Environmental Science and Policy Committee

Meeting will be held at the Rosebank Motor Lodge, 265 Clyde Street, Balclutha.
ORC Official YouTube Livestream

Members:

Cr Lloyd McCall (Co-Chair)	Cr Andrew Noone
Cr Alexa Forbes	Cr Gretchen Robertson
Cr Gary Kelliher	Cr Bryan Scott
Cr Michael Laws	Cr Alan Somerville
Cr Kevin Malcolm	Cr Elliot Weir
Cr Tim Mepham	Cr Kate Wilson

Senior Officer: Pim Borren, Interim Chief Executive

Meeting Support: Trudi McLaren, Governance Support Officer

26 April 2023 10:00 AM

Agenda Topic — Page

1. WELCOME

2. APOLOGIES

No apologies were noted prior to publication of the agenda.

3. PUBLIC FORUM

Requests to speak should be made to the Governance Support team on 0800 474 082 or to governance@orc.govt.nz at least 24 hours prior to the meeting, however, this requirement may be waived by the Chairperson at the time of the meeting. No requests to speak were made prior to publication of the agenda.

4. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation as to why they cannot be delayed until a future meeting.

5. DECLARATION OF INTERESTS

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have. Councillor interests are published on the ORC website.

7. CLOSURE

6.1. Land Science Update

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2306
Activity:	Environmental: Land
Author:	Ben Mackey, Team Leader - Land Erik Button, Land and Soil Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	26 April 2023

PURPOSE

[1] This paper provides an update of the major land and soil science mapping and monitoring programmes currently underway.

EXECUTIVE SUMMARY

[2] The ORC science team has been rebuilding capability in land and soil science over the past two years, with an initial focus on mapping and quantifying land use and developing programmes to improve soil mapping and monitoring. This paper introduces and describes the key workstreams, which are land use and irrigation mapping, expanding soil mapping coverage in Otago, and developing soil health and soil moisture monitoring networks.

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*

BACKGROUND

[3] The land and soil science programme was re-established at ORC in early 2021 following a hiatus in land-focused science over the past decade or so.

[4] The long-term vision for the land science programme is to be able to predict and measure the impacts of land use on water quality. The land and soil science programme's initial focus is to build the required knowledge of Otago's physical environment and land use practices. This work comprises identifying and filling key knowledge gaps related to the physical environment and land resource use. Currently, this is being achieved via land use and irrigation mapping, and the establishment of soil mapping and monitoring programmes.

[5] The land science work currently has a dual focus: both to inform the development of the proposed Land and Water Regional Plan (pLWRP), and to establish monitoring programmes to provide a scientific basis for environmental management over the coming decades.

LAND USE MAPPING

[6] Land use mapping allows quantification of the various land use pressures affecting the environment and provides a record of how land use activities have changed over time.

Maintaining an accurate and up to date record of land use is challenging, given evolving land use activities, and the need to categorise a wide range of agricultural and horticultural activities. In particular, mixed-use properties or cyclical land uses can be difficult to appropriately classify.

[7] Land use mapping of the Otago region was undertaken in 2021 and 2022 by consultants Great South. The mapping drew on a range of ORC data and external information (primarily Agribase managed by AsureQuality) to generate a best estimate land use at the property scale. An example is shown in Figure 1. The full database is housed in ORC's internal GIS database, while a publicly accessible version is available through Otago Maps.[1]

[8]

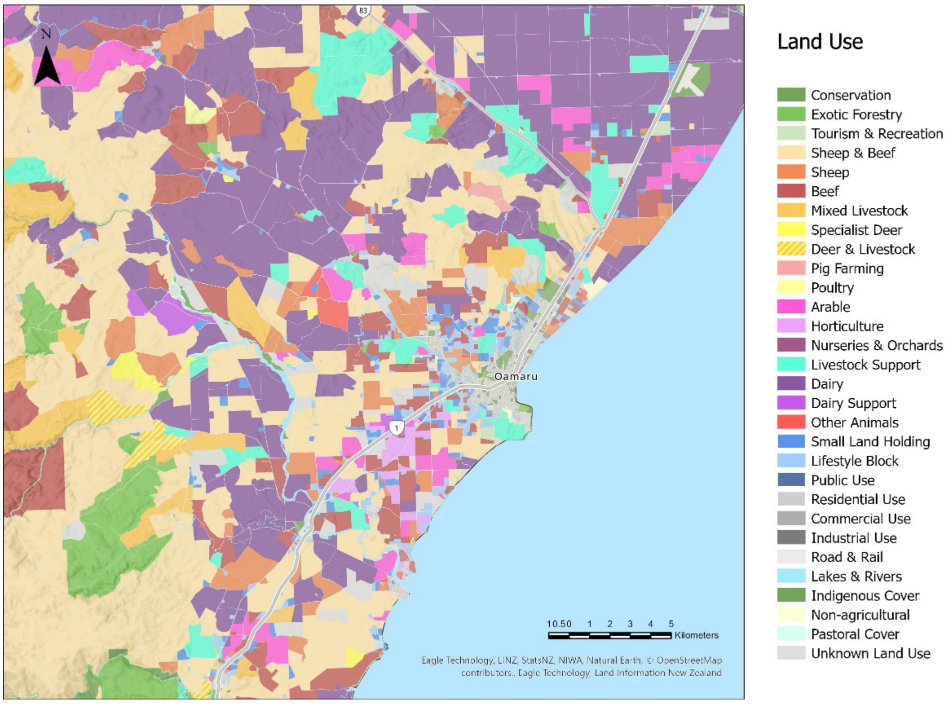

Figure 1. Example of the land use map in the North Otago area showing a relatively diverse mix of land uses.

[9] While generally accurate, the current ORC land use map (compiled 2022) has some incorrectly classified properties, based on comparison with known sites, and feedback from landowners at public events. Errors in the land use map are attributable to either incomplete or inaccurate source datasets, or misclassifications when aggregating and categorising land use to generate the map. Staff are currently investigating how to efficiently improve the land use map to ensure it is as accurate as possible, including working with industry bodies and custodians of the source databases.

[1] An online version of the map is available here: https://maps.orc.govt.nz/portal/home/item.html?id=0f5b885722fc4715a546e8596f762fc3

[10] A component of the 2022 land use map was a technical map, which combines existing datasets about soil, drainage characteristics, topography, irrigation, and rainfall. This technical map can be used to identify areas with similar physical characteristics (e.g., flat, poorly drained, warm, wet areas) that may face common environmental risks or be suitable for similar mitigation options. When combined with the land use map, the technical map underpins efforts at quantifying nutrient loss across Otago.

[11] Also completed in 2021 was an updated irrigation map for the Otago region, which builds upon existing national-scale irrigated area mapping commissioned by the Ministry for the Environment in 2017. There are now nearly 6,000 irrigated areas mapped across Otago, with a total irrigated land area of 123,000 hectares. With the recent dry summer and availability of high-quality satellite imagery, staff are intending to undertake a further update of the irrigation map by utilising the high visual contrast between irrigated and non-irrigated land.

SOIL MAPPING

[12] S-Map is New Zealand's modern soil mapping programme managed by Manaaki Whenua – Landcare Research. It builds upon historic soil surveys to generate a consistent national geospatial soil database, with S-Map data publicly available through the S-Map web portal.[2] Soil information is a key component of farm and nutrient management. S-Map data underpins nutrient management tools (such as Overseer) and helps landowners better manage the environmental effects of various land uses. It will be a key input when developing farm environmental plans. It is also important for assessing the value of land. Key soil parameters that are mapped in S-Map include depth (dig ability), depth to slowly permeable layer, rooting depth, rooting barrier, horizon thickness, stoniness, clay and sand content, and profile available water.

[13] Approximately 26% of Otago is currently included in the S-Map programme, with valuable soil data provided by the ORC 'GrowOtago' programme from 2004. However large tracts of land, including some areas with high production capabilities, are yet to be mapped at the standard required for S-Map. In a screening exercise, ORC and Manaaki Whenua – Landcare Research soil scientists identified large relatively contiguous unmapped areas with high land use potential (Land Use Capability or LUC classes 1-4). The three highest priority locations are parts of the Catlins, Tuapeka West, and Moa Flat areas. In a three-year project (funded by ORC with 80% co-funding from MPI), soil scientists from Manaaki Whenua – Landcare Research will be mapping 276,335 ha for inclusion in S-Map.

[14] Manaaki Whenua – Landcare Research soil scientists have completed field and laboratory work for the Catlins area, with soil maps on track to be upload to S-Map later this year. Reconnaissance trips to the Tuapeka West and Moa Flat areas will be undertaken over the coming months.

SOIL HEALTH MONITORING NETWORK

Background

[15] As defined by New Zealand's Land Monitoring Forum[3], soil health is the capacity of the soil to function and sustain biological productivity, maintain environmental quality, and

[2] The national S-Map database is available here: https://smap.landcareresearch.co.nz/

promote plant and animal health. Healthy soil provides flood mitigation, agricultural production, carbon storage, biodiversity, and nutrient, water and gas filtration and storage. [4] A reduction in soil health can result in lower agricultural yields, increased erosion, and less resilient soil and land ecosystems.

[16] Healthy soils are also resilient to a wide range of natural and human pressures such as climate and land use change. Monitoring soil is important to understand the pressures on the soil resource and support decision making[5].

Framework

[17] Under the RMA, Regional Councils have a legislative mandate to monitor, and report on the quality of soils. Specifically, monitoring and reporting on the 'life supporting capacity of soil' and the capacity of current practices to meet the 'foreseeable needs of future generations' is required.

[18] Soil monitoring follows the 'Soil Quality and Trace Element Monitoring' National Environmental Monitoring Standard[6] (NEMS) and analyses are completed by accredited laboratories.

[19] ORC is currently supporting an Envirolink Advice Grant awarded to Manaaki Whenua – Landcare Research to review soil health indicators. The aim of this work is to assist with interpretation of soil health data and ensure nationally consistent reporting.

Network establishment

[20] The soil health monitoring programme is designed to monitor long term trends in various indicators that inform the health of soil. These indicators determine the structural integrity, nutrient status and fertility of the soil and together give a robust gauge of soil health.

