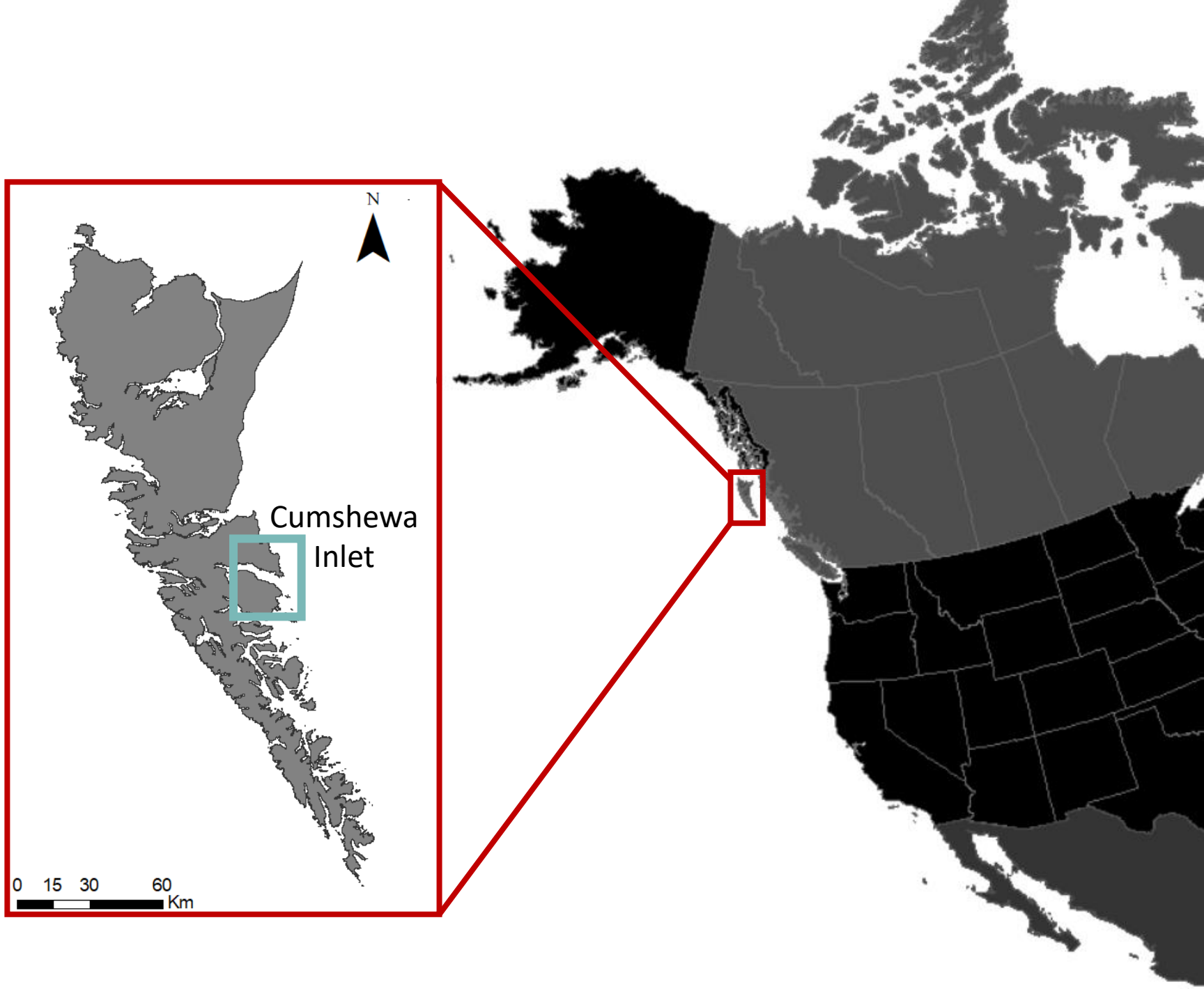


SPECTRAL
Remote Sensing Laboratory

Kelp Resilience (KELPR) Project

Goal: *Historical data + modern day remote sensing data to understand the spatial and temporal trends of BC's kelp forests and drivers of change.*

What are the spatial and temporal trends and drivers of change of Haida Gwaii kelp forests?



Nautical charts

Satellite & Aerial Imagery

1870

1949

1973

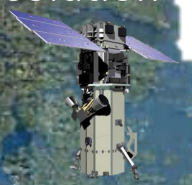
2005

2021

Costa *et al.*, 2020

Medium resolution

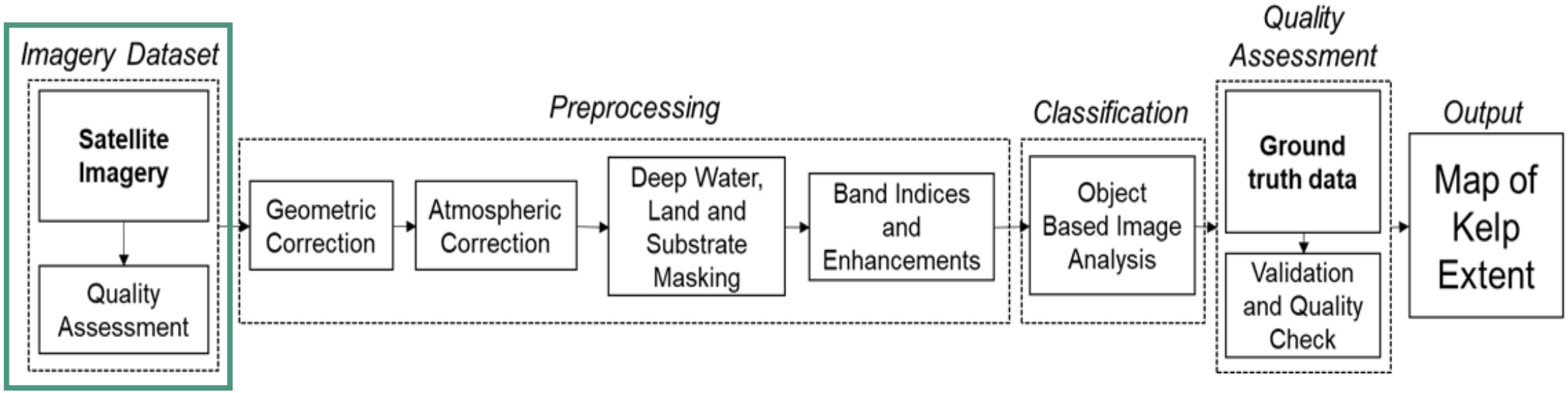
High resolution

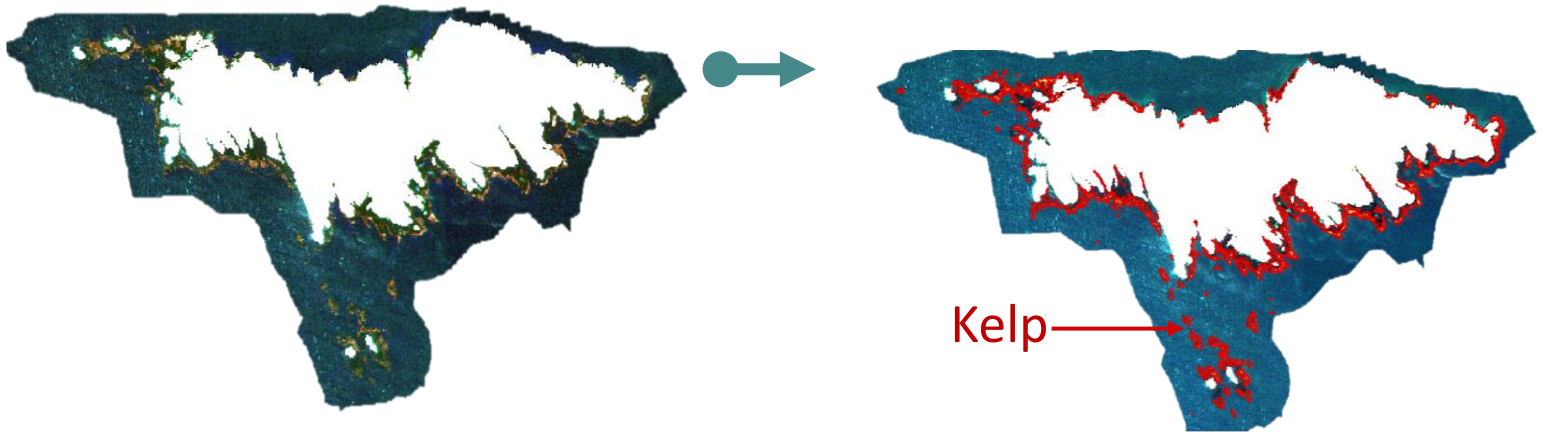


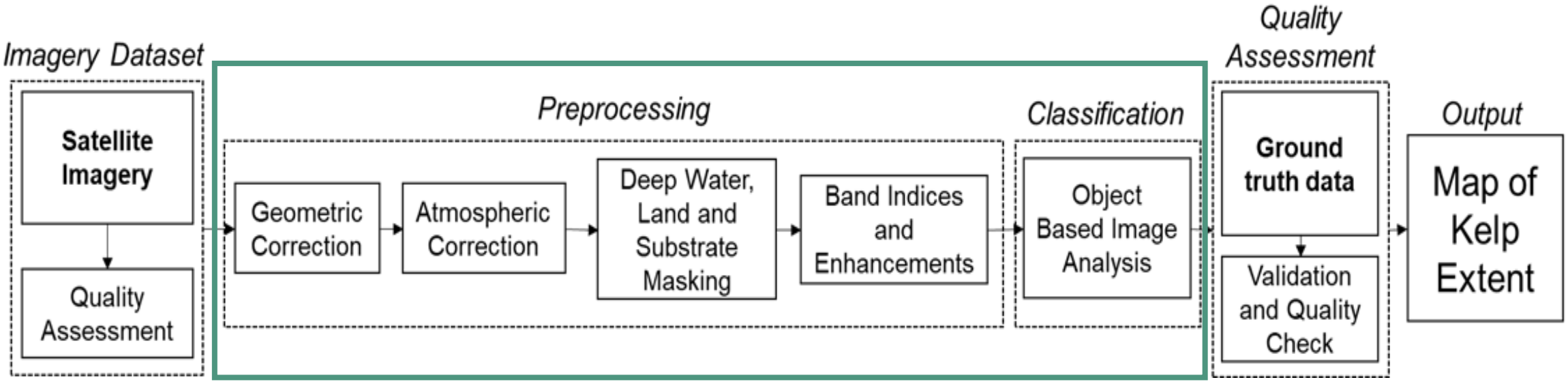
Low Resolution

High Resolution

Landsat	Sentinel-2	SPOT 1-7	RapidEye	Quickbird-2	Geoeye-1	Worldview 2,3	PlanetScope	Aerial Imagery
1973-Present	2017- Present	1996-Present	2009- Present	2001-2015	2008-Present	2009-Present	2018-Present	1980s-Present



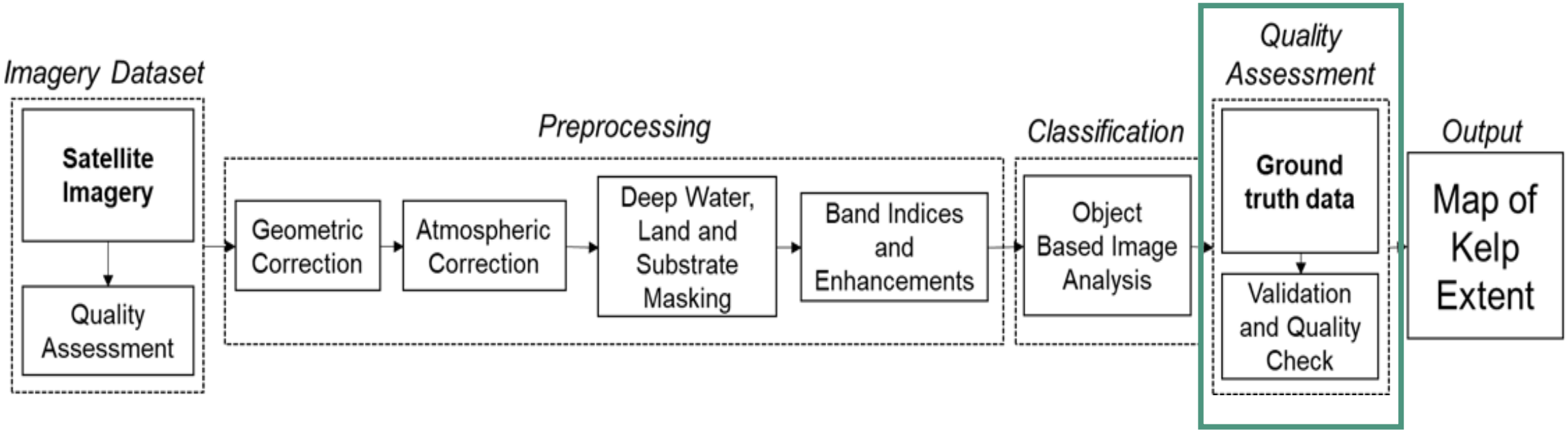

Kelp


Imagery Dataset
Satellite Imagery
Quality Assessment
Preprocessing
Geometric Correction
Atmospheric Correction
Deep Water, Land and Substrate Masking
Band Indices and Enhancements
Classification
Object Based Image Analysis
Quality Assessment
Ground truth data
Validation and Quality Check
Output
Map of Kelp Extent

Fisheries and Oceans Canada

ShoreZone

Environment and Climate Change Canada



Fisheries and Oceans Canada

Environment and Climate Change Canada

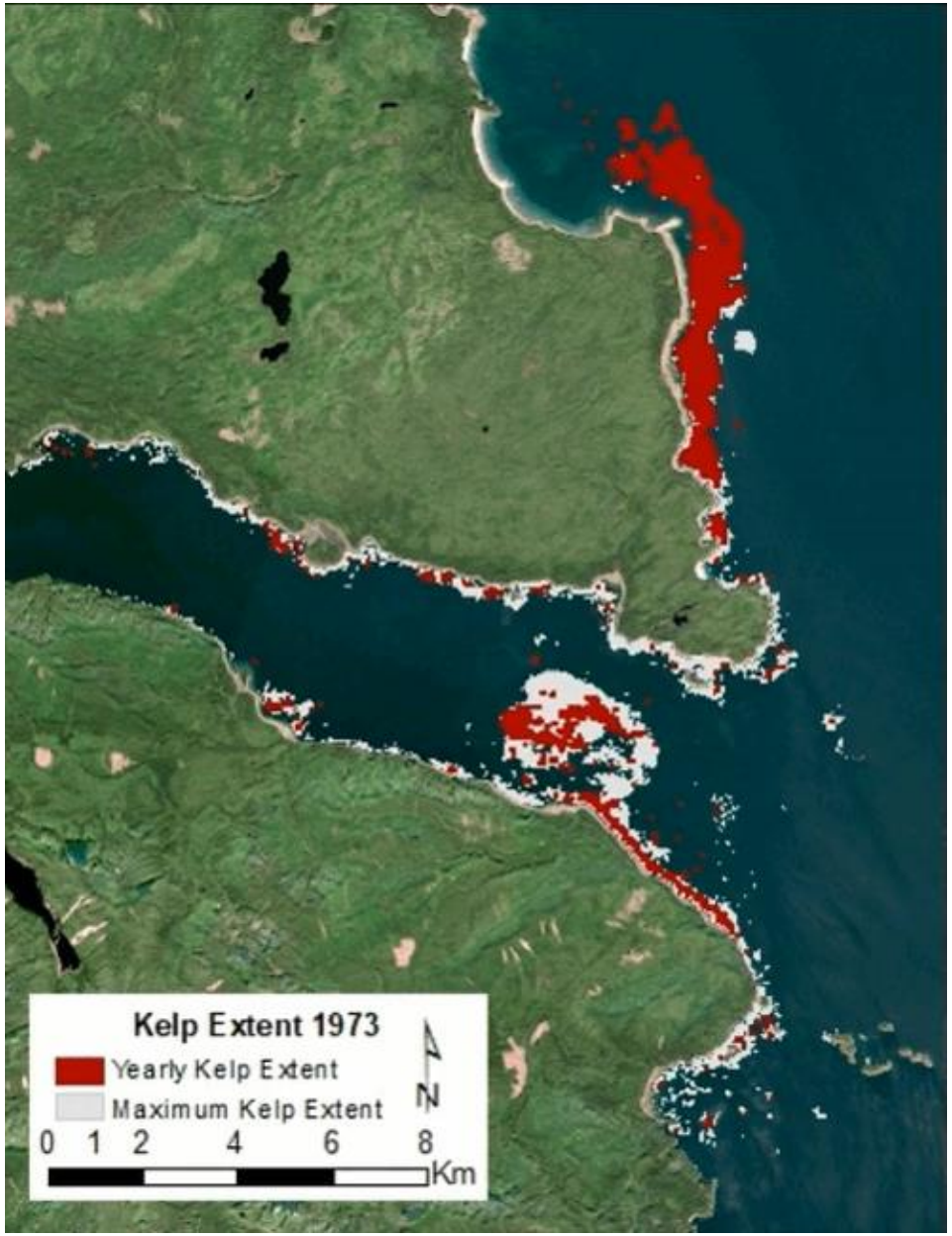
ShoreZone

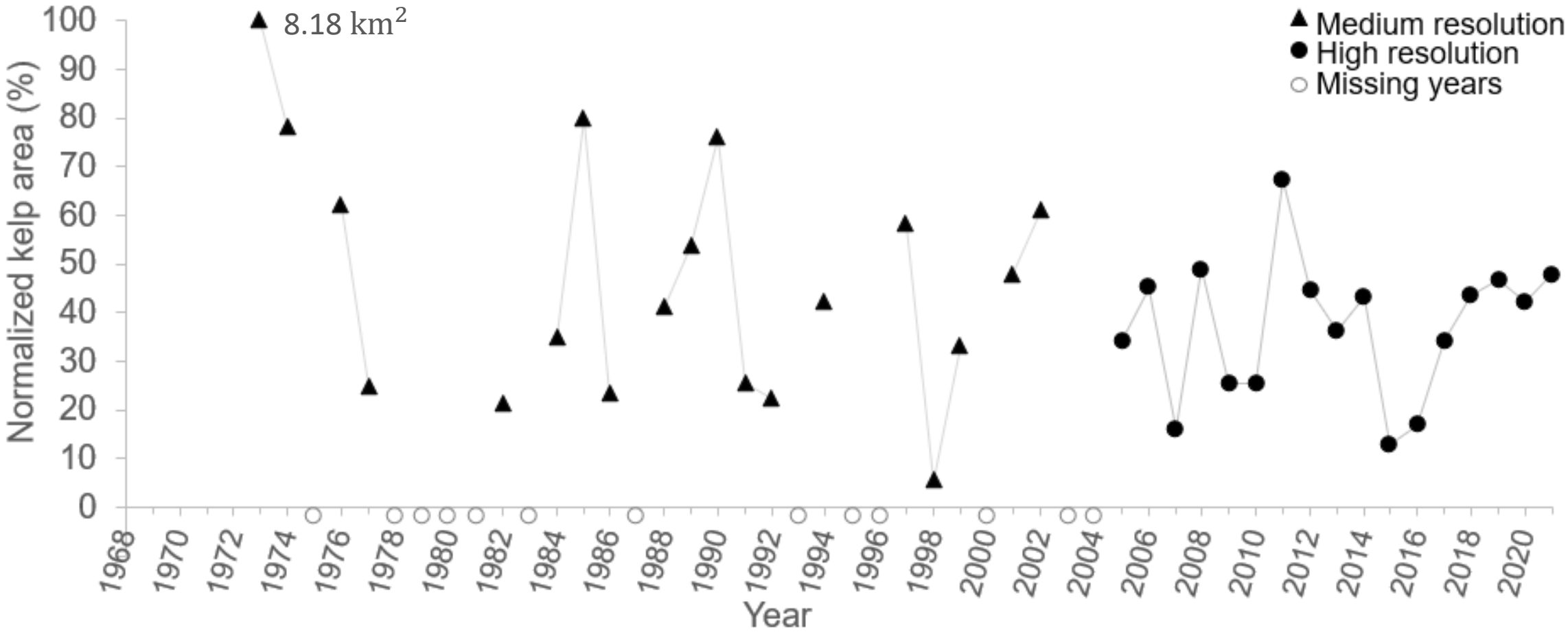
Timing	*Satellite (Resolution)*	*Kelp User's Accuracy*	*Kelp Producer's Accuracy*	*n=*	*Non-Kelp User's Accuracy*	*Non-Kelp Producer's Accuracy*	*n=*	*Global Accuracy*	*n=*
Concurrent	**PlanetScope**	100	92	171	70	100	30	94	201
	Spot 7	100	88	64	86	100	48	93	112
	Landsat-5	97	82	113	64	92	39	89	152
	Aerial	100	83	6	75	100	3	88	9
	Rapid Eye	100	88	7	100	100	1	88	9
Non-Concurrent	**Quickbird-2**	90	96	47	95	89	45	92	92
	Geoeye-1	95	89	64	77	89	27	89	91
	Worldview-2	98	84	50	85	98	46	91	96