[21] ORC's land and soil scientists are currently establishing a regional State of the Environment (SOE) soil health monitoring programme, an activity undertaken by all regional councils in New Zealand. The monitoring programme requirements and methodologies are outlined by the national Land Monitoring Forum. This involves identifying a range of suitable sites and collecting small soil samples for assessment every 3-5 years (depending on the intensity of land use). It is planned to establish 10-15

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[3] Hill, R.B., Sparling, G.P. 2009. Soil quality monitoring. Land and soil monitoring: A guide for SoE and regional council reporting. Land Monitoring Forum. pp. 27-86.

[4] Ministry of Primary Industries. 2015. Future Requirements for Soil Management in New Zealand. National Land Resource Centre, Palmerston North.

[5] Taylor, M.D. and Hill, R.B., 2018. The 20 Year Evolution of the Waikato Region Soil Quality Monitoring Programme.

[6] National Environmental Monitoring Standard (NEMS), 2022. Soil Quality and Trace Elements - Sampling, Measuring, and Managing Soil Quality and Trace Element Data.

soil health SOE sites per year to develop a network of approximately 50 representative sites across the region.

[22] Establishing a soil SOE site involves digging a soil pit and formally describing the soil with a pedologist (soil scientist). Samples are taken along a 50 m transect using a plug sampler for chemical analyses, and undisturbed soil samples are collected for physical analyses, such as bulk density and porosity. Samples are sent to a laboratory for analysis. The soil description and sampling results are provided to the landowner.

[23] Since starting in Otago in 2021, 22 SOE soil health sites have been established across the region (Figure 2). These sites include six different land uses and five soil orders. The network will be expanded to be more regionally representative of land use, soil, climate, and area, with 10 new sites planned for 2023. These will include areas of unfarmed native cover (e.g., forest, tussock) which will provide important reference sites which are not subject to active land management (e.g., grazing, fertilizer, ploughing).

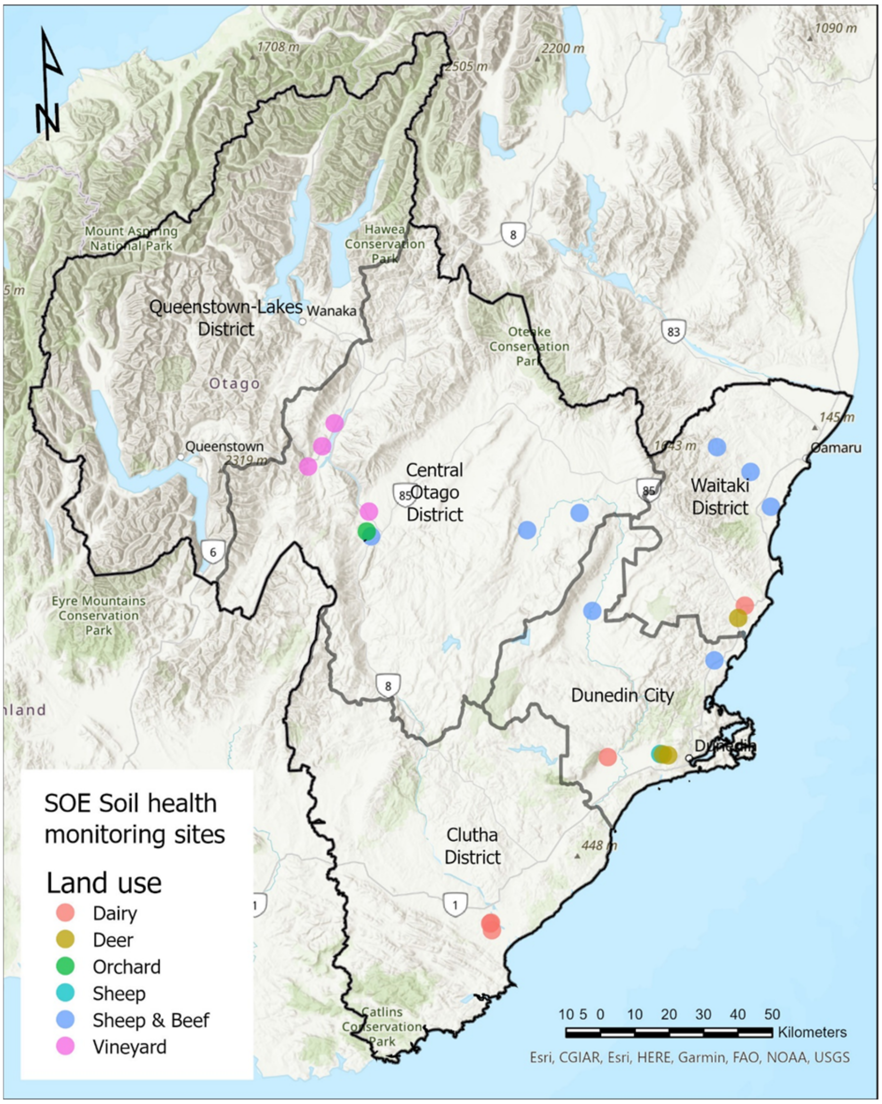


Figure 2. The location of current SOE soil health monitoring sites coloured by the land use classes. Lines are boundaries of Otago and regional districts.

[24] Information collected as part of the soil health monitoring programme will serve to document long-term trends in soil health and can be used to identify adverse effects of land use that can impact on soil properties (e.g., compaction, loss of organic matter). The monitoring programme will feed into the national SOE reporting for soil quality.

Initial results

[25] The real value of the soil health monitoring network will be as a longitudinal survey of soil over the coming decades, to enable quantification of any changes to the soil through time.

[26] The data collected over the past two years does allow initial comparison between different soil types and land uses. For example, Figure 3 below shows the compilation of some chemical parameters across different types of land use.

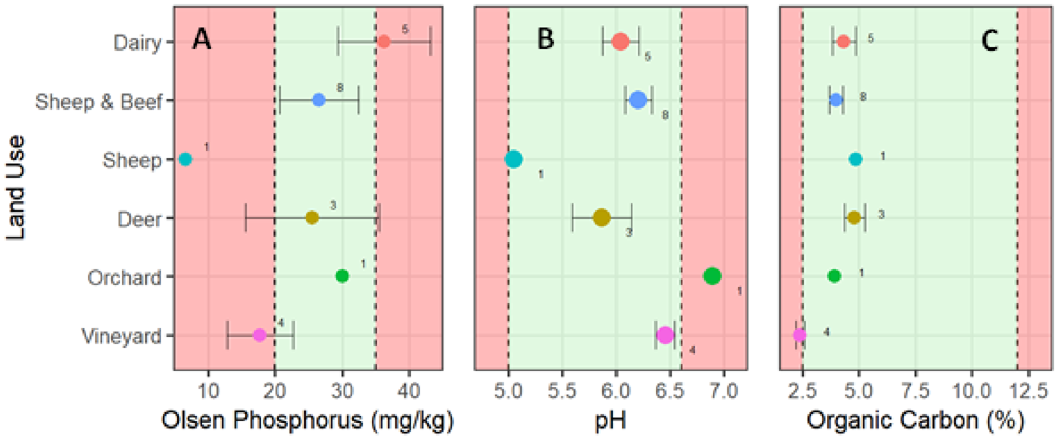


Figure 3. Soil chemical parameters A) Olsen phosphorus, B) pH, and C) organic carbon. The vertical dotted lines represent indicative lower and upper limits of the range for healthy soil. The error bars are the standard error of the mean and numbers next to points indicate the number of sites in each land use.

SOIL MOISTURE MONITORING NETWORK

[27] Soil moisture is the amount of water that is held in the soil column. Soil moisture measurements are widely used for determining the optimum timing and quantity of irrigation and can indicate when the soil is too saturated for safe effluent application to paddocks, or for land working.

[28] The ORC manages three long-established soil moisture sites in South Otago, with information available in near real-time through the ORC website, which is well utilised. In addition, ORC has recently installed or upgraded sites in Millers Flat, Slopedown, Paradise, and Karitane, (Fig. 4) with plans to expand the network with five further soil sites across the region.

[29] The ORC's recently installed high quality sensors record soil moisture and temperature at 10 cm intervals to a depth of at least 50 cm so the behaviour of moisture in the soil profile can be quantified. Soil moisture sensors are paired with a rain gauge, which expands the ORC rain gauge network.

[30] Soil moisture data can be used as a support tool for landowners who can access soil moisture information in their area in near real-time and can tailor their management, accordingly, minimising environmental impacts. In addition, data that is generated from the soil moisture monitoring network can be used to calibrate regional and national climatic models. For example, the NIWA national soil moisture deficit maps rely on water balance models that are calibrated using in-situ soil moisture data. The publicly available data can also be used to support stream flow and groundwater recharge monitoring, flood forecasting, drought modelling and water allocation studies.

[31] As several other agencies also measure soil moisture (including in Otago), NIWA were engaged to identify key gaps in Otago's soil moisture monitoring network in 2022[7] to ensure there are not inadvertent duplication of sites or environmental conditions. This assessment has been used to prioritise sites for future installations. Of note, Central Otago's semi-arid soils are rare in New Zealand and will be a focus of upcoming soil monitoring efforts.

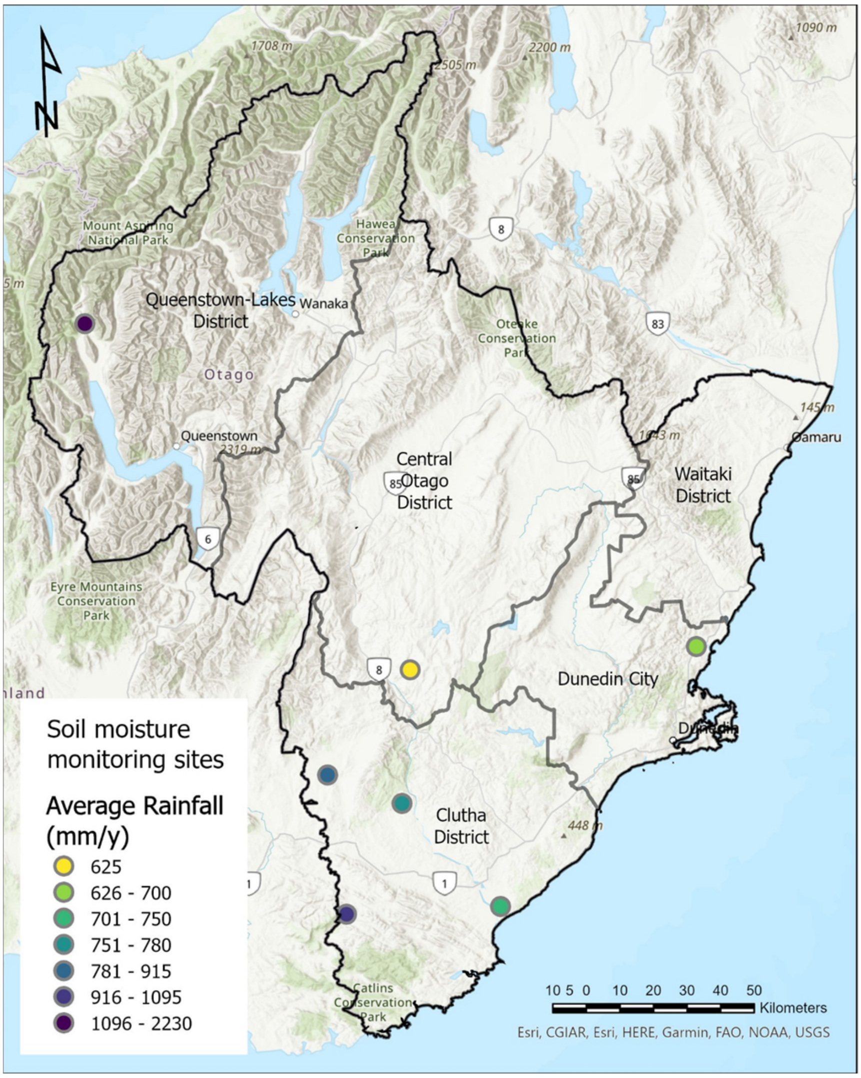


Figure 4. Locations of current ORC managed soil moisture sites relative to average annual rainfall.

[7] NIWA, 2022: ORC Rainfall, Climate and Soil Moisture Network Review. 172 pp.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[32] This work promotes best practice land management, for soil conservation, water quality and water use efficiency.

Financial Considerations

[33] The Land and Soil work programme is a funded and planned work stream

Significance and Engagement

[34] N/A

Legislative and Risk Considerations

[35] N/A

Climate Change Considerations

[36] Monitoring networks are being designed with climate change as a key consideration and will help to monitor any environmental changes in response to climate change.

Communications Considerations

[37] N/A

NEXT STEPS

[38] These projects will continue as outlined above.

ATTACHMENTS

Nil

6.2. 2022 Air Quality SOE Report

Prepared for: Environmental Science and Policy Comm

Report No. SPS2305

Activity: Governance Report

Author: Sarah Harrison, Scientist - Air Quality

Endorsed by: Anita Dawe, General Manager Policy and Science

Date: 26 April 2023

PURPOSE

This annual report presents the results of the State of the Environment (SoE) monitoring for air quality for the calendar year 2022.

EXECUTIVE SUMMARY

[1] Monitoring of particulate matter - PM_{10} and $PM_{2.5}$ - was undertaken at seven sites across Otago. Of the sites, Alexandra, Arrowtown and Mosgiel all recorded exceedances of the NESAQ[1] for PM_{10}during the winter months, with a total of 17 exceedances.

[2] $PM_{2.5}$ was monitored at Arrowtown, Central Dunedin, Clyde, Cromwell and Milton. There is currently no National Environmental Standard for $PM_{2.5}$ but one was proposed in 2020 and likely to be introduced in the updated National Environmental Standard for Air Quality(NESAQ).

RECOMMENDATION

That the Environmental Science and Policy Committee*:*

1) ***Notes** this report.*

BACKGROUND

[3] Otago has several towns where air quality is considered degraded during winter, namely Alexandra, Arrowtown, Clyde, Cromwell and Milton. Under the Resource Management Act 1991 (RMA) regional councils are required to monitor air quality, and improve it where necessary. The main pollutant of concern is particulate matter which is measured as PM_{10} and $PM_{2.5}$. Particulate matter are products of combustion. PM_{10} is all particle matter with a diameter of less than 10 micrometres (µm), while $PM_{2.5}$ consists of fine particles less than 2.5 µm.

[4] In Otago the main source of particulate matter is home heating emissions in winter (Wilton, 2019). Long term exposure to PM_{10} and $PM_{2.5}$ contribute to the risks of developing cardiovascular and respiratory conditions, or exacerbating existing conditions, which makes fine particulates a serious threat to human health (WHO, 2005). Furthermore, recent research provides evidence that air pollution is dangerous at lower concentrations than previously thought, and supports the lowering of existing guidelines (WHO, 2021).

[1] National Environmental Standards for Air Quality - the limit for PM_{10} is 50 µg/m³ over a 24-hour average

[5] ORC has an SOE monitoring network to monitor PM_{10} and is required under the NESAQ to report[2] exceedances (50 µg/m³, 24-hour average). The network is currently being upgraded to include monitoring for $PM_{2.5}$ in anticipation of the new standards being adopted. The upgrade process includes a twelve-month period of co-location and subsequent equivalence testing of the new instruments compared to the existing ones. Currently the instruments at Central Dunedin and Arrowtown have undergone this process for PM_{10} and will need to do the same for $PM_{2.5}$. For this reason, the $PM_{2.5}$ data presented in this report for these sites is uncorrected and cannot be compared to standards and guidelines.

[6] In the past, ORC has implemented a work programme as part of the Air Quality Strategy 2018 to help improve air quality in targeted towns. This has led to the long-term reduction in PM_{10} concentrations in Alexandra, Arrowtown, Cromwell, Clyde, and Milton (ORC, 2021). For regional context, Table 1 is reproduced from the 2021 air quality SOE report and shows the number of annual exceedances at monitoring sites from 2010-2019. Despite these improvements, significant reductions in emissions are still required for these towns to consistently comply with the NESAQ limit of 50 µg/m³ (24-hour average) for PM_{10}.

Site	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Alexandra - 65 Ventry Street	51	40	40	46	51	22	38			
Alexandra - 5 Ventry Street								3	2	6
Arrowtown - School	39	27	24	15						
Arrowtown - Alexander Place					48	30	32	45	29	19
Balclutha	2	4	13	4	3	9	10	14	5	
Central Dunedin	11	14	1	1	0	0	0	0	1	0
Clyde	40	23	9	10	21	10	18	23	6	4
Cromwell	43	27	30	33	49	27	34	41	13	13
Milton	46	20	37	44	14	30	35	48	16	20
Mosgiel	8	8	NA	5	5	7	9	9	4	4

Table 1. Number of NESAQ exceedances per site for 2010-2019. Shaded squares represent sites that were not in operation. Alexandra and Arrowtown monitors were relocated due to site availability (from ORC, 2021). See also Table 5 below.

AIR QUALITY ASSESSMENT FRAMEWORK

[7] Under the RMA, councils are required to monitor air quality and work towards meeting the standards of the NESAQ. The NESAQ is currently being updated to include limits for $PM_{2.5}$, with proposed limits released in 2020 (Table 2). The NESAQ is the legal standard for air quality in New Zealand. In 2021 the World Health Organization (WHO) released updated Air Quality Guidelines (AGL) which recommended new and stricter limits for pollutants (WHO 2021). The relevant standards and guidelines are given below (Table 2) alongside the WHO standards.

[2] The ORC currently reports exceedances monthly in the ODT by way of public notice.

Table 2 Standards and guidelines for PM_{10} and $PM_{2.5}$

Pollutant	Averaging Time	NESAQ 2004		Proposed NESAQ 2020		WHO 2021	
		Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances
PM_{10}	24-hour	50	1 per year	50	1 per year	45	3-4[b]
	Annual	20[a]	NA	NA	NA	15	NA
$PM_{2.5}$	24-hour			25	3 per year	15	3-4[b]
	Annual			10	NA	5	NA

[a] AAQG (Ambient Air Quality Guideline, 2002) limit and NESAQ guideline

[b] 99th percentile, means there can be 3 to 4 allowable exceedances per year

[8] The air quality results can also be categorised according to the Ministry for Environment (MfE) Environmental Performance Indicators (EPI), outlined in the Ambient Air Quality Guidelines (AAQG, 2002). The EPI categories indicate an appropriate action according to the concentrations (Table 3).

Table 3 MfE Environmental Performance Indicators for air quality

Category	Monitoring result compared to guideline	Description
Action	Exceeds the guideline	Unacceptable and action is required to reduce emissions
Alert	66-100%	Warning level which could lead to exceedances if trends are not curbed
Acceptable	33-66%	Maximum values might be a concern in sensitive locations, urgent action is not warranted
Good	10-33%	Peak measurements not likely to affect air quality
Excellent	0-10%	Not recommended for PM_{10} monitoring, PM_{10} in this range is classified as good instead

SOE MONITORING RESULTS: PM_{10}

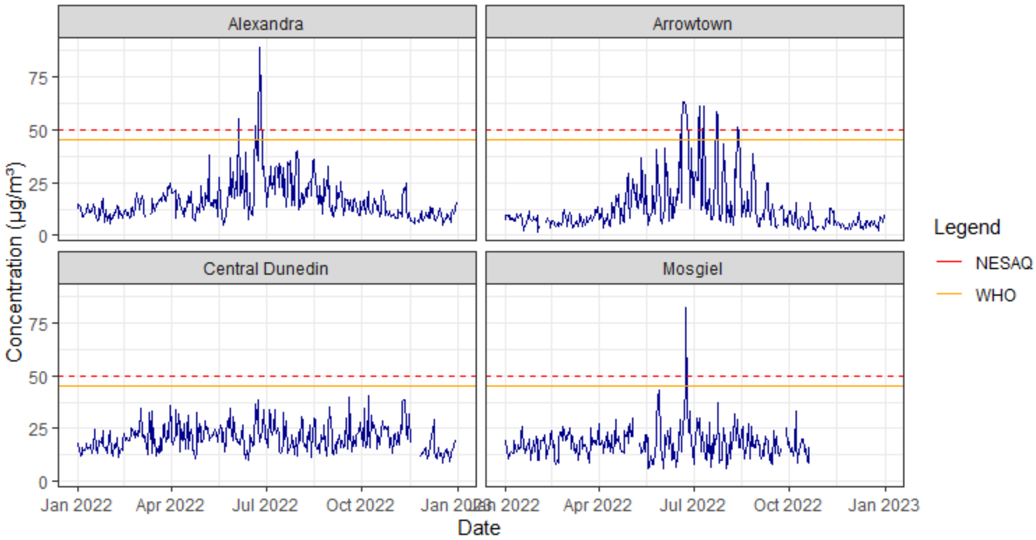
[9] PM_{10} was monitored at four sites in 2022: Alexandra, Arrowtown, Central Dunedin and Mosgiel. A summary of the key PM_{10} monitoring indicators for 2021 are given in Table 4, with a detailed breakdown of exceedances in Appendix 1. Arrowtown had the most NESAQ exceedances with 12, however Central Dunedin had the highest annual average of 20 µg/m³. Arrowtown and Alexandra had the highest winter means of 24 and 23 µg/m³, respectively. Alexandra and Mosgiel had the highest maximum 24-hour concentrations of 89 and 83 µg/m³, respectively.