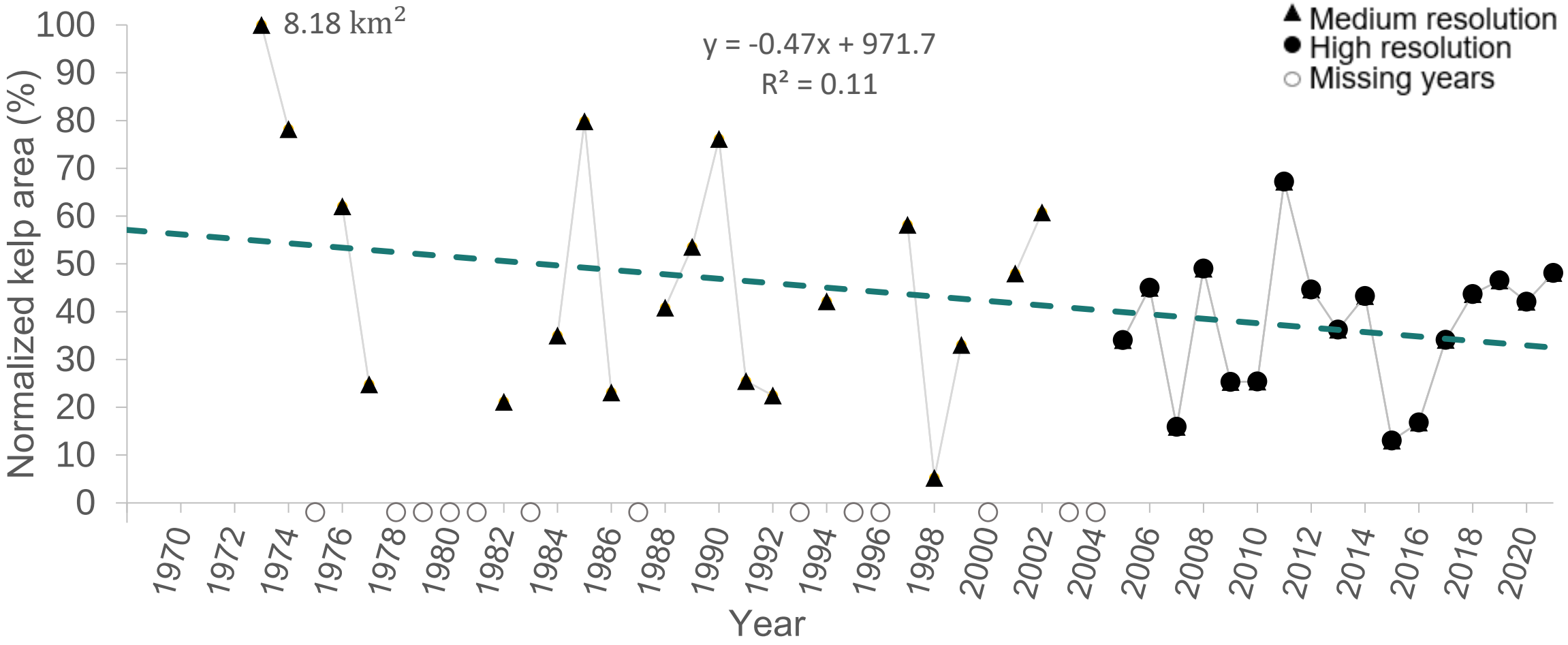
Scale of analysis

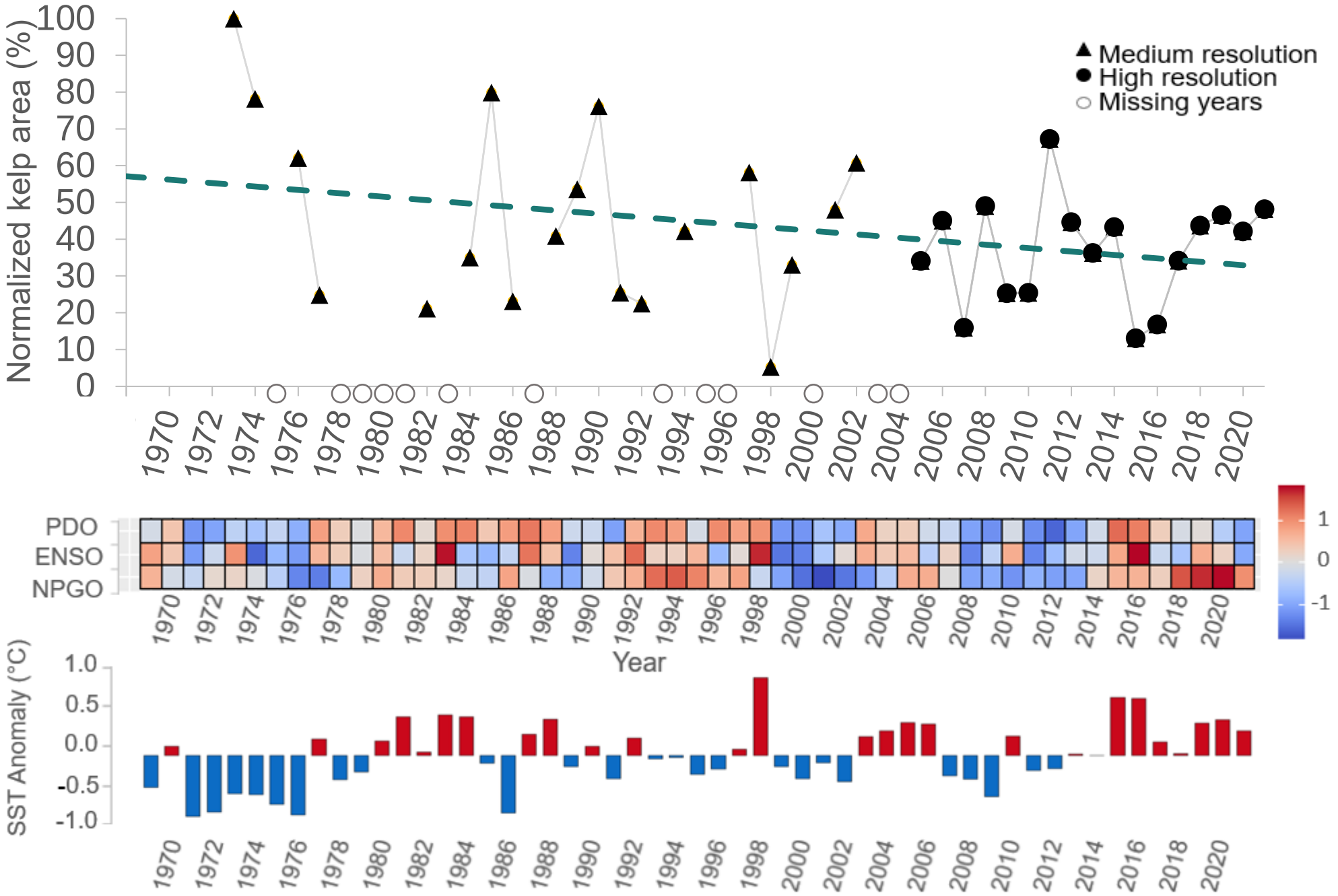
Regional – Entire study region

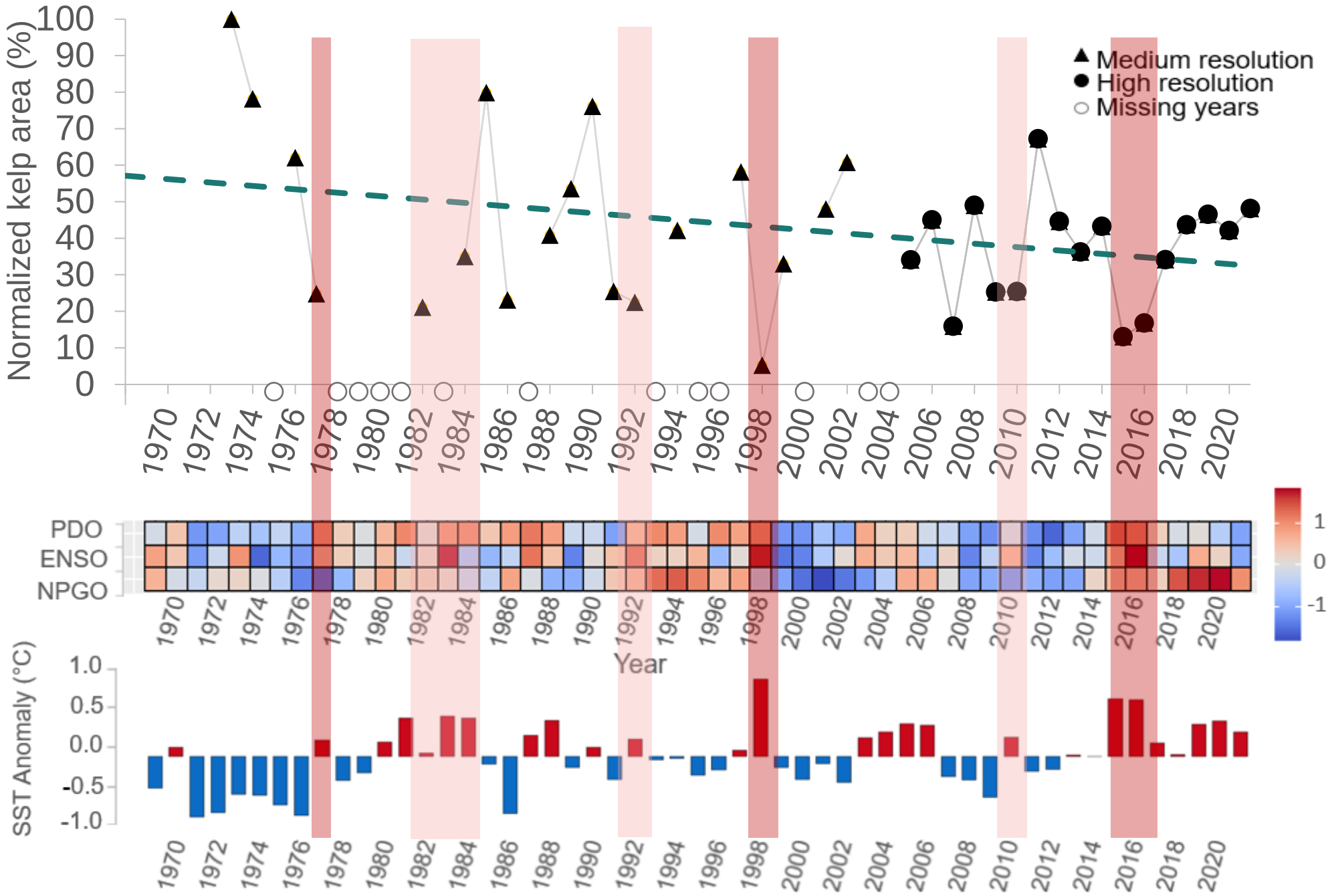
Subregional

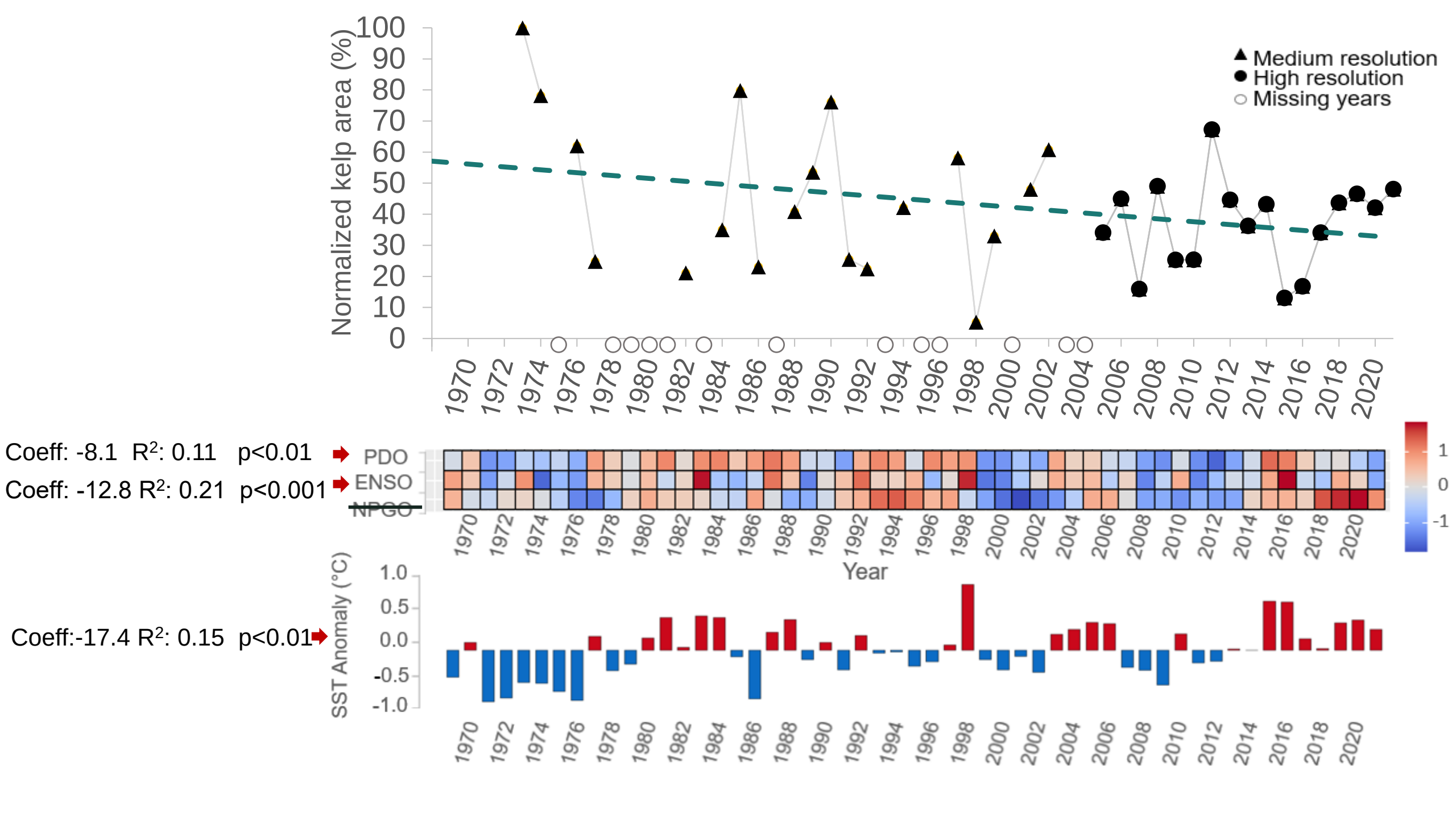

Kelp Extent 1973
Yearly Kelp Extent
Maximum Kelp Extent
N
0 1 2 4 6 8
Km


8.18 km2
Medium resolution
High resolution
Missing years
Normalized kelp area (%)
Year
100
90
80
70
60
50
40
30
20
10
0
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020


8.18 km²
y = -0.47x + 971.7
R² = 0.11
Medium resolution
High resolution
Missing years
Normalized kelp area (%)
100
90
80
70
60
50
40
30
20
10
0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year


Normalized kelp area (%)
100
90
80
70
60
50
40
30
20
10
0
Medium resolution
High resolution
Missing years
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
PDO
ENSO
NPGO
1
0
-1
Year
SST Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0

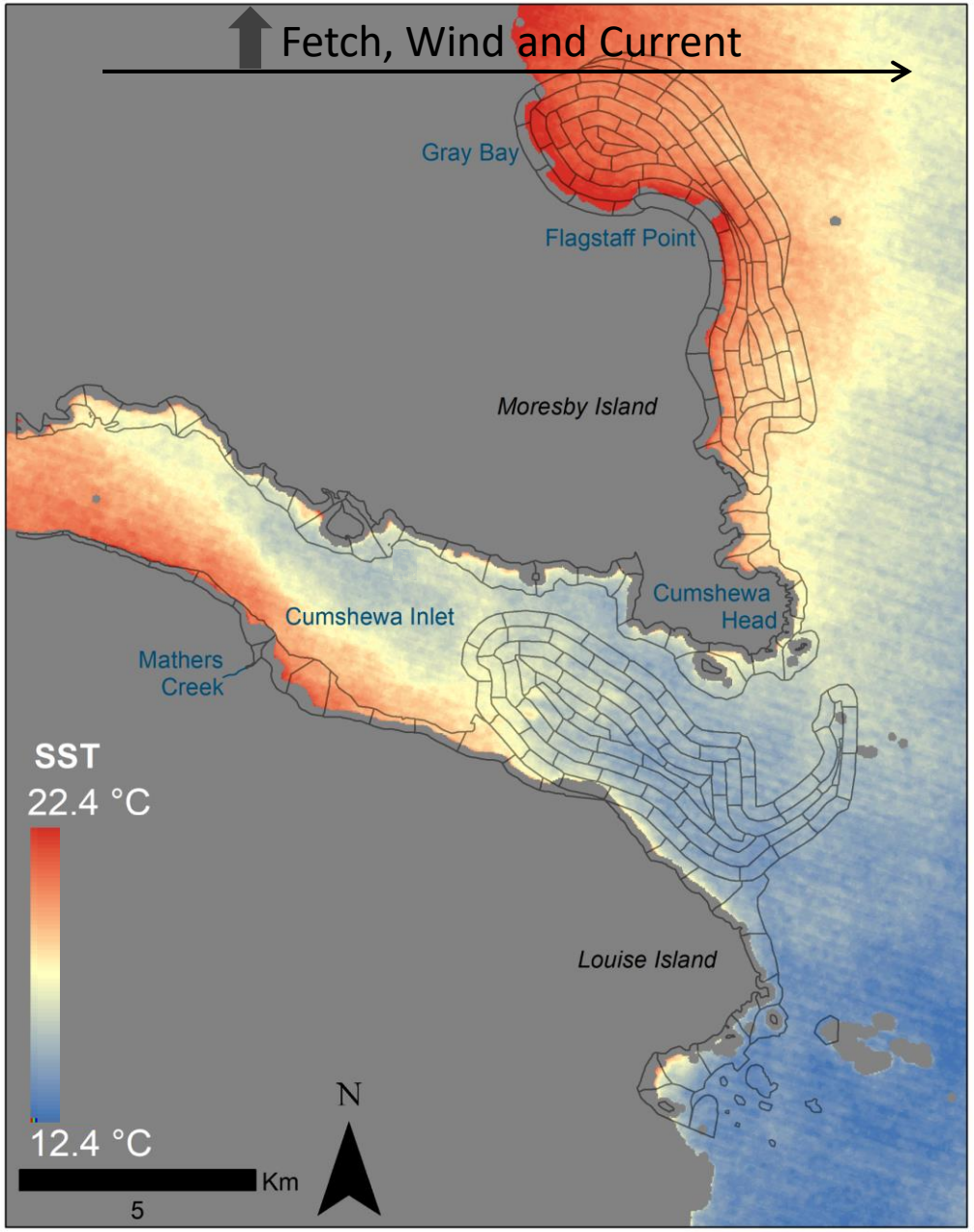

Normalized kelp area (%)
100
90
80
70
60
50
40
30
20
10
0
Medium resolution
High resolution
Missing years
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
PDO
ENSO
NPGO
1
0
-1
Year
SST Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0


Normalized kelp area (%)
100
90
80
70
60
50
40
30
20
10
0
Medium resolution
High resolution
Missing years
1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020
Coeff: -8.1 R²: 0.11 p<0.01
Coeff: -12.8 R²: 0.21 p<0.001
PDO
ENSO
NPGO
1
0
-1
Year
Coeff:-17.4 R²: 0.15 p<0.01
SST Anomaly (°C)
1.0
0.5
0.0
-0.5
-1.0

Scale of analysis

Regional – Entire study region

Subregional – Areas experiencing similar local conditions



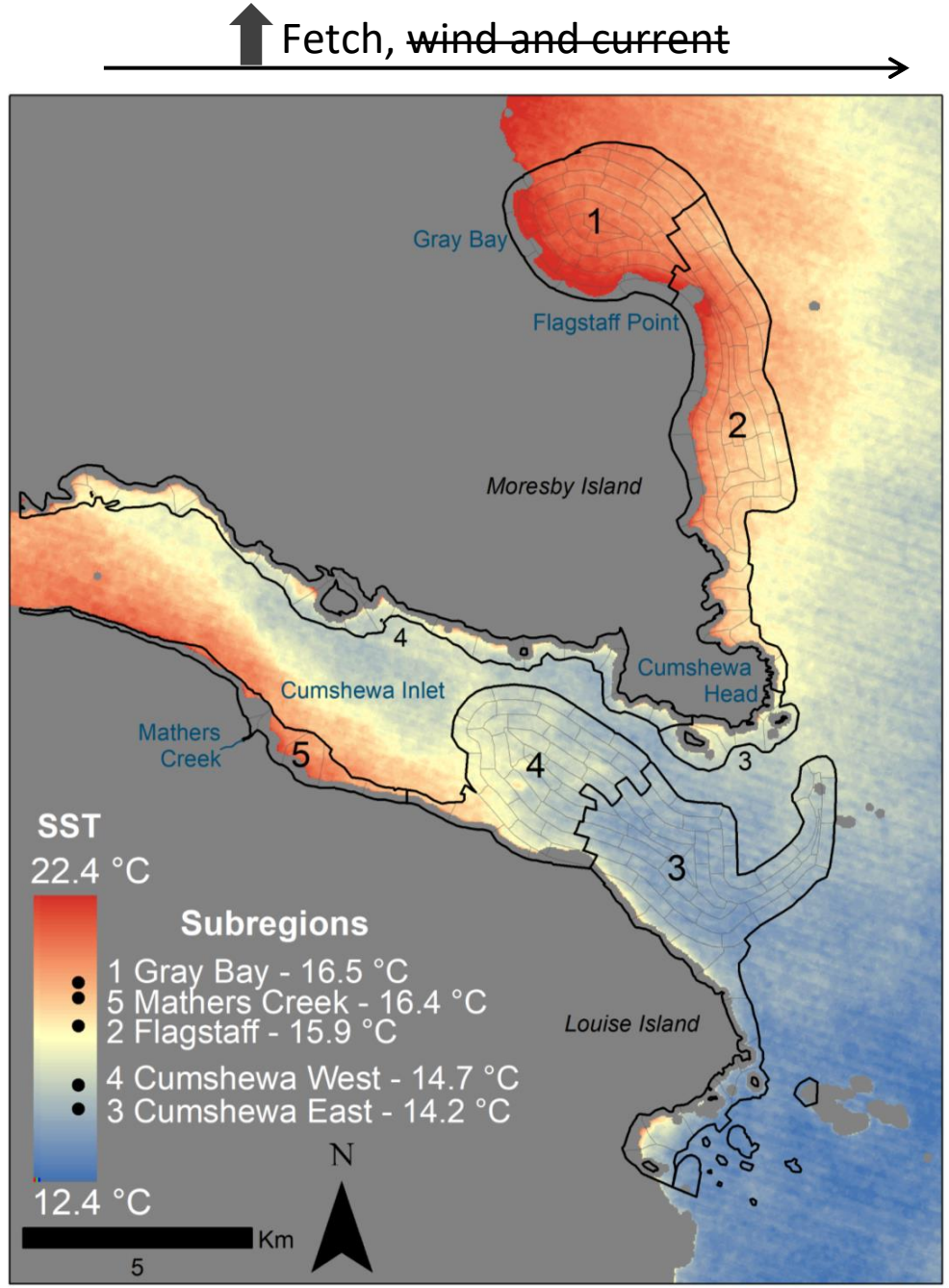
Clustering analysis

Sea Surface Temperature (Landsat)

Fetch (DFO)

Wind (Global Wind Atlas)