Table 4 Key indicators for PM_{10}

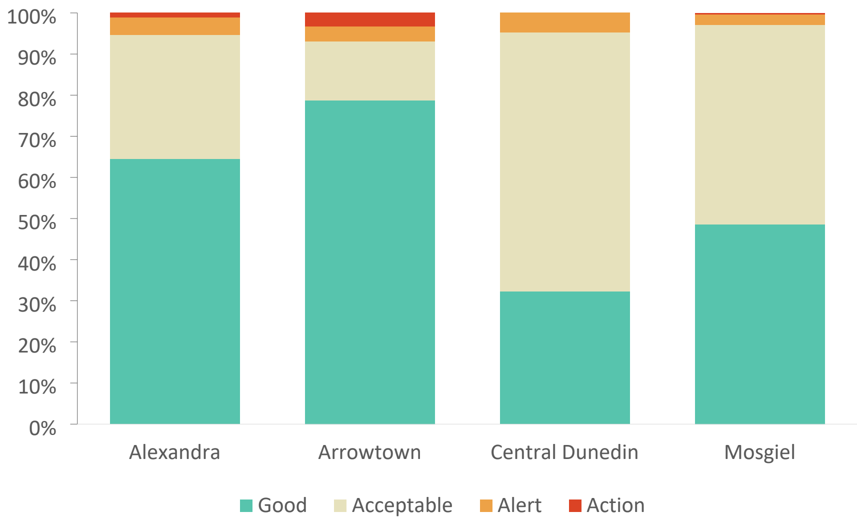
Site	Annual mean (µg/m³)	Winter mean (µg/m³)	Maximum daily concentration (µg/m³)	2nd highest daily concentration (µg/m³)	Number of NESAQ exceedances	Data capture (%)
Alexandra	16	24	89	64	4	98
Arrowtown	13	23	63	63	12	97
Central Dunedin	20	21	41	39	0	97
Mosgiel	18	20	83	46	1	76*

*Due to the site upgrade Mosgiel is missing data from 21st October onwards

[10] **Figure 1 PM_{10} concentrations for 2022 (24-hour average)**



[11] **Figure 2 PM_{10} concentrations as air quality indicator categories for 2022 (24-hour average)**



[12] When the PM_{10} data is categorised into MfE indicator categories, Central Dunedin and Mosgiel have the most data within the "acceptable" categories compared to Alexandra and Arrowtown which have between 60-80% of days in the "good" category. All sites have less than 10% of data in the "alert" and "action" categories (Figure 2). Only 30% of Central Dunedin's data was within the "good" category, compared to almost 70% in 2021. The most likely explanation for this is that there was significant construction taking place close to the air quality station during 2022. The air quality monitoring site has now been relocated 200m to the north-west.

[13] When compared to previous years, all sites except Arrowtown had higher annual averages. Both Arrowtown and Mosgiel had lower means than previous years (Figure 3). Arrowtown and Mosgiel had fewer exceedances than previous years (Table 5).

[14] **Figure 3 Annual PM_{10} means for 2022 compared to 2019-2021**

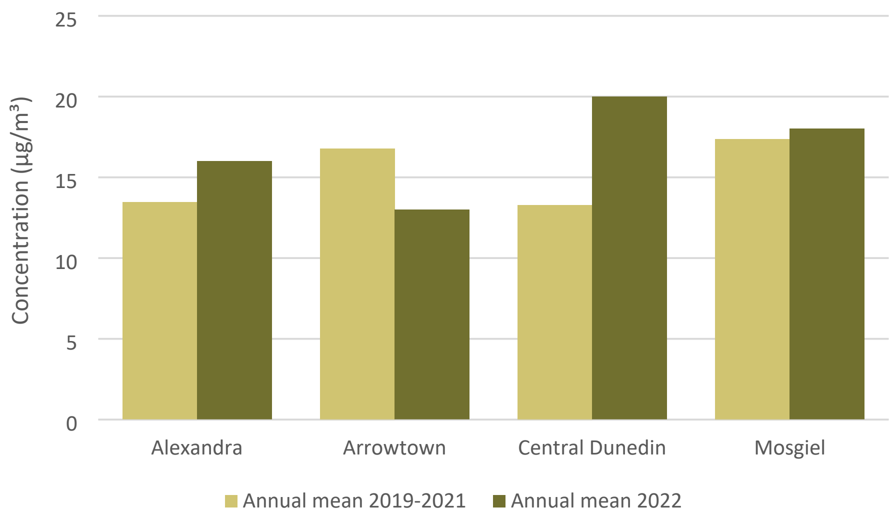


Table 5 Number of exceedances of PM_{10} for 2013 – 2022

Site	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Alexandra					3	2	6	6	3	4
Arrowtown		48	30	32	45	29	19	25	23	12
Central Dunedin	1	0	0	0	0	1	0	0	1	0
Mosgiel	5	5	7	9	9	4	4	5	4	1

SOE MONITORING RESULTS: $PM_{2.5}$

[15] $PM_{2.5}$ was monitored in five locations during 2022. Similarly, to PM_{10}, all sites except for Central Dunedin had high concentrations during the winter (Figure 5). The sites with high winter concentrations also had very low summer concentrations, bringing their annual averages lower than that of Central Dunedin. Arrowtown had the highest winter mean of 27 µg/m³, and Milton had the highest daily concentration of 126 µg/m³ (Table 6).

[16] Some of these values are higher than the PM_{10} averages and concentrations for the same site. This is because in Arrowtown and Central Dunedin, the new instruments have been used and correction factors are still required before these data can be compared to PM_{10} instruments, or to standards and guidelines. For Clyde, Cromwell and Milton, the instruments used are non-reference method and are unable to be compared to standards and guidelines, therefore the below data is provisional only.

Figure 5 $PM_{2.5}$ concentrations for 2022 (24-hour average)

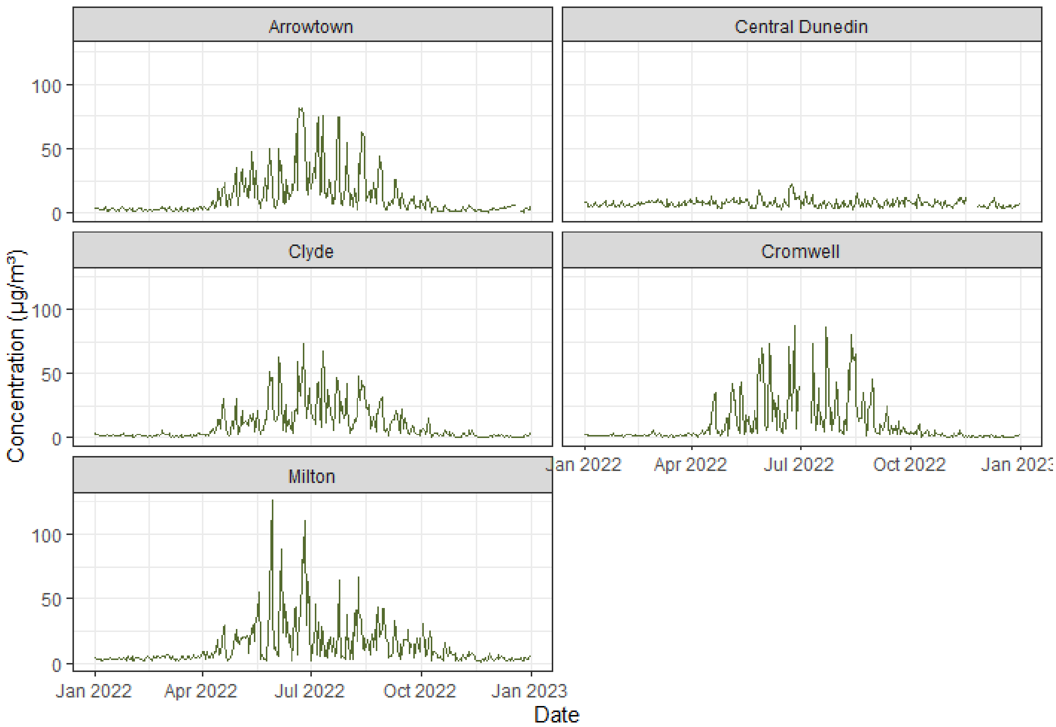


Table 6 Key $PM_{2.5}$ indicators for 2022

Site	Annual mean (µg/m³)	Winter mean (µg/m³)	Maximum daily concentration (µg/m³)	2nd highest daily concentration (µg/m³)
Arrowtown	12	27	81	81
Central Dunedin	7	8	22	20
Clyde	10	23	73	67
Cromwell	11	25	87	77
Milton	13	26	126	111

CONSIDERATIONS

Strategic Framework and Policy Considerations

[17] The work outlined in this paper contributes to the following elements of ORC's Strategic Direction

a. Monitoring air quality in the region and investigate pollution sources
b. Provide best available information on Otago's air quality

Financial Considerations

[18] The Air Quality work is a budgeted and planned activity.

Significance and Engagement Considerations

[19] N/A

Legislative and Risk Considerations

[20] N/A

Climate Change Considerations

[21] N/A

Communications Considerations

[22] ORC's Air quality communications ("Burn dry, breathe easy" campaign) will continue for winter 2023.

NEXT STEPS

[23] Monitoring site upgrades (Wanaka and Queenstown) will continue in 2023

[24] New proposal for monitoring network upgrades, including monitoring of $PM_{2.5}$ and NO_2 will be included for the next LTP cycle

ATTACHMENTS

Nil

REFERENCES

Otago Regional Council, 2021. *Air Quality 2010 – 2019 SoE Report.* State of the Environment Report, September 2021. https://www.orc.govt.nz/media/11935/soe-air-quality-state-and-trends-2010-2019.pdf

Wilton, E. 2019. *Wanaka, Cromwell and Clyde Air Emission Inventory – 2019*. Environet Ltd

World Health Organisation, 2006. *Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005: Summary of risk assessment.* Retrieved from https://www.who.int/airpollution/publications/aqg2005/en/

World Health Organisation, 2021. *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Retrieved from https://apps.who.int/iris/handle/10665/345329

APPENDIX 1: Exceedance table for 2022

Site	Alexandra	Arrowtown	Central Dunedin	Mosgiel
Date	**Concentration (µg/m³) 24-hour average**			
5/06/2022	55			
20/06/2022		52		
21/06/2022	52	63		
22/06/2022		63		
23/06/2022		61		
24/06/2022		61		83
25/06/2022	89	54		
26/06/2022	64			
6/07/2022		51		
7/07/2022		61		
11/07/2022		61		
23/07/2022		59		
24/07/2022		57		
12/08/2022		51		
Total number of exceedances	**4**	**12**	**0**	**1**

6.3. 2022 Air Quality Projects – NO2 & SO2 Monitoring and ULEB testing

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2310
Activity:	Governance Report
Author:	Sarah Harrison, Scientist - Air Quality
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	26 April 2023

PURPOSE

[1] This report presents the results of the two air quality projects undertaken during 2022: Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2) monitoring in Central Dunedin, and in home Ultra-Low Emission Burner (ULEB) testing in Arrowtown.

EXECUTIVE SUMMARY

[2] Nitrogen dioxide and sulphur dioxide were monitored in Central Dunedin for a period of three months, with the resulting concentrations compliant with the NESAQ limits.

[3] Ultra-low emission burner (ULEB) testing was undertaken within seven homes in Arrowtown, in order to accurately record the emissions from real-life use of the burners. This information contributes towards national understanding of the factors that influence emissions and efficiency of wood burners.

RECOMMENDATION

That the Environmental Science and Policy Committee*:*

1) ***Notes*** *this report.*

BACKGROUND

[4] In addition to required State of the Environment air quality monitoring, ORC air quality scientists periodically undertake specific projects to address key questions or monitor sites or parameters that are outside the regular SOE air quality monitoring programme.

NITROGEN DIOXIDE AND SULPHUR DIOXIDE MONITORING PROJECT

[5] A short-term project was undertaken at the Central Dunedin air quality monitoring site over the winter months of 2022 to monitor nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) using continuous gas analysers. Watercare Laboratory Services provided the sampling equipment and undertook the monitoring.

[6] NO_2 forms during the combustion of fossil fuels, and vehicle emissions are the main sources of NO_2 in urban areas. SO_2 is produced during the combustion of sulphur-containing fossil fuels such as coal. Diesel vehicle and industrial emissions are primary sources of SO_2 in Otago.

[7] Previous monitoring between 1998 and 2005 of NO_2 and carbon monoxide (CO) has been undertaken in Dunedin and Alexandra, and there were no exceedances of New Zealand standards or guidelines. Carbon monoxide (CO) concentrations have been significantly reduced in New Zealand (due to increased vehicle emission requirements), and concentrations are now much lower than the NESAQ (MfE, 2021), so monitoring for CO in the 2022 campaign was not considered necessary. The standards and guidelines for NO_2 and SO_2 are given in Table 1.

Table 1 Standards and guidelines for NO_2 and SO_2

Pollutant	Averaging Time	NESAQ 2004		AAQG 2002		WHO 2021	
		Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances
NO_2	1-hour	200	9				
	24-hour			100	NA	25*	3-4
	Annual					10	NA
SO_2	1-hour	350	9				
	1-hour	570	NA				
	24-hours			120	NA	40*	3-4

*99th percentile

[8] The results of the monitoring are shown in the following graphs. NO_2 concentrations were below the NESAQ 1-hour limit of 200 µg/m³, and the AAQG 24-hour limit of 100 µg/m³. On 01/08/2022 the 24-hour average NO_2 concentration was 29 µg/m³, an exceedance of the WHO guideline of 25 µg/m³ (Figure 1), however this guideline allows between 3-4 exceedances per year. SO_2 concentrations did not exceed any standards or guidelines (Figure 2).

Figure 1 NO$_2$ concentrations for July – November 2022

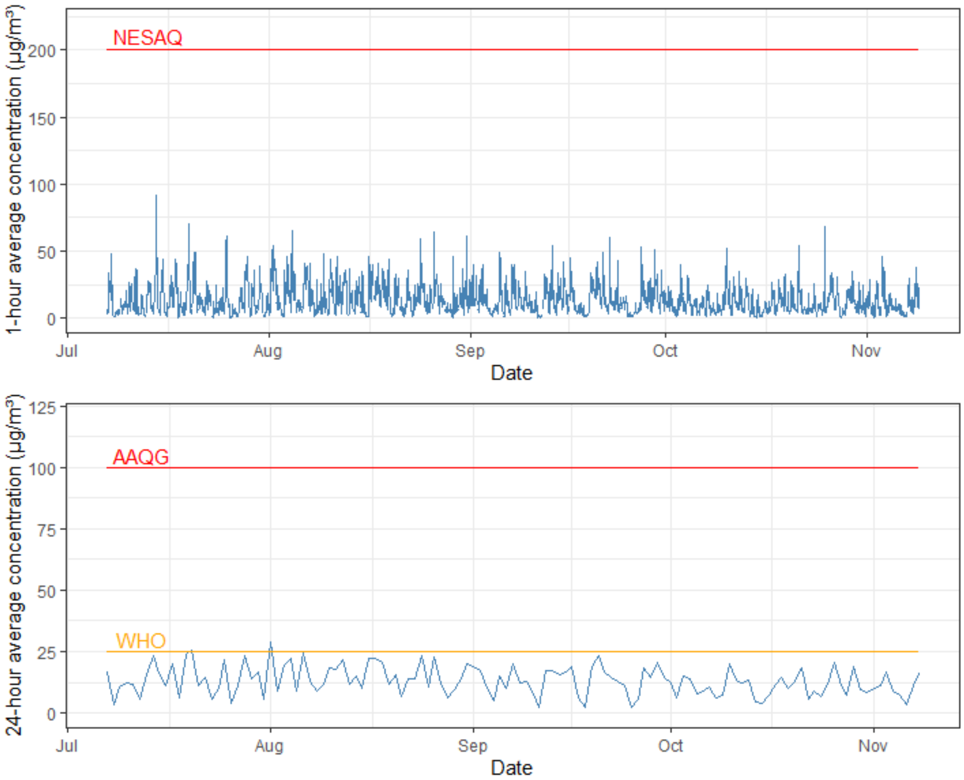
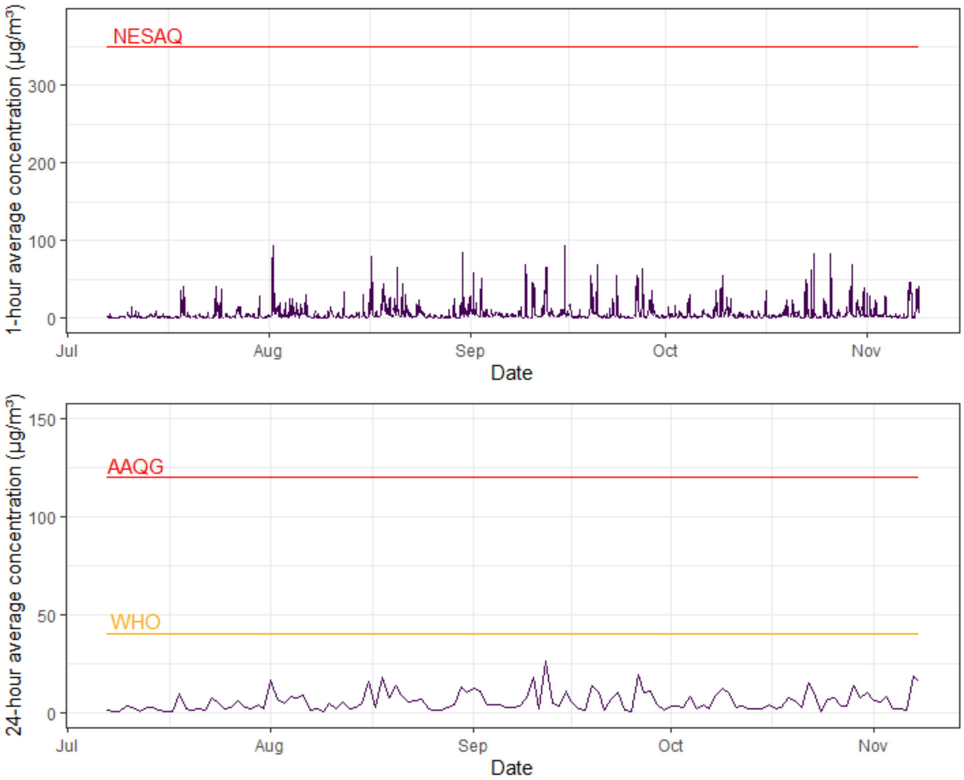
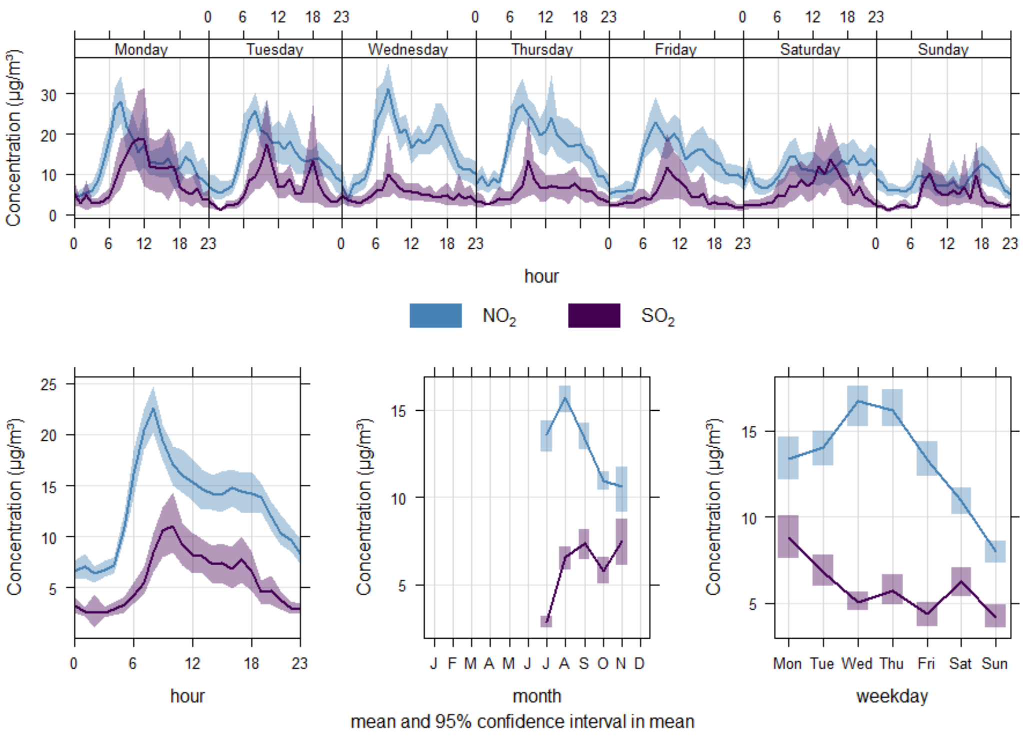