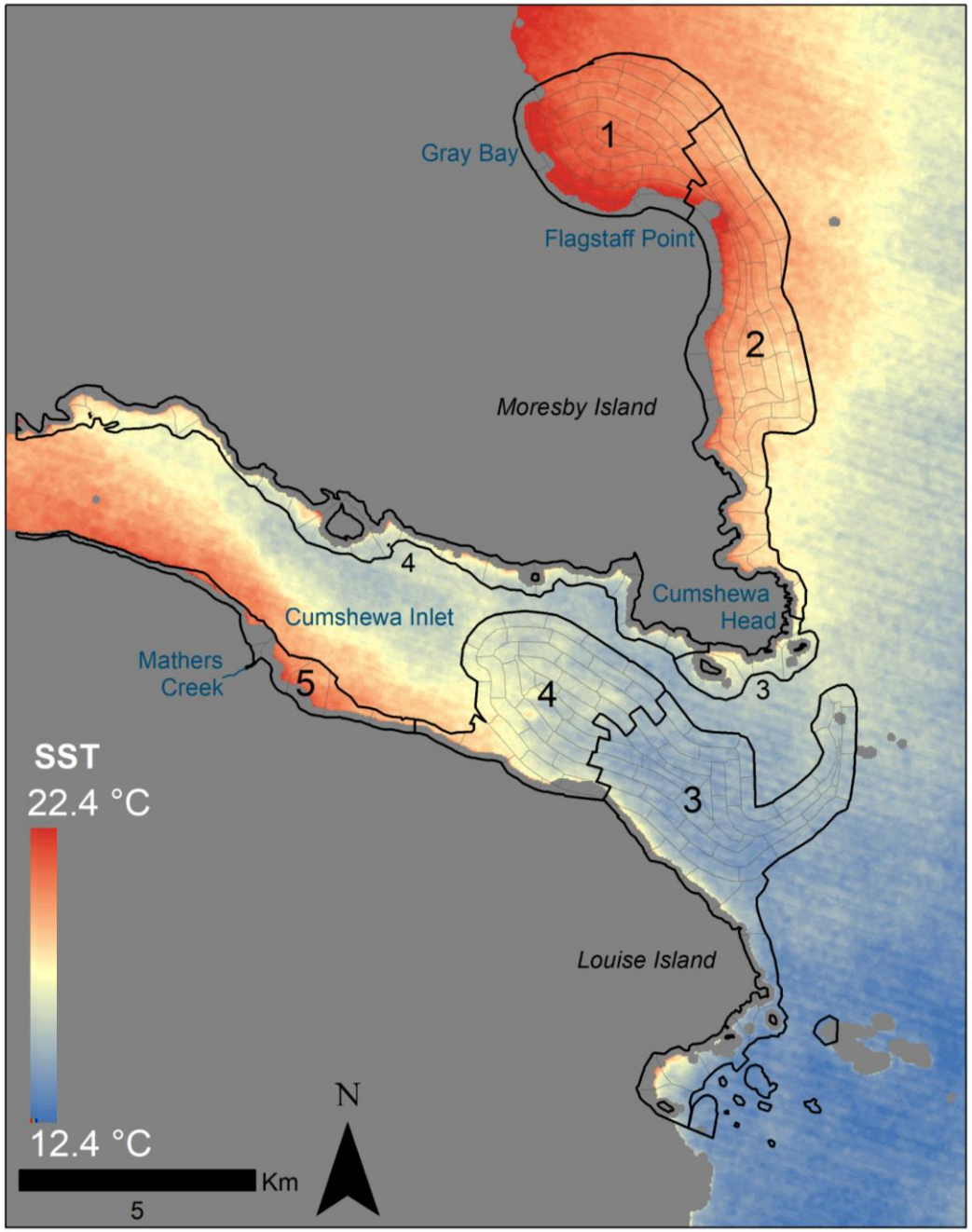
Tidal Current (BCMCA)



Clustering analysis

5 subregions

pseudo-f-statistic
4 groups = 272.92
5 groups = 303.61
6 groups = 279.9233



Historical Loss

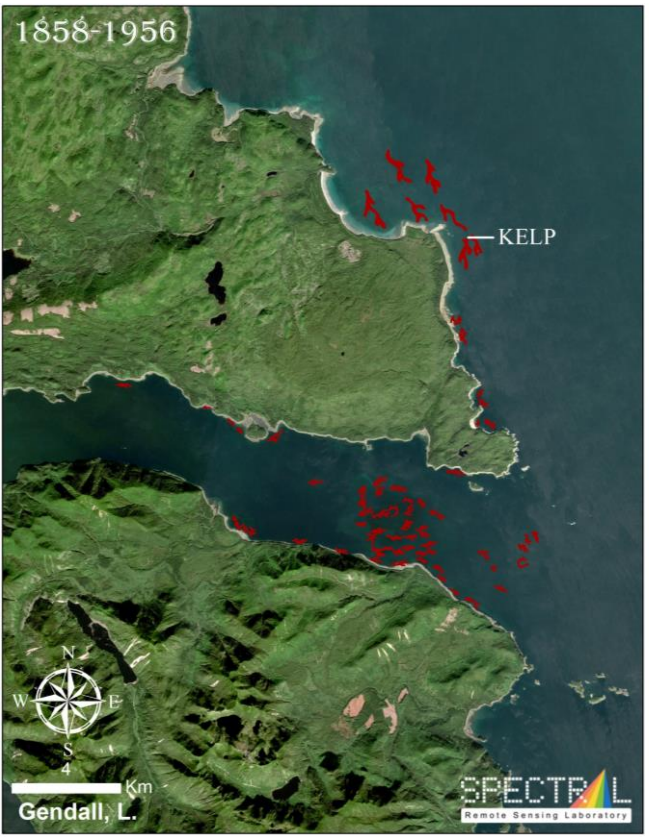
Variability and Resilience


1867-1923
Flagstaff
Costa *et al*., 2020

Historic Loss

"… I think three years ago we went out for k'aaw … we went looking for kelp everywhere in our traditional kelp grounds on the east coast? And there was none. Nothing. … it was unreal. Flagstaff ***there wasn't even a leaf****… maybe… some k'aaw-pickers did it; I don't know. But I can't see that they'd pick everything… they just pick the good leaves."*

Tommy Greene, 2008, Haida Marine TEK Volumes III, page 58


1858-1956
KELP
N
W
E
S
4
Km
Gendall, L.
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1973
KELP
N
W
E
S
4
Km
Gendall, L.
SPECTRAL
Remote Sensing Laboratory


1977
KELP
N
W
E
S
4
Km
Gendall, L.
SPECTRAL
Remote Sensing Laboratory


1984
KELP
N
W
E
S
4
Km
Gendall, L.
SPECTRAL
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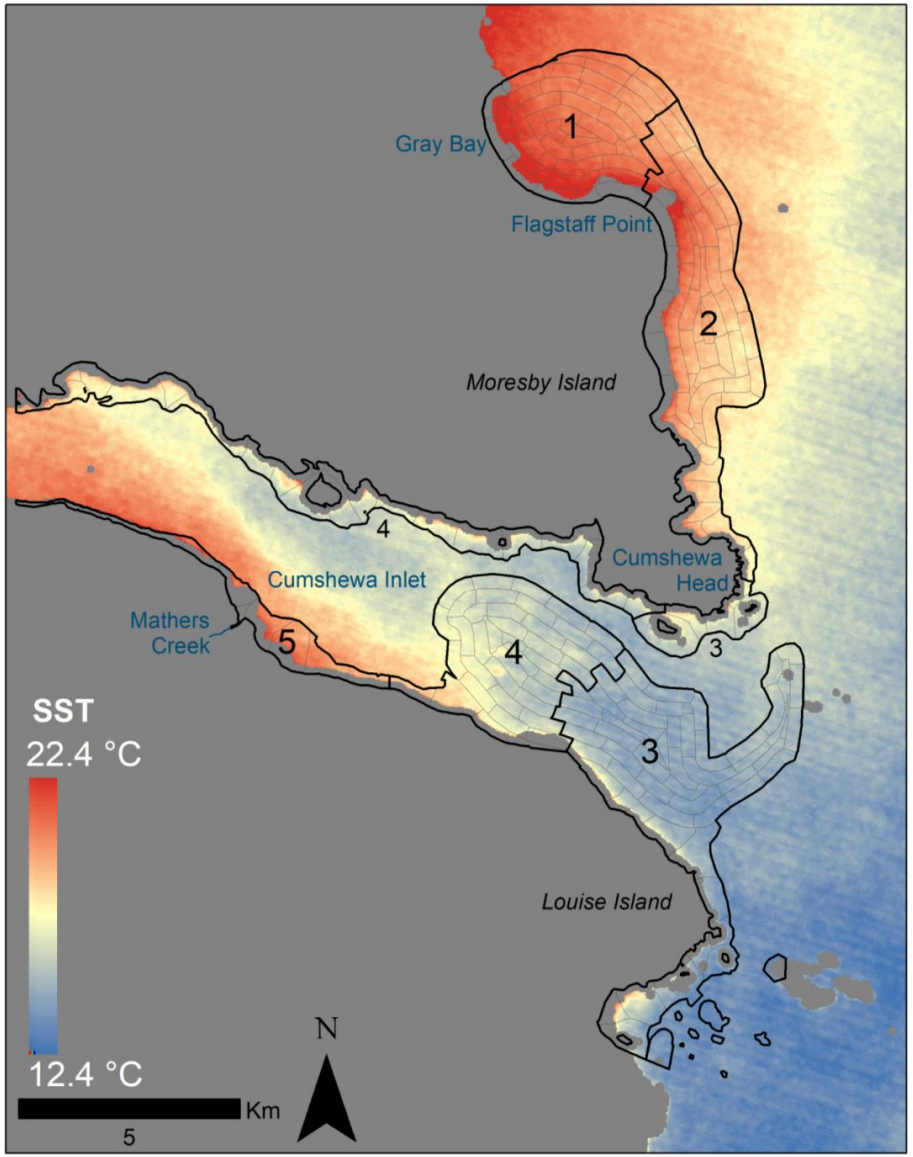
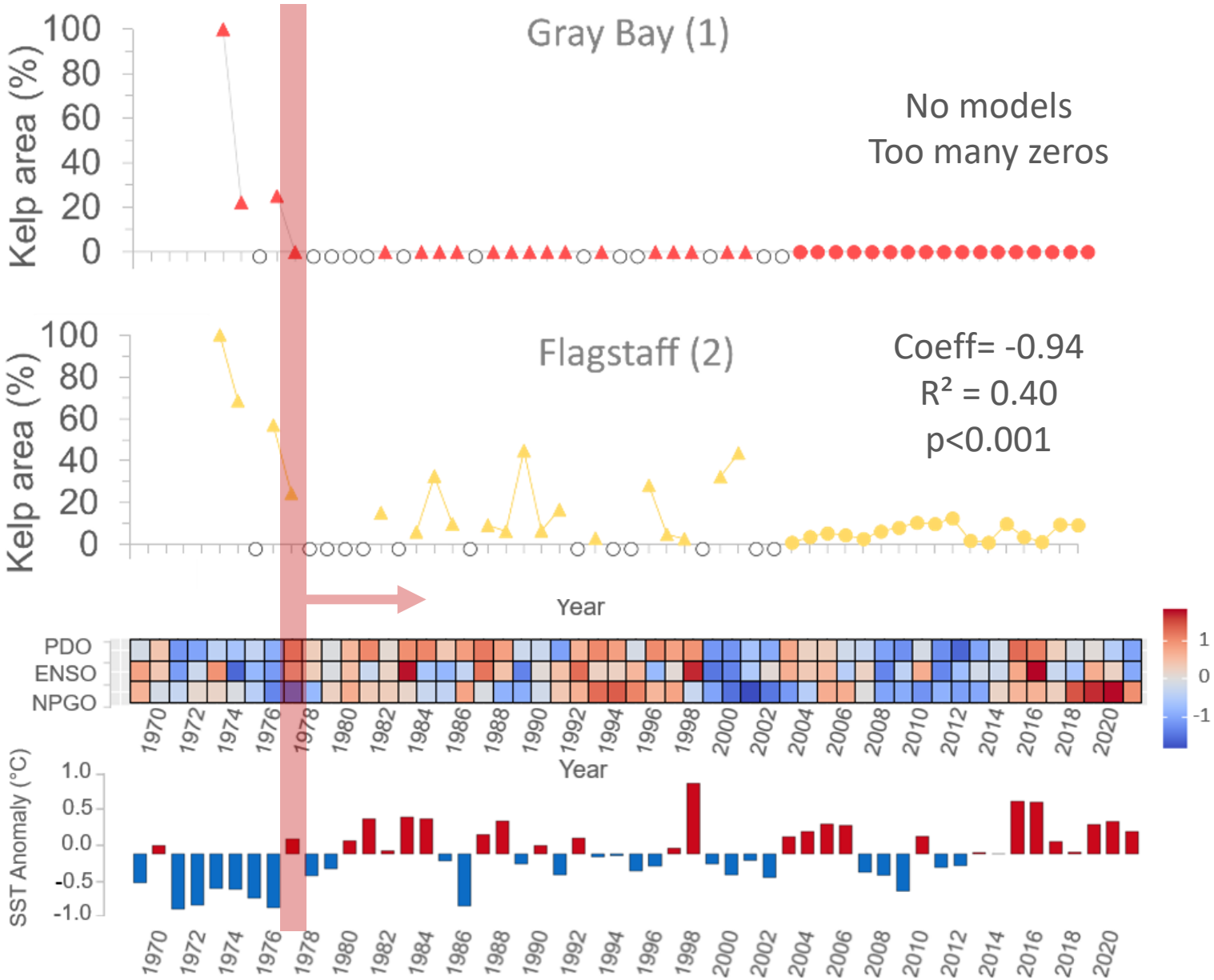
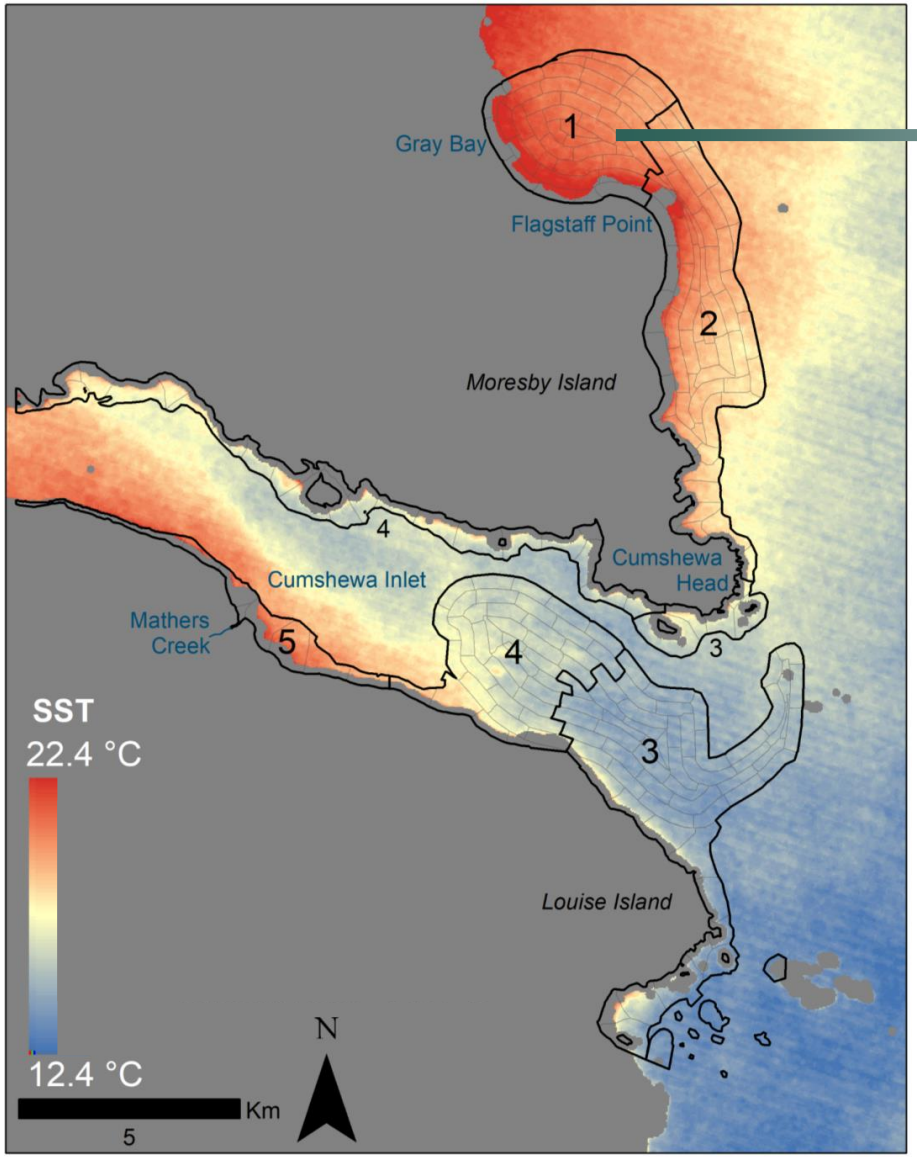
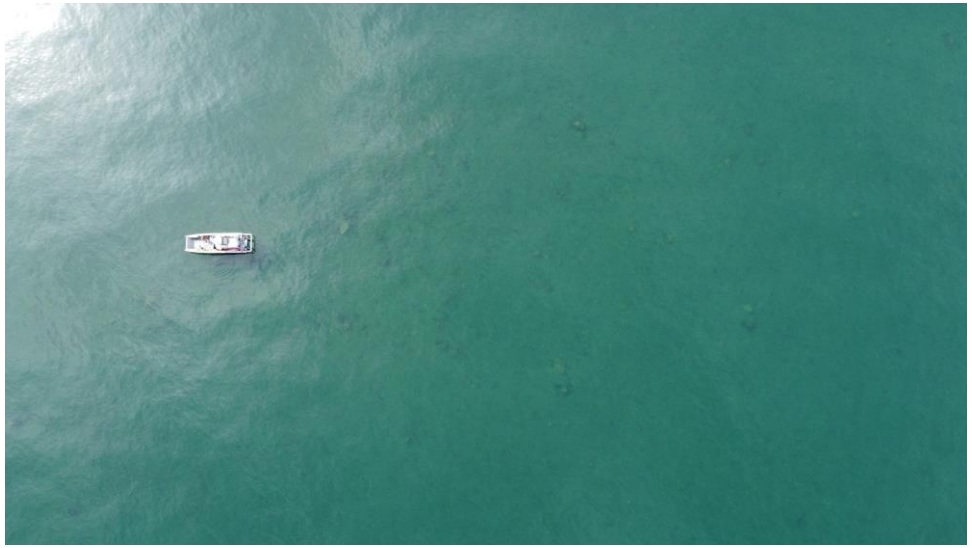
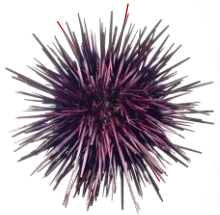

Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Mathers Creek
Louise Island
1
2
3
4
5
SST
22.4 °C
12.4 °C
Km
5
N


Gray Bay (1)
Kelp area (%)
No models
Too many zeros
Flagstaff (2)
Coeff= -0.94
R² = 0.40
p<0.001
Year
PDO
ENSO
NPGO
SST Anomaly (°C)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020



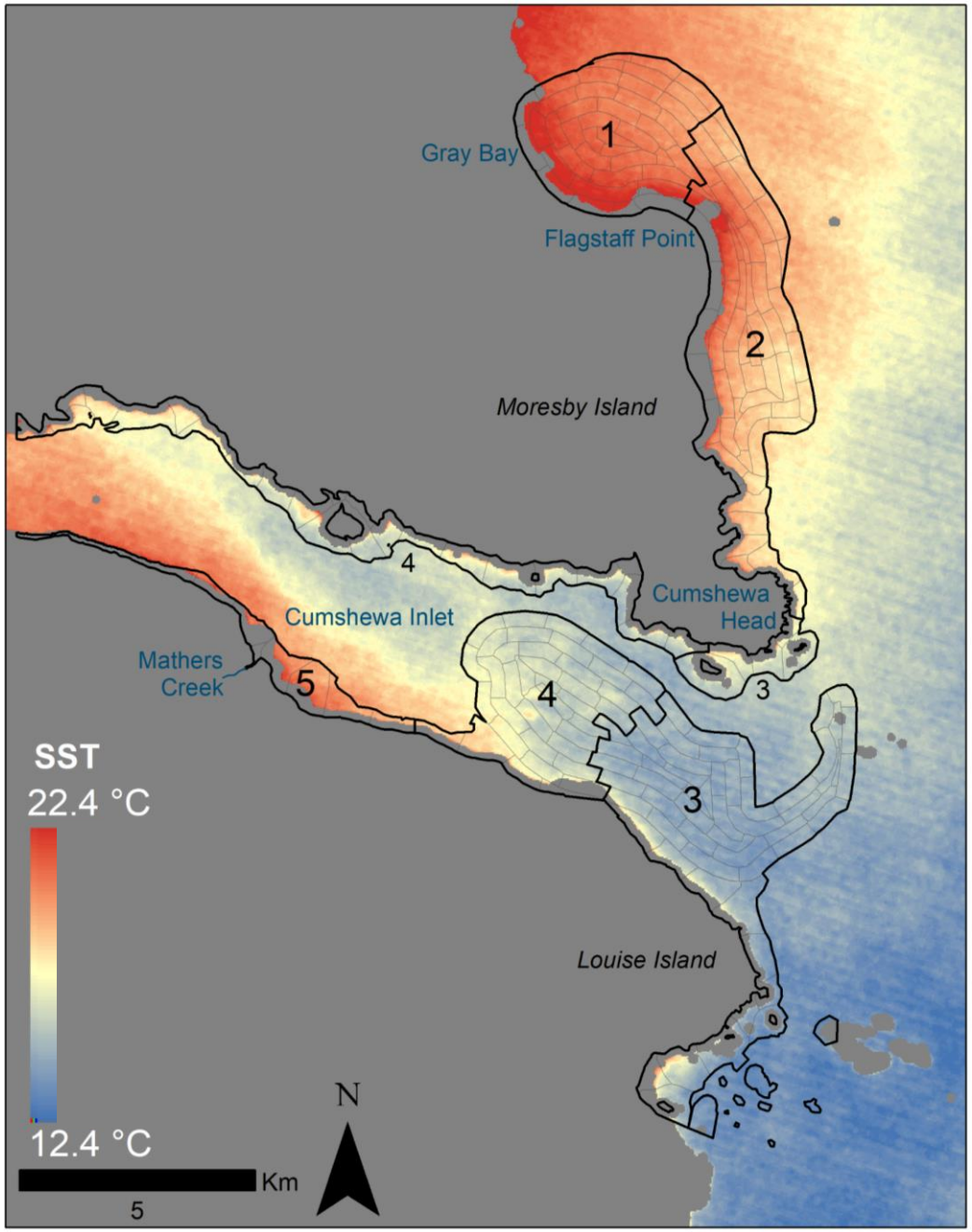


Cobble/boulder substrate



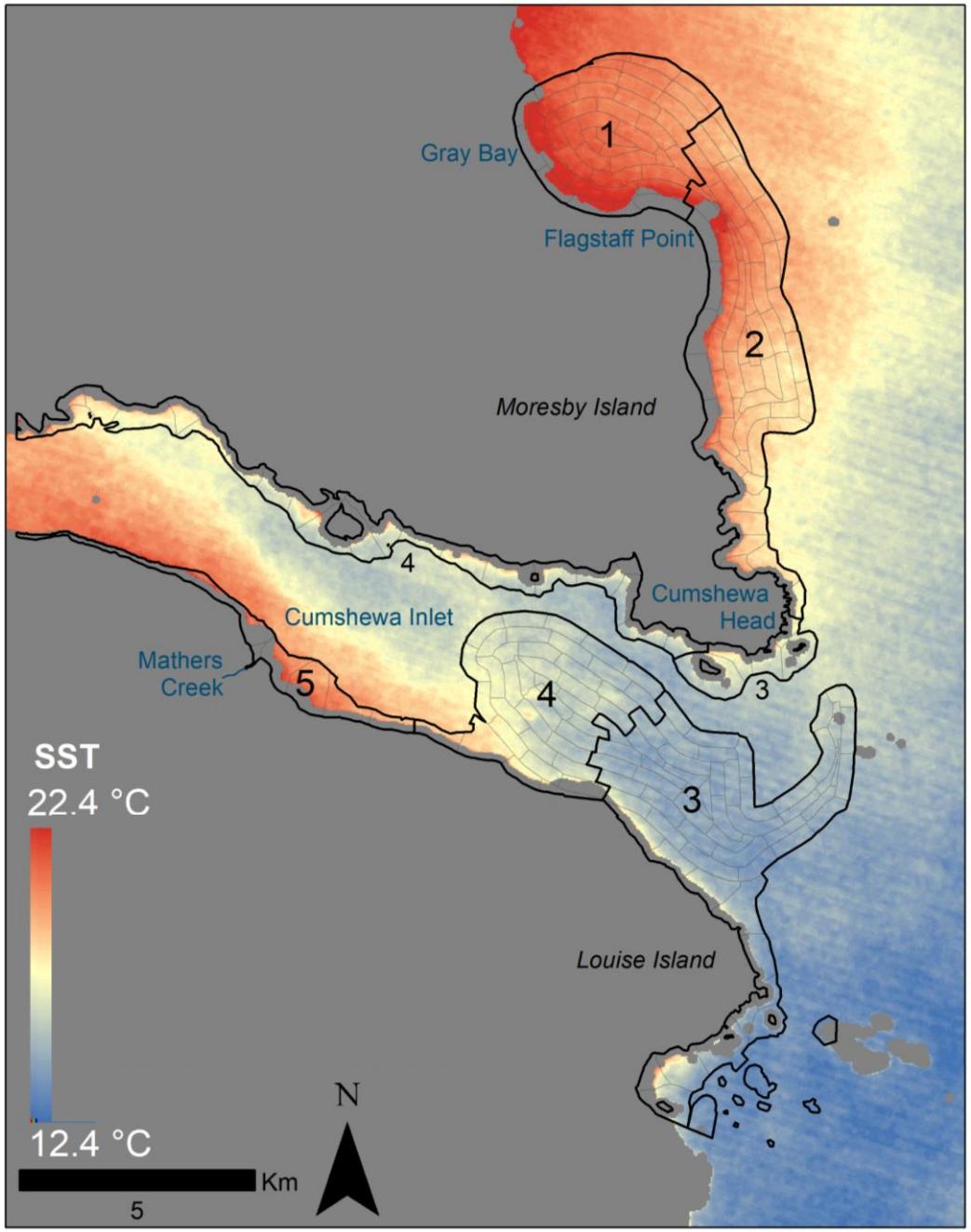
Limited urchin presence

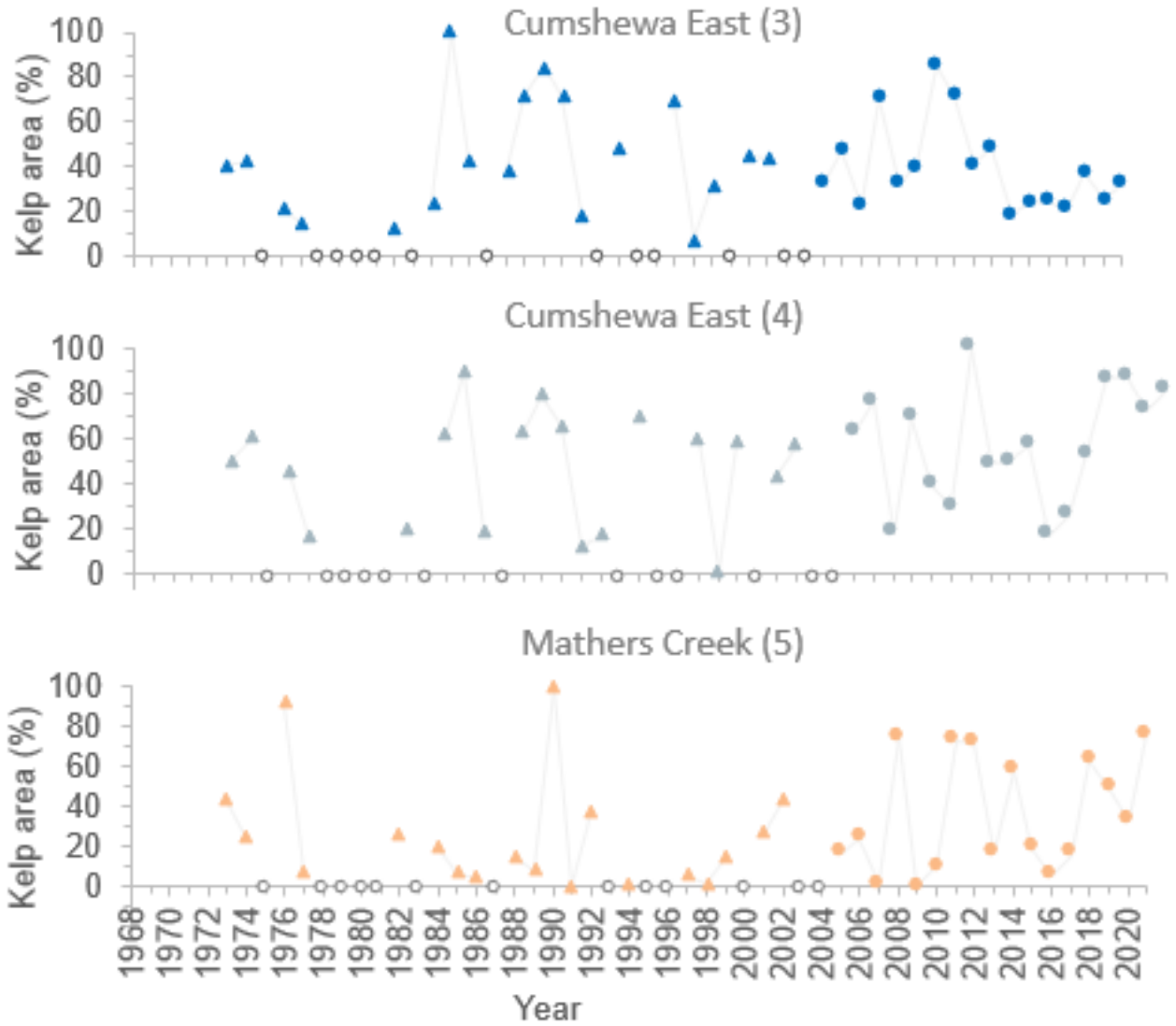
Turf where kelp disappeared



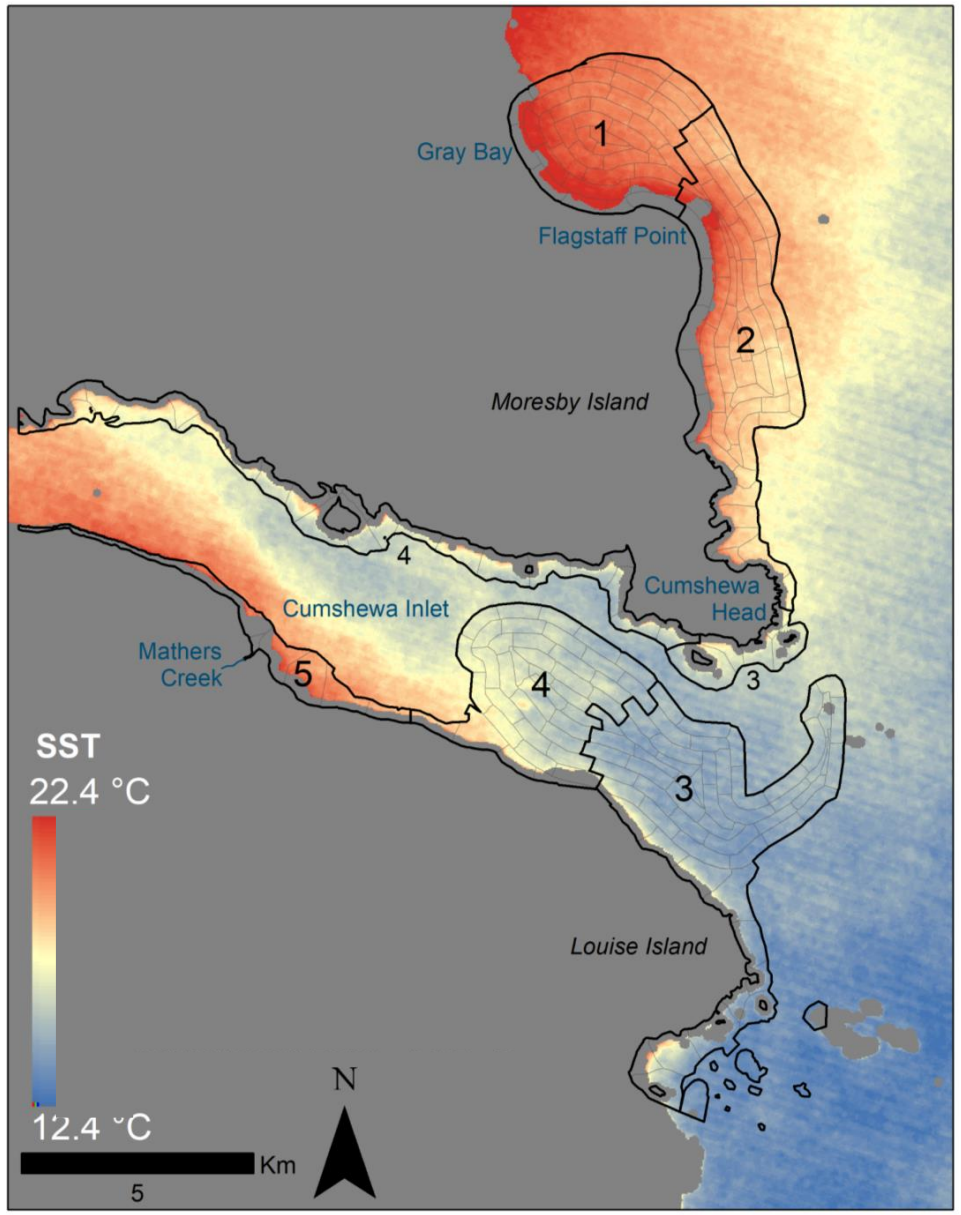
Historical Loss

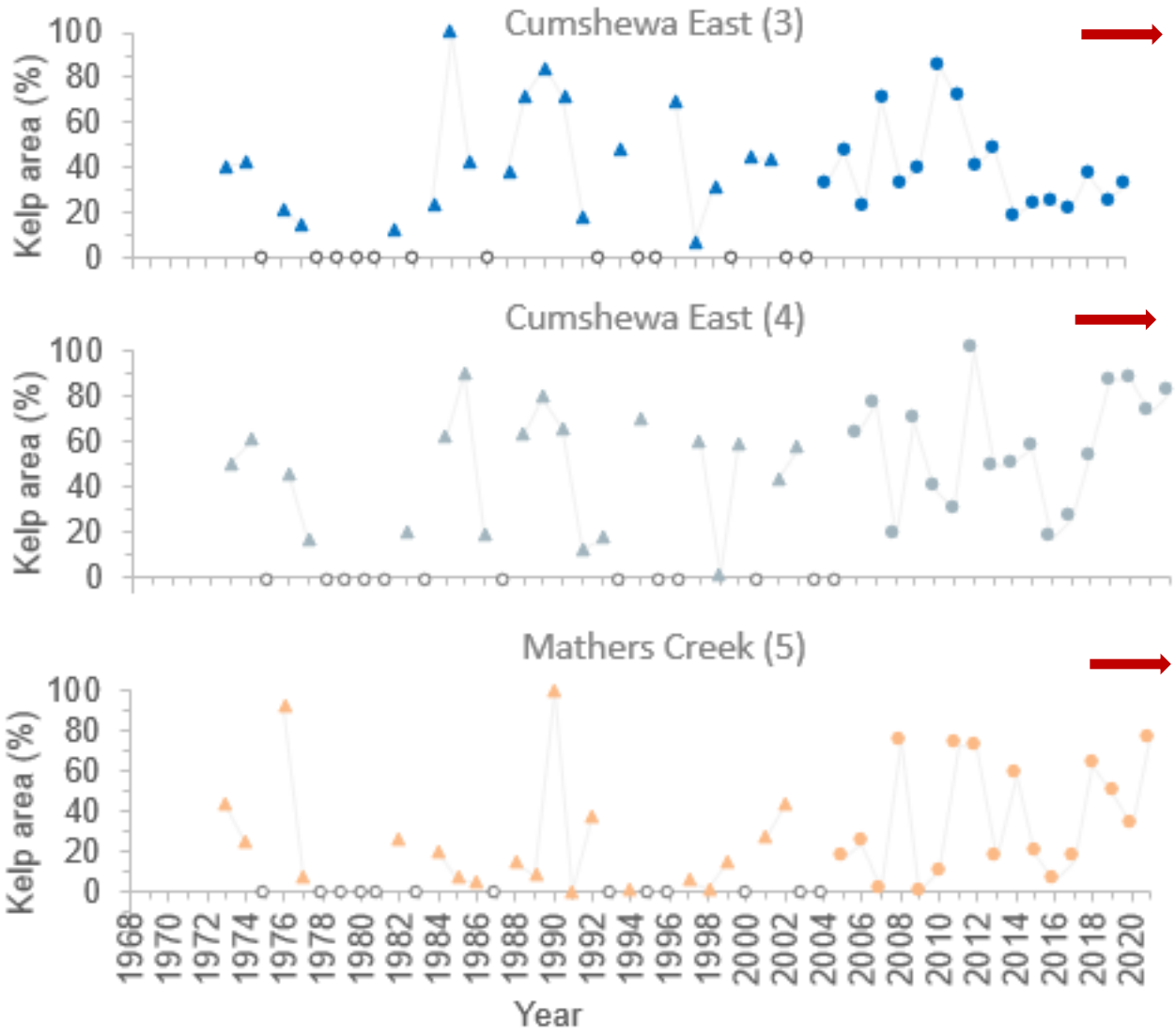
Variability and Resilience


Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Mathers Creek
Louise Island
1
2
3
4
5
SST
22.4 °C
12.4 °C
N
Km
5


Cumshewa East (3)
Cumshewa East (4)
Mathers Creek (5)
Kelp area (%)
0
20
40
60
80
100
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year