Figure 2 **SO_2 concentrations for July – November 2022**



[9] The time variation plots in Figure 3 show the concentrations of NO_2 and SO_2 averaged by time of day, month, and weekday. This shows that there are higher concentrations of NO_2 during the weekdays, which suggests traffic and industrial emission sources. Concentrations for both pollutants are elevated in the morning between 6am and noon, and are lowest at night. The month with the highest NO_2 concentrations was August, and the months with the highest SO_2 concentrations were September and November. SO_2 was lowest on Sundays, however there is not a strong pattern for day of the week like there is for NO_2.

Figure 3 Time variation for NO_2 and SO_2



REAL-LIFE EMISSIONS TESTING

[10] Ultra-low emission burners (ULEB) have been developed by various manufacturers in response to wood burner pollution in New Zealand and increased regulatory requirements. ULEBs are now effectively the only type of wood burner allowed to be installed in Air Zone 1 (Alexandra, Arrowtown, Clyde and Cromwell) under the Air Plan (Rule 16.3.1.2) that requires an emission rate of less than 0.7 g/kg, and an efficiency of >65%.

[11] However, the performance of ULEB's is known to differ under domestic use ('real life') in comparison to the controlled laboratory testing they undergo to become classified as an ULEB (Canterbury Method 1 test). The real-life emissions from a wood burner may vary by type of wood used (species, dryness, size, and weight of pieces), and the general use such as air flow settings, load size, and frequency of loading wood.

[12] ORC and other regional councils use emission inventories as tools to assess the impact of policies, rules, and interventions on the air quality of an airshed over time (e.g., Wilton, 2019). Emission inventories are calculated based on the number of consented wood burners (and other sources) within an airshed and their predicted emission rate. This testing of real-life emissions enables a more accurate estimate of overall emissions within an airshed; if default wood burner emission rates are used, then the contribution of ULEBs to an airshed's total particulate matter mass may be underestimated.

[13] During winter 2022, ORC contracted Applied Research Services to undertake testing and analysis of real-life emissions from ULEBs in Arrowtown. The report is attached as Appendix 1.

[14] Seven burners were tested within the homes of volunteers for seven days each. Testing involved placing an automated sensor inside the flue, and having participants document the weight, type, and timing of wood added to the fire, and the control settings. The in-flue sensor underwent daily maintenance by a technician.

[15] The tests found that the emissions varied between and within households (Figure 4), but the overall average was consistent with previous studies (Figure 5). The variability between the households strongly indicate that fuel type and operation of the burner have an impact on the emission rates (Applied Research Services, 2023). For example, HH7 used small pieces of wood, resulting in high flue temperatures, low emissions, but with low efficiency[1].

[16] The average emission rates from the national studies are compared in Figure 5. Previous studies include the testing of low-emission burners (LEB), which are burners compliant with MfE standards (emission rate <1.5 g/kg, and efficiency >65%) as well as ULEBs. This study contributes to a growing national body of real-life emission data from domestic wood burners.

Figure 4 **Emission rates by household. Source: Applied Research Services 2023**

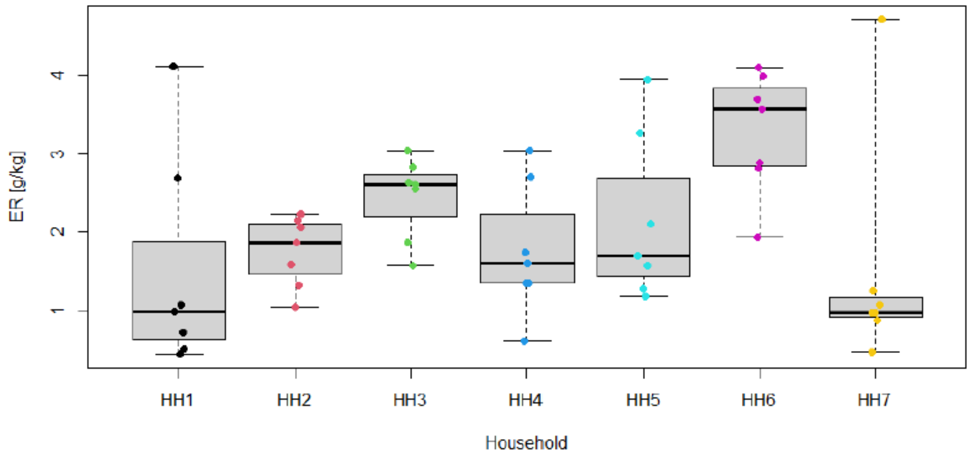
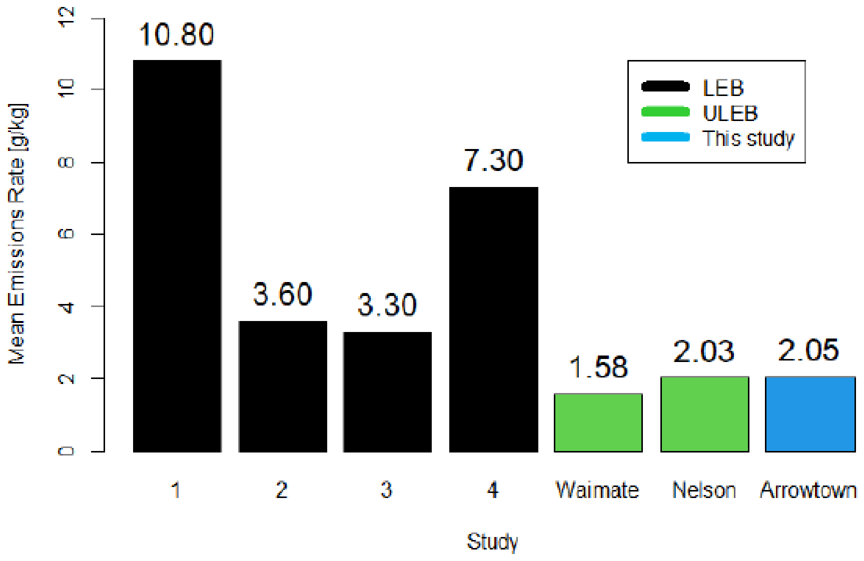


Figure 5 **Emission rates of all New Zealand real-life emission studies. Source: Applied Research Services, 2023**

[1] Emission rate and efficiency are a trade-off, as reducing emissions means that the fire is burning closer to complete combustion, which requires lots of oxygen. The more airflow supplied to the fire means that the more heat is lost up the chimney, thereby reducing thermal efficiency. Conversely, increasing the efficiency also increases particulate matter emissions.



CONSIDERATIONS

Strategic Framework and Policy Considerations

[17] The work outlined in this paper contributes to the following elements of ORC's Strategic Direction

a. Monitoring air quality in the region and investigate pollution sources
b. Provide best available information on Otago's air quality

Financial Considerations

[18] The Air Quality work is a budgeted and planned activity.

Significance and Engagement Considerations

[19] N/A

Legislative and Risk Considerations

[20] N/A

Climate Change Considerations

[21] N/A

Communications Considerations

[22] ORC's Air quality communications ("Burn dry, breathe easy" campaign) will continue for winter 2023.

NEXT STEPS

[23] New proposal for monitoring network upgrades, including monitoring of NO_2 will be included for the next LTP cycle.

[24] The ULEB study data will be shared with other regional councils in New Zealand and will inform future emission inventory studies of Otago airsheds.

ATTACHMENTS

1. Applied Research Ltd 2023 - Arrowtown wood burner testing [**6.3.1** - 31 pages]

REFERENCES

Applied Research Services Ltd, 2023. *Real Life Emissions from Wood Burning Heaters in Arrowtown*. Report 23/3115.

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Real Life Emissions from Wood Burning Heaters in Arrowtown

Customer: **Otago Regional Council**
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Report 23/3115 **February 2023**

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Attention: **Sarah Harrison**

Real Life Emissions from Wood Burning Heaters in Arrowtown

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1.0 Overview

In-home measurements of particulate emissions from domestic wood fired heaters were made in Arrowtown, Otago, during the winter of 2022. Tests were carried out by sampling flue gases using automated sampling equipment installed in participant's homes. While sampling was taking place the householders were asked to record information about what was loaded into the heater and how the controls were set.

This report summarises the information obtained during the sampling program.

2.0 Methodology

2.1 Location

Arrowtown is a small town in the Queenstown-Lakes District in Otago, 19 kilometres North-East from the larger resort town of Queenstown. It has high levels of wintertime air pollution from wood burning [1] which is associated with increased risks of diseases such as acute respiratory infection [2].

2.2 Selection of Households

A list of households willing to participate in the sampling program was provided to us by the Otago Regional Council (ORC). All the participants had wood burners as their main source of heating. ORC identified seven households willing to participate in the study. Six of the participants were located within the residential area of Arrowtown and one was located about 3 km south of the town. Table 1 below details the location and heater model for each participant.

Apart from households 1 and 7, all the households also had heat pumps as a secondary source of heating.

Household 2 had underfloor heating on their ground floor, although their wood burner and heat pump were on the first floor.

Table 1 The participants and their heater

Household	Location	Heater	Category
1	Centennial Ave, Arrowtown residential	Blaze King Chinook 30	ULEB
2	Adamson Street, Arrowtown residential	Woodsman Serene	ULEB
3	Norfolk Street, Arrowtown residential	Pyroclassic IV	ULEB
4	Nairn Street, Arrowtown residential	Pyroclassic IV	ULEB
5	Devon Street, Arrowtown residential	Pyroclassic IV Wetback	LEB
6	Thames Street, Arrowtown residential	Metro Wee Rad Ultra	ULEB
7	McDonnell Road, Arrowtown rural	Pyroclassic IV Wetback	LEB

2.3 The Heaters

Four out of five of the models tested in this program were 'Ultra-Low Emissions Burners' (ULEBs), a term coined by Environment Canterbury [3] to describe burners which "meet an emissions and efficiency standard of 38 milligrams per megajoule of useful energy" when tested to Canterbury Method 1 [4].

In two households a Pyroclassic IV had been fitted with a water heating coil (wetback). The heater fitted with wetback has been tested for compliance to the 'Low Emissions Burners' (LEBs) category of burners but not the ULEB category. The LEB term describes a burner which "meets an emission standard of 1 gram of particulate per kilogram of fuel burned or less, and have a thermal efficiency of 65% or greater" when tested to AS/NZS 4012 & 4013 test methods [5],[6].

The official test results obtained for the heaters when tested to these standards are given in Table 2.

All heaters tested in this study have a single combustion chamber (in contrast to the dual chamber heaters tested in Waimate in 2018 during a similar program [7].

2.3.1 Blaze King Chinook 30

Based on information in the operating manual for the Blaze King 30 Series [8] it has the following features: -

- A manually operated catalytic combustor located within the firebox at the top of the unit.
- The appliance has a thermometer that indicates when the catalytic combustor is active or inactive and therefore when the bypass should be engaged or disengaged. The bypass is manually operated using a handle located on the right side of the unit.
- A thermostat control that automatically adjusts the primary air intake and therefore the combustion rate and heat output. The thermostat knob, located at the rear of the appliance, can be set anywhere between a low and a high setting.

The operating manual notes the following requirements for operating the heater: -

- During the initial light-up phase, the bypass should be in the open position and the thermostat knob set to high and that the door must remain ajar until the first intermediate load is fully on fire.
- The bypass should be closed only once the catalytic thermometer needle is in the active zone. The thermostat must remain at a high setting for 20 to 30 minutes.
- The bypass must always be open before opening the loading door.
- The heater must be operated at a high setting for 20 to 30 minutes after every reload of wood.

Figure 1 Location of Controls on the Blaze King Chinook

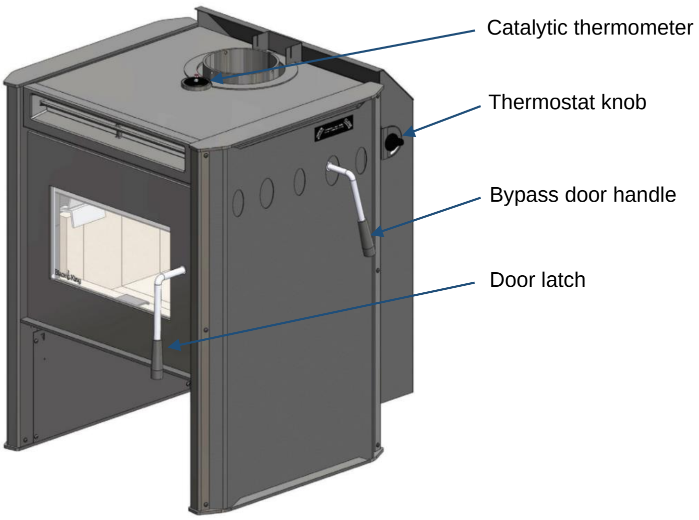

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Table 2 Published Test Results for the five tested heaters [3]

Test Method	**Canterbury Method 1**	**AS/NZS 4012/3**
Appliance name	**Blaze King Chinook 30**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	28 mg/MJ	22 mg/MJ
Emission rate	0.38 g/kg	0.30 g/kg
Efficiency	68%	69%
Water heater	None	None
Approval number	182697	182628
Appliance name	**Woodsman Serene**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	26 mg/MJ	not supplied
Emission rate	0.33 g/kg	0.36 g/kg
Efficiency	63%	66%
Water heater	None	None
Approval number	194586	193597
Appliance name	**Pyroclassic IV**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	33 mg/MJ	20 mg/MJ
Emission rate	0.44 g/kg	0.30 g/kg
Efficiency	67%	74%
Water heater	None	None
Approval number	194576	121121
Appliance name	**Pyroclassic IV Wetback**	
Situation		Freestanding
Fuel type		Dry wood
Emission		17 mg/MJ
Emission rate		0.30 g/kg
Efficiency		65%
Water heater		Yes
Approval number		121122
Appliance name	**Metro Wee Rad Ultra**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	35 mg/MJ	26 mg/MJ
Emission rate	0.46 g/kg	0.35 g/kg
Efficiency	66%	67%
Water heater	None	None
Approval number	191262	191263

2.3.2 Woodsman Serene

The Woodsman Serene is a single chamber burner with a cuboid firebox. It has an air slide to adjust the level of combustion. The location of the control is shown in Figure 2. The Serene instruction manual [9]indicates that the door should be fully closed from the start and that before reloading the air slide should be set to the high setting for 5 minutes.

Figure 2 Location of Controls on the Woodsman Serene

2.3.3 Pyroclassic IV and Pyroclassic IV Wetback

The Pyroclassic IV and Pyroclassic IV Wetback have the same tubular ceramic firebox. It has an air slide to boost the air supply when starting up the heater and when reloading.. The location of the controls is shown in Figure 3. The instruction manual [10] indicates that the air slide can be set to low ten minutes after the third intermediate fuel load has been loaded, or approximately 80 to 90 minutes after starting up and that the air slide must be set to high at each refuelling, then can be lowered when the new load of fuel is well lit.

The heater in household 3 was fitted with a 150 mm flue. The heaters in households 4, 5 and 7 were fitted with a 100 mm flue. Households 5 and 7 had a Pyroclassic IV fitted with a wetback.

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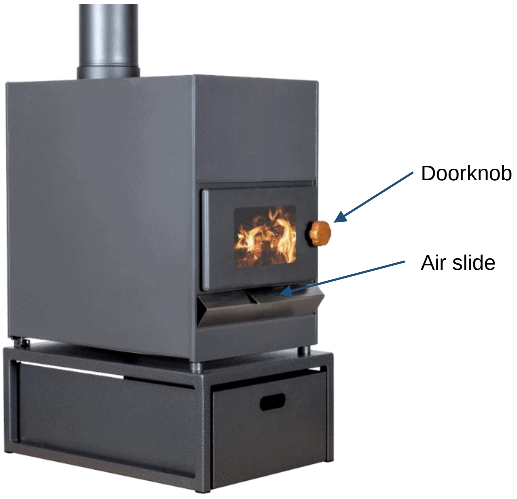
Figure 3 Location of Controls on the Pyroclassic IV and Pyroclassic IV Wetback



2.3.4 Metro Wee Rad Ultra

The Metro Wee Rad Ultra is a single chamber burner. It has an air slide to adjust the level of combustion. The location of the control is shown in Figure 4.
The instruction manual [11] indicates that the air slide must be set to high before opening the door and that after each refuelling, the air control must be left on high until the fire is re-established.

Figure 4 Location of Controls on the Metro Wee Rad Ultra

2.4 Fuel

Each household was asked to burn whatever they would normally burn, using their own firewood stack. Information on the wood species is based on information supplied by the householders.

Household 1 burned a mix of split gum logs and Douglas fir logs. This household usually doesn't use much kindling as they run their heater non-stop. When they need to carry-out a start-up, they use firelighters and either small pieces from their firewood stack or a bag of kindling from the supermarket. The firewood stack was located near the wood burner inside the living room; so the firewood was always at room temperature and not subjected to weather.

Household 2 burned a mix of split gum and pine logs and used cedar decking offcuts for kindling. Pine-cones, newspaper, then cardboard or dried leaves (when available), were used for start-up. Their firewood stack was outside, well covered with good airflow.

Household 3 burned a mix of split gum and pine logs. They use kindling from their firewood stack and pine-cones for the start-up. Their firewood stack was outside under the deck, mostly covered from the rain and with good airflow.

Household 4 burned split blue gum logs. They use kindling from their firewood stack and firelighters for the start-up. Their firewood stack was outside, well covered with good airflow. Their heater had a large, raised hearth with a wood storage drawer underneath it. The householders were storing their firewood for the day in this drawer to keep it at room temperature and potentially dry it.

Household 5 burned split larch logs. They use kindling from their firewood stack and reusable firelighters which are soaked with methylated spirits before use [12]. Their firewood stack was outside, well covered with good airflow.