Best models

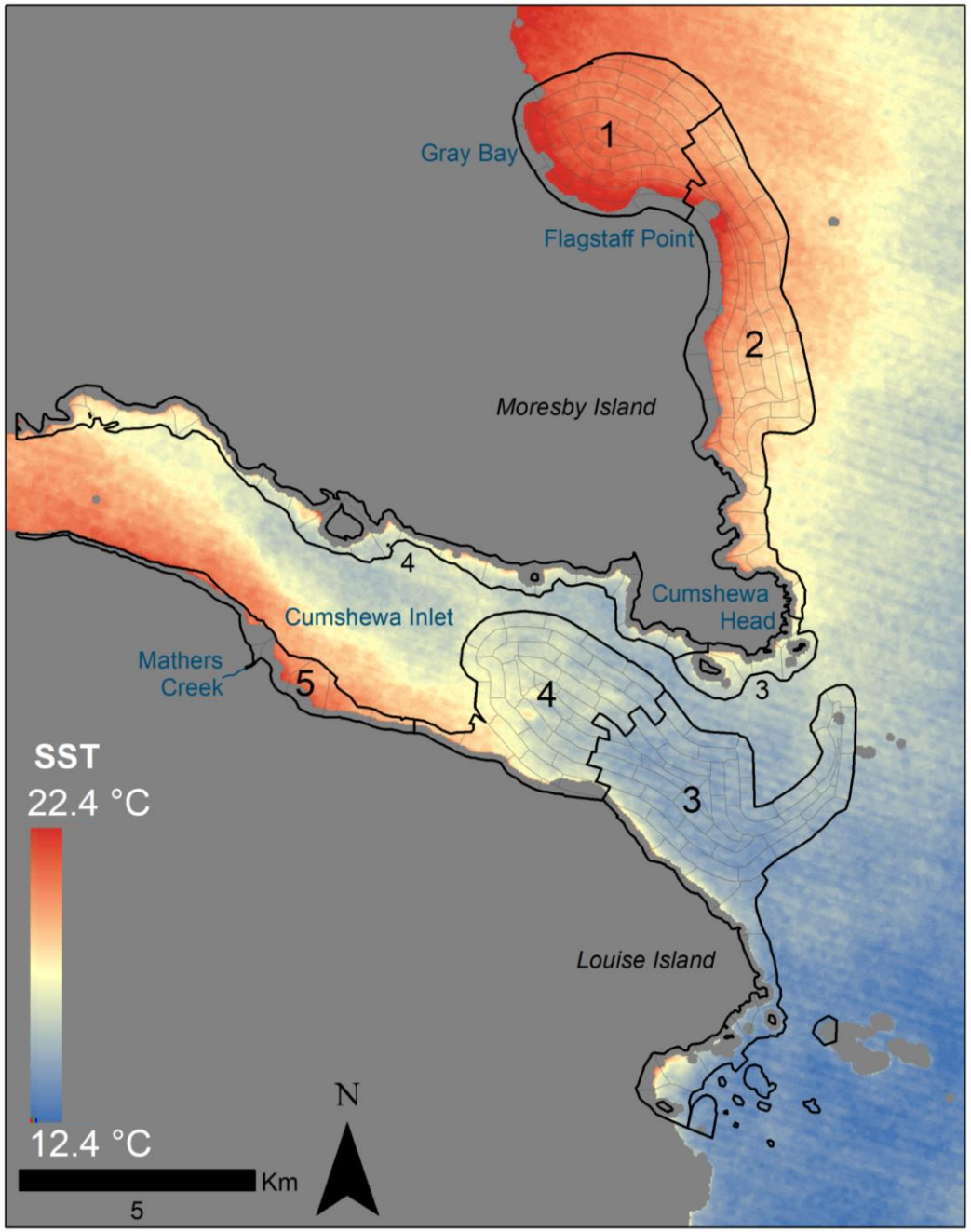


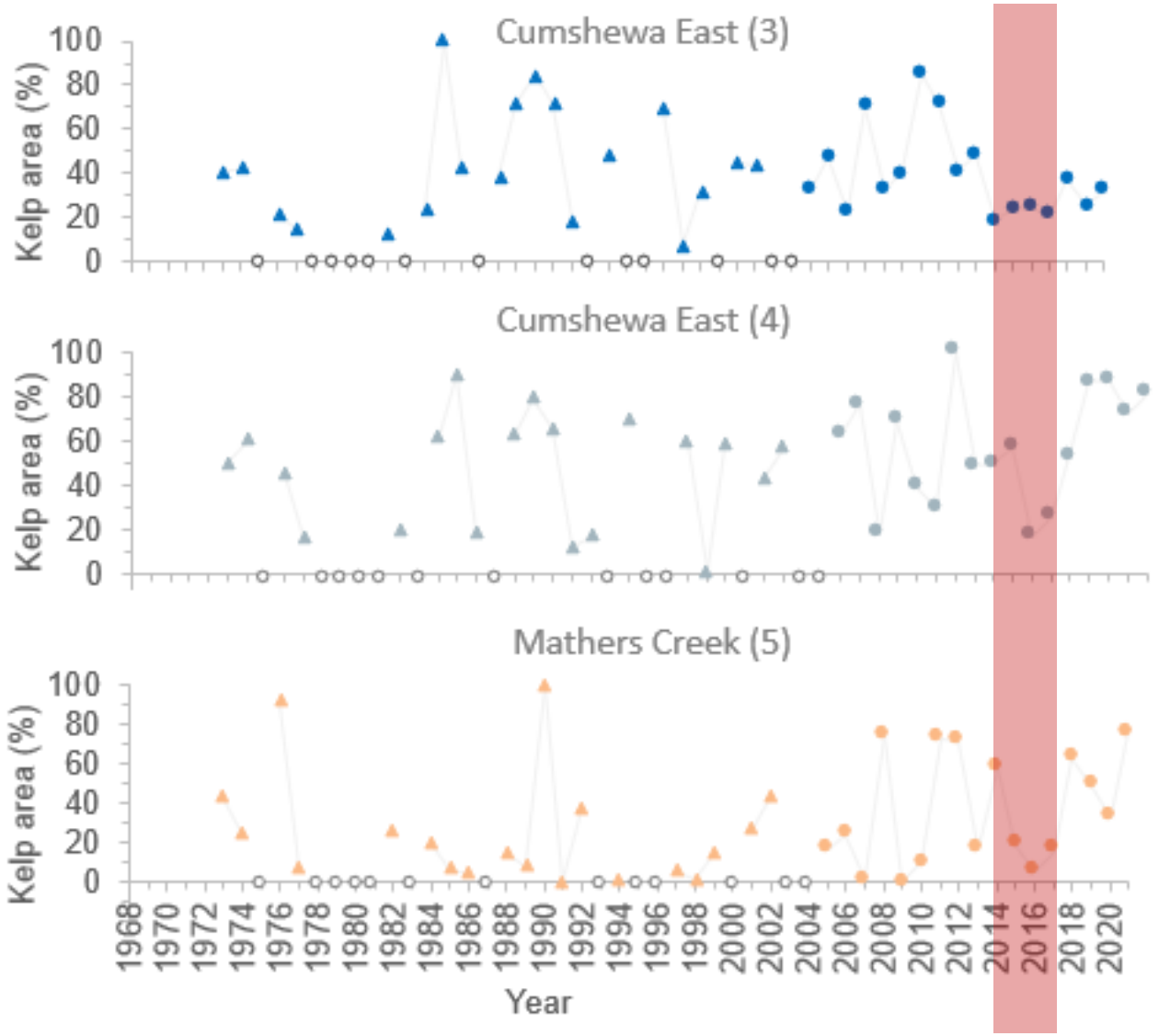


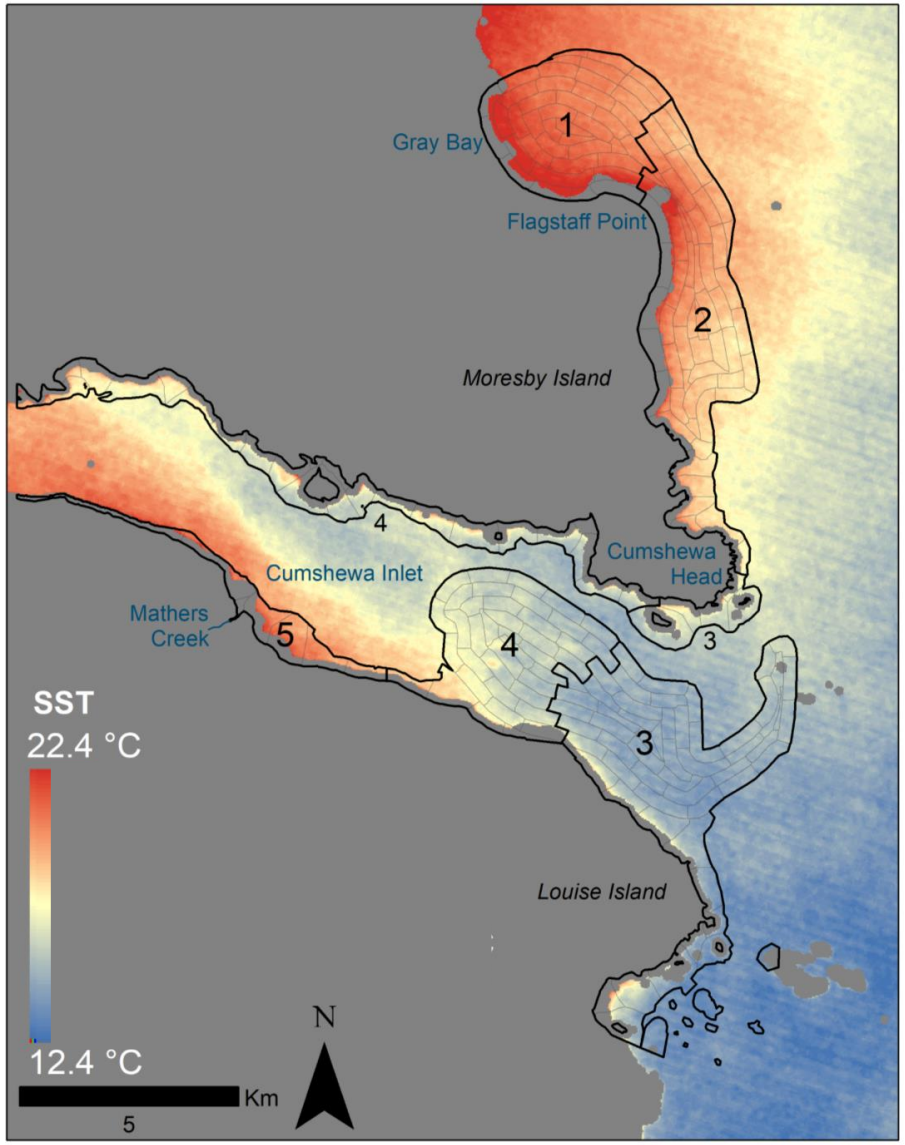
ENSO (2 year)
Coeff= -21.3
R^2 = 0.20
p<0.001

ENSO (1 year)
Coeff=-19.8
R^2 = 0.32
p<0.001

PDO (1-year)
Coeff= -15.3
R^2 = 0.21
p<0.001


Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Mathers Creek
Louise Island
1
2
3
4
5
SST
22.4 °C
12.4 °C
N
Km
5


Cumshewa East (3)
Cumshewa East (4)
Mathers Creek (5)
Kelp area (%)
0
20
40
60
80
100
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year



Historic Loss

Variable and Resilient

British Columbia

Sutherland et al., 2007

Burt et al., 2018

Watson & Estes, 2011

Starko *et al.*, 2022

Schroeder *et al.*, 2020

Berry *et al.*, 2020

Decrease

Stable

Increase

Conclusions

- Longest time series of kelp forest canopy to date on the coast of North America
- First to highlight a climate-driven loss as early as the 1970s

- Local and regional conditions = important!
- Clustering analysis = effective tool
- ENSO, PDO & SST anomalies drive inter-annual variability in kelp abundance

SPECTRAL
Remote Sensing Laboratory

BRITISH COLUMBIA
KELP RESILIENCE
KelpR

University of Victoria
GEOGRAPHY

It takes a community

Maycira Costa, Margot Hessing-Lewis, Natalie Bann, Luba Reshitnyk, Peter Wills, Sarah Schroeder, Gita Narayan, Brian Timmer, Sam Starko, Lynn Lee, Niisii Guujaw, Stu Crawford, Courtney Edwards, Tayler Brown, Rebecca Martone, Will McInnis, Dafne Romero, Nikki Saadat, Hakai's Geospatial Team, the participants and authors of the Haida Marine Traditional Knowledge Volumes, the BC Kelp Analytical Working Group, all the members of the SPECTRAL Remote Sensing Lab, & many many more…

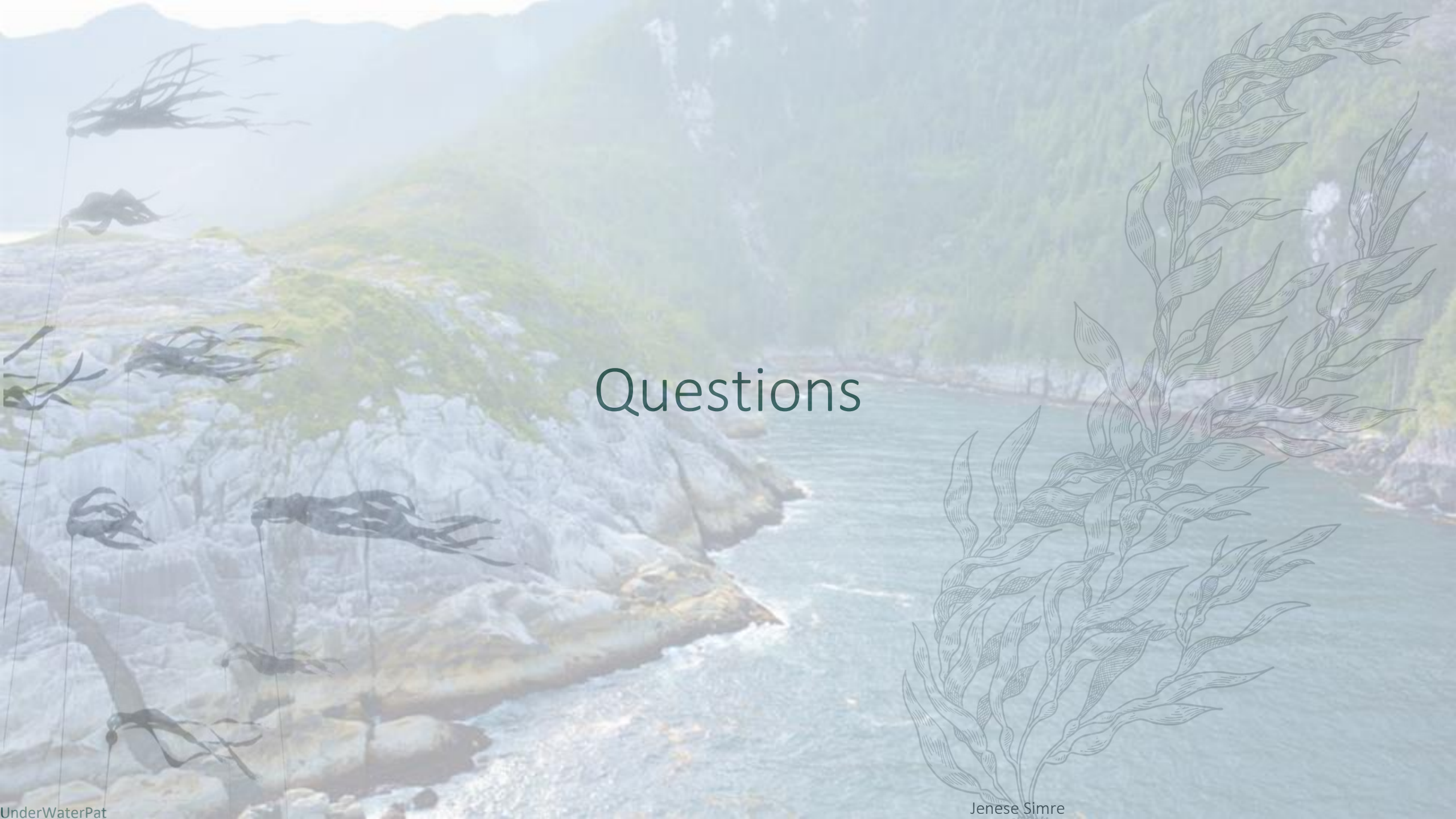
MaPP

Canadian Hydrographic Service
Service hydrographique du Canada

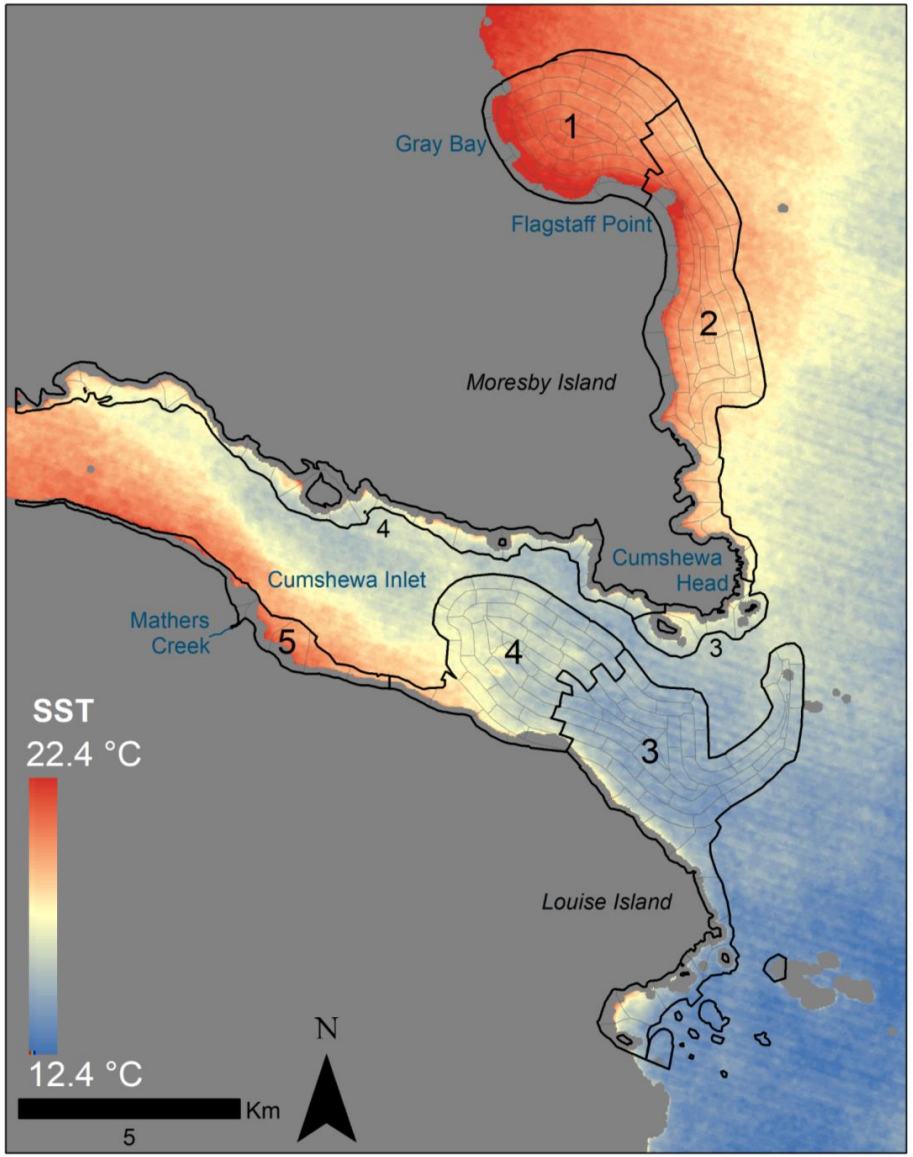
Hakai
Science on the Coastal Margin

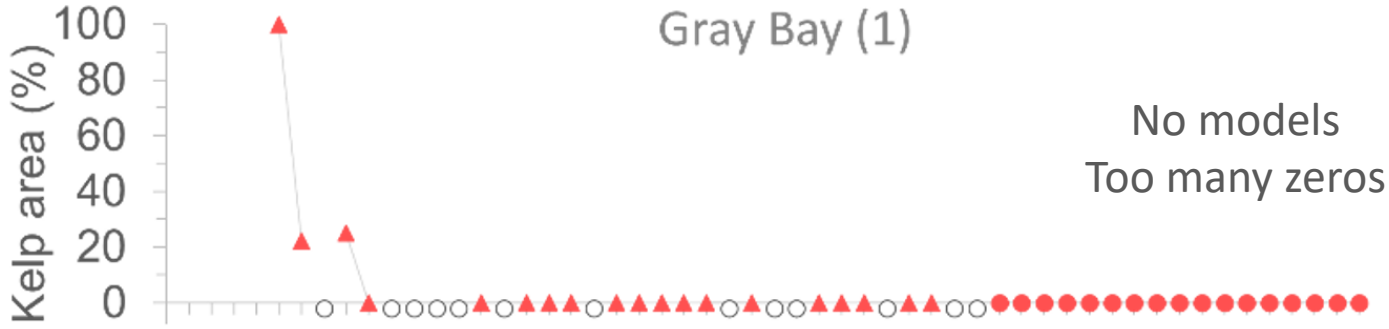
Environment and Climate Change Canada

Fisheries and Oceans Canada



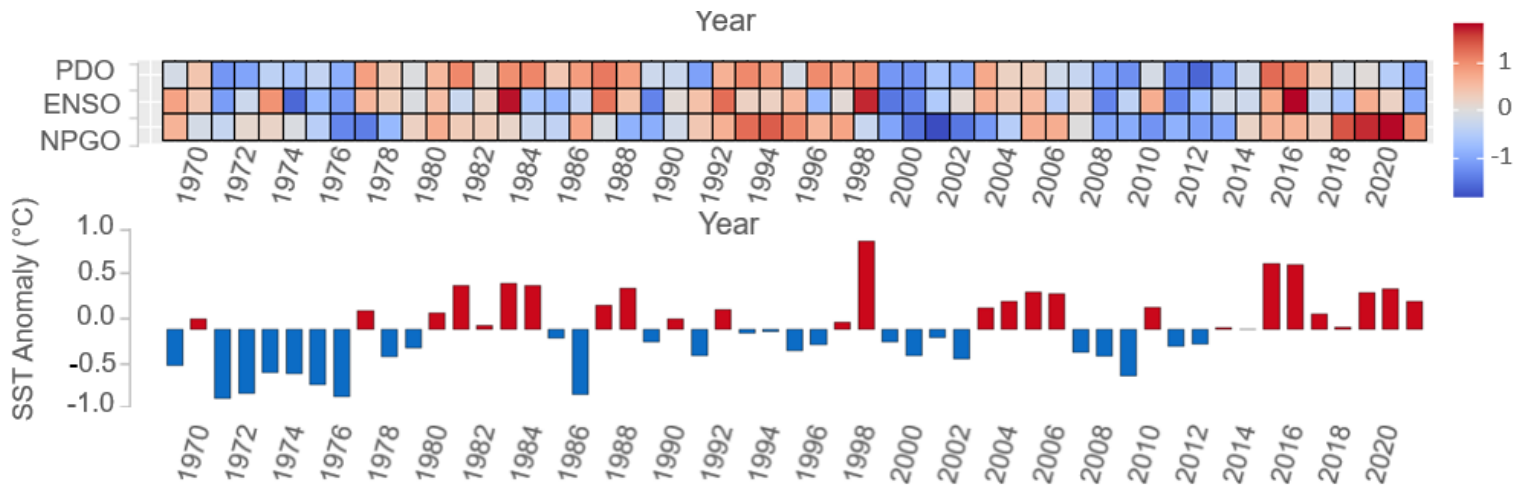
Questions

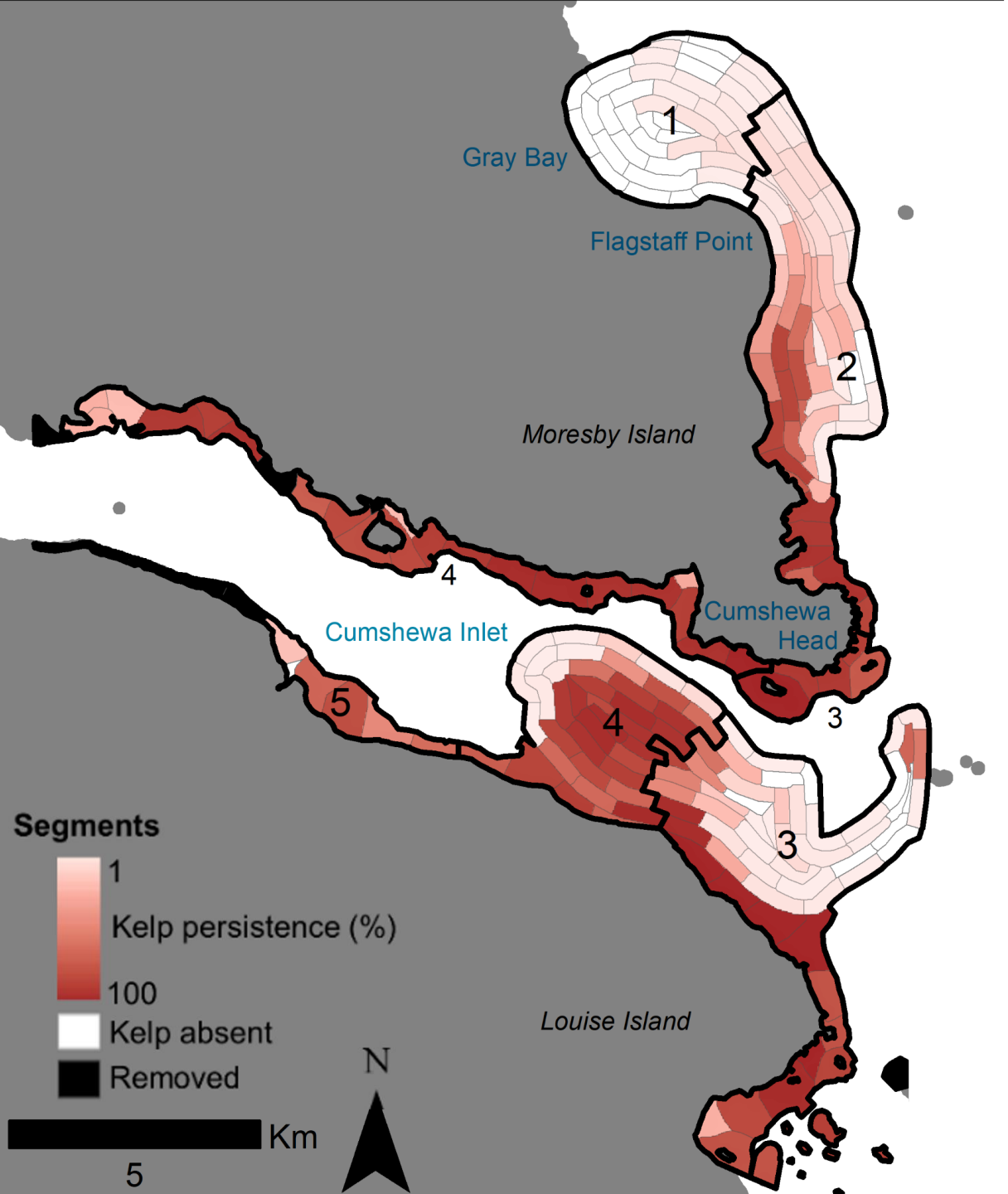


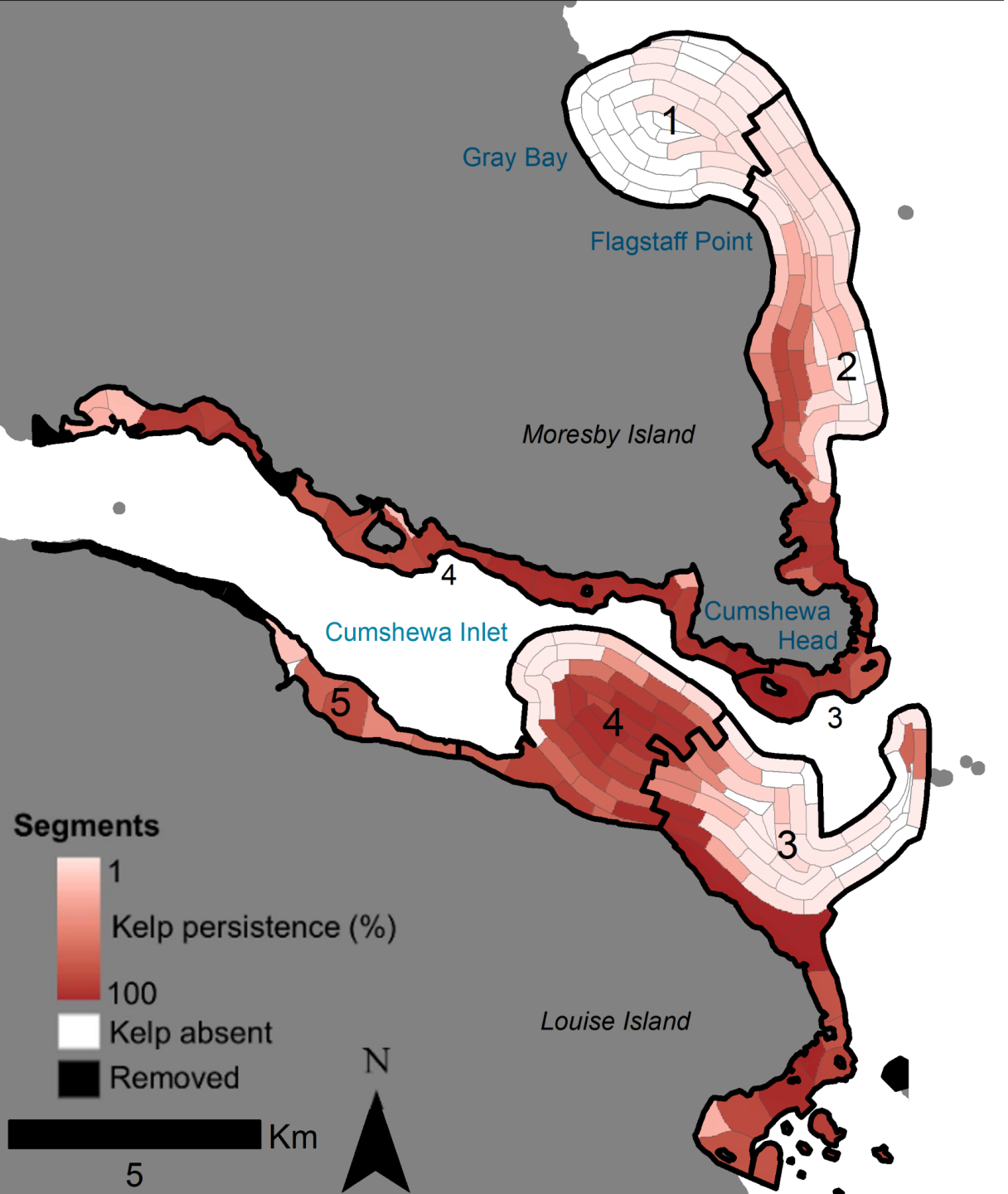


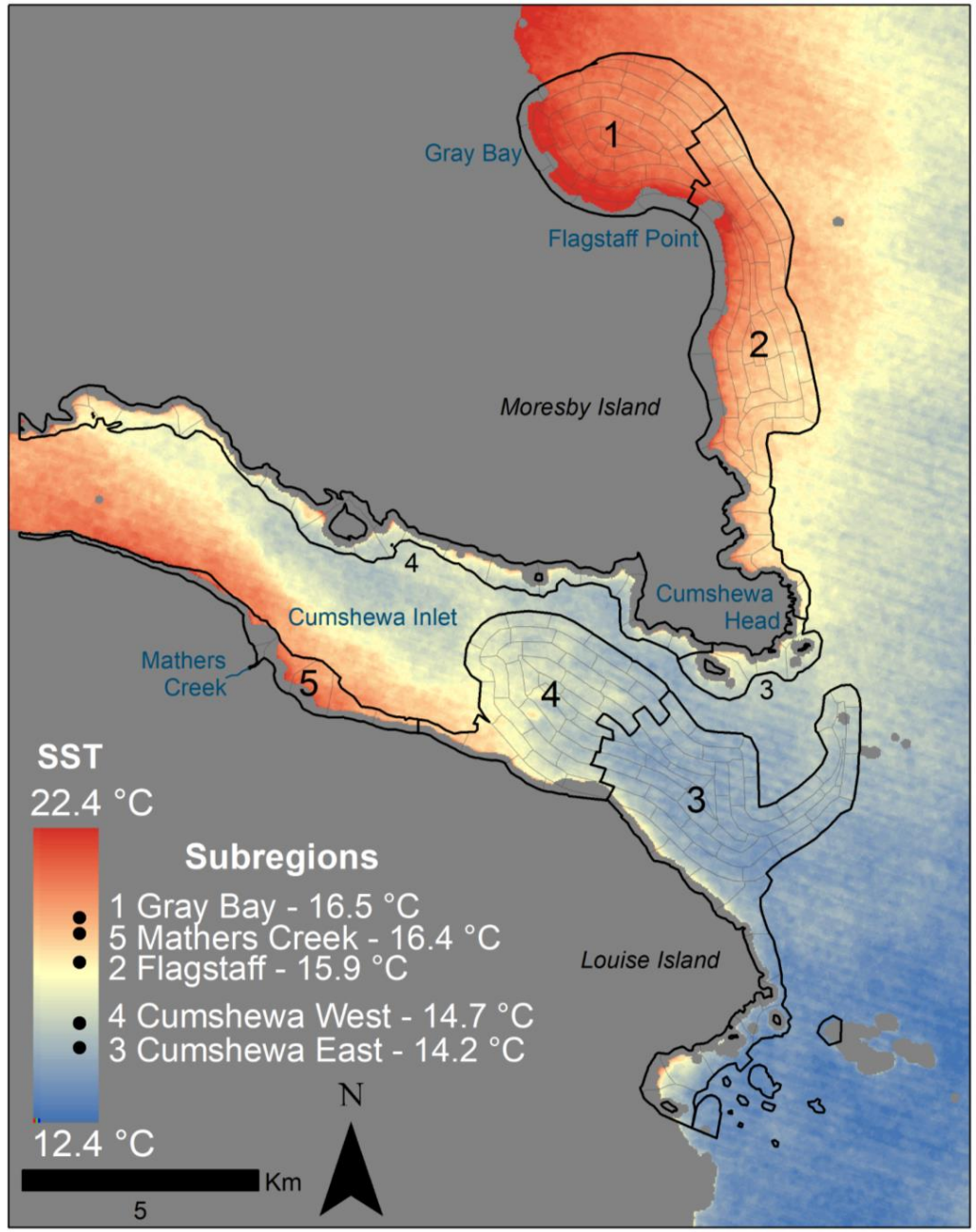
No models
Too many zeros

SST (3 years)
ENSO (3 years)
$R^2 = 0.50$
$p<0.001$




Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Louise Island
1
2
3
4
5
4
3
Segments
1
Kelp persistence (%)
100
Kelp absent
Removed
N
Km
5


Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Louise Island
1
2
3
4
5
Segments
1
Kelp persistence (%)
100
Kelp absent
Removed
N
Km
5


Gray Bay
Flagstaff Point
Moresby Island
Cumshewa Inlet
Cumshewa Head
Mathers Creek
Louise Island
1
2
3
4
5
SST
22.4 °C
12.4 °C
Subregions
1 Gray Bay - 16.5 °C
5 Mathers Creek - 16.4 °C
2 Flagstaff - 15.9 °C
4 Cumshewa West - 14.7 °C
3 Cumshewa East - 14.2 °C
N
Km
5

Contributions of the research

Regional

- Haida Nation
- MaPP & the Northern Shelf Bioregion

Provincial

- Longest time series of kelp forest canopy through time to date
- Methods to be expanded coastwide

Global

- Fills a spatial gap in the global coverage of kelp data
- Literature on remote sensing of kelp forests
- First to highlight climate-driven loss as early as the 1970s

Limitations and Future Research

Limitations

- Availability of imagery
- Limited to 1-2 images per year
- Lack of driver data (continuous in situ data, nutrient, salinity, storm)

Future work

- Expanded resolution analysis
- Scale up to larger geographic regions
- Apply conclusions to highlight areas of vulnerability
- Couple with climate models to predict areas of resilience/vulnerability into the future