Household 6 burned a mix of split pine, Oregon pine (Douglas fir) and gum logs. They use newspaper, small logs from their firewood stack and pine-cones for the start-up. Their firewood stack was outside, well covered with good airflow.

Household 7 burned cut up pallet wood. They used newspaper and small pieces cut from the pallets as kindling for the start-up. Their pallet stack was outside, loosely covered with a tarpaulin. The householder was cutting up a couple of pallets every couple of days, then putting the pieces in cardboard boxes in the lounge by the wood burner. This allowed the firewood to be at room temperature and to dry.

The moisture content of a representative portion of the fuel was measured on-site with an electronic moisture meter (Carrel Electrade C901 with hammer probe). For household 2, the cedar pieces were too small and too hard to allow the moisture content to be measured on site. Its moisture content was determined in our laboratory by oven drying.

All seven households burned dry wood (fuel moisture < 20% on a wet weight basis (wwb)).

In addition, wood samples from each household were returned to the laboratory for determination of density. The resin content of a composite sample from each household was determined using a method based on ASTM-D1108-96. The composite was prepared based on the proportion of each fuel burned by the household during the test period. The resin content and density results relate only to the samples analysed in the laboratory and may not be representative of all the fuel burned.

Information on the fuel is given in Appendix 2.

2.5 Data Recorded by Householders

Participants were asked to complete a worksheet during each run on which they recorded details of the operation of the heater and the weight and description of what was burned. An example of this worksheet is shown in Appendix 3. A set of electronic kitchen scales was provided for this purpose. Households varied in the level of information they provided on these worksheets.

2.6 Emissions Sampling

A portable emissions sampler was installed in each household for the duration of the tests. Details of this sampler are given in our Technical Bulletin 72 (Appendix 1). Results from the sampler can be used to calculate an emission rate in g/kg (dry wood basis) independently of any information recorded by the householder. The samplers operate when the flue gases are above 90 °C.

The sampling equipment is designed to be set up and monitored by trained technicians. A staff member from our Nelson laboratory (Gus Roux) stayed in Arrowtown during the test program to maintain the samplers and carry out daily changes of filters and desiccant.

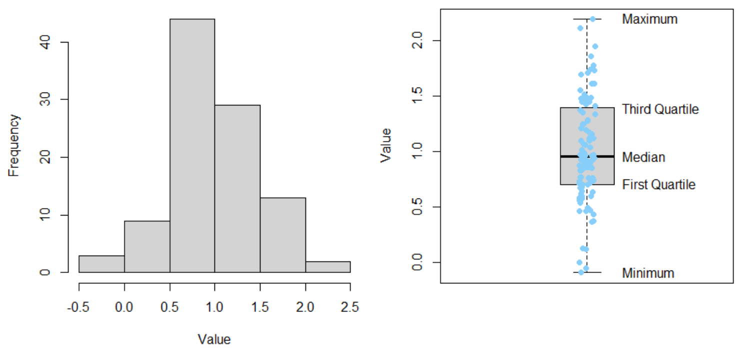
There were two samplers operating during the test program and seven days of testing were completed at all seven participating households. Test dates for each household are given in Appendix 4.

2.7 Statistical Analysis

Statistical analysis was carried out using R [13], p-values are given at the 95% confidence level. Where data has been fitted to a log-normal distribution both geometric and arithmetic mean (average) results are given as each is appropriate for particular uses. Confidence intervals for the arithmetic mean of log-normally distributed data were calculated using Land's method [14] as implemented in the EnvStats package for R [15].

In some cases, the distribution of data is shown using box and whisker plots such as that on the right of Figure 5. This is a convenient way of visualising the distribution of large numbers of data points, where the individual points (shown in blue) may be omitted. A quartile is the range of values that contain 25% of the data points. The same data is shown on the left of Figure 5 in a histogram which gives the number of observations that fall in a particular range.

<u>**Figure 5** Examples of Histogram and Box and Whisker Plots</u>



3.0 Results and Analysis

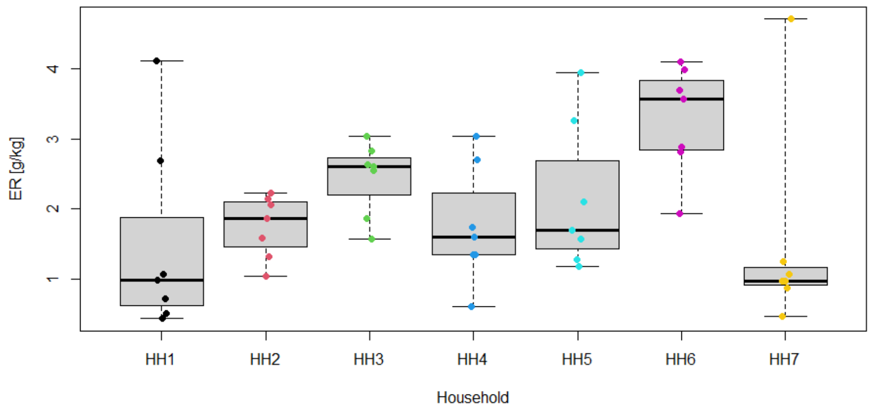
3.1 Emissions Data

Emission rates expressed as grams of emissions per kilogram of fuel on a dry weight basis are given in Table 3 and shown graphically, by household, in Figure 6.

Table 3 Emission Rates

Emission Rates [g/kg]		Household						
		1	2	3	4	5	6	7
Run	a	1.0	1.3	2.5	1.3	3.3	3.7	4.7
	b	0.4	1.9	3.0	1.3	1.2	1.9	1.0
	c	2.7	1.0	2.6	1.7	1.3	4.1	1.2
	d	0.5	2.1	1.9	2.7	2.1	3.6	1.0
	e	0.7	2.1	1.6	3.0	1.7	2.8	1.1
	f	4.1	2.2	2.6	0.6	1.6	4.0	0.5
	g	1.1	1.6	2.8	1.6	3.9	2.9	0.9
Mean		1.5	1.7	2.4	1.8	2.1	3.3	1.5

Figure 6 Emission Rates by Household



Overall, the emission rates range from 0.4 to 4.7 g/kg with an overall arithmetic mean of 2.05 g/kg. The arithmetical means of the individual households are presented in Table 3

The distribution of emission rates is approximately log-normal (p = 0.15 for the Shapiro-Wilke test) with an approximately linear diagnostic plot (see Figure 7). On this basis the overall emission rate data has a geometric mean of 1.74 g/kg. Assuming a log-normal distribution for the emission rates, the 95% confidence interval for the arithmetic mean emission rate is estimated to be 1.76 and 2.58.

Four of the households (households 3,4,5, and 7) had a Pyroclassic IV heater, two of which (Households 5 and 7) were fitted with a wetback. There is considerable variability in the median emission rates for these four households which indicates that installation, fuel and operating procedures have a significant effect on the overall results.

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Figure 7 Diagnostic Plot showing near normality of log(ER) data

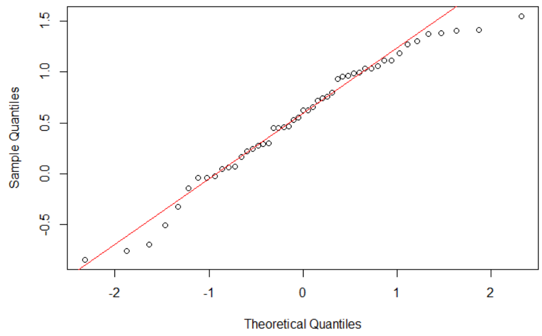
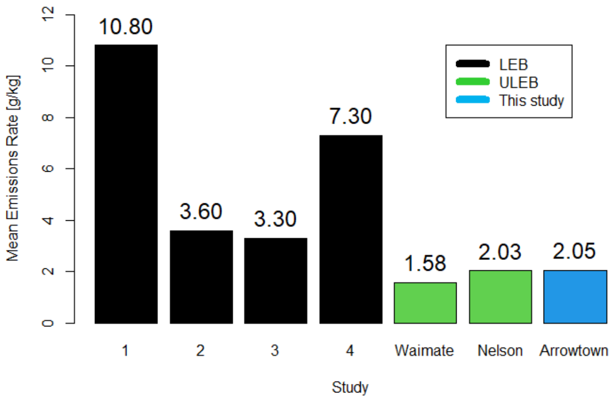


Figure 8 gives a comparison of the results of this study with those from earlier studies. The average emission rate for the seven heaters in this study is lower than the average emission rates obtained from 4 similar studies on single chamber LEB wood burners which achieved emission rates below 1.5 g/kg when tested to AS/NZS 4012/3. These studies are represented by bars 1, 2, 3 and 4 in Figure 8.

The 'Waimate' bar in Figure 8 gives the result of a previous in-home study carried out in 2018 in Waimate on downdraft ULEBs [7]. Downdraft burners have two combustion chambers. The gases flow from the burning fuel in the upper chamber down into a lower chamber for additional combustion time.

The 'Nelson' bar in Figure 8 gives the results of a study carried out in 2021 in Nelson on single combustion chamber ULEBs [16].

Figure 8 Comparison with Earlier Studies



3.2 Other Data

Although the primary focus of the test program was to measure emission rates, additional information was obtained during this test program which is relevant to understanding the performance of the appliances and the impact of wood burning on the air shed in general.

3.2.1 Flue Temperatures

Flue gas temperature is an important variable in combustion analysis. It varies with time and depends on parameters such as the type of fuel, the design of the heater, the control settings on the heaters or how the fuel is loaded in the fire box. Flue temperatures were recorded at 30 second intervals while the samplers were running. The samplers run when the flue temperature is above 90 ^{o}C. This avoids blockage of the sampling probe by condensation. The flue gas velocities are much lower below this temperature because the flue draft depends on flue temperature and so the quantity of emissions at lower flue temperatures is expected to be small.

Table 4 gives the average flue temperature for each household and the distribution of flue temperature for each household is summarised in Figures 9 and 10.

Table 4 Average Flue Temperature by Household

Average Flue Temperature [Degree C]	Household						
	1	2	3	4	5	6	7
	154.9	188.7	165.5	219.6	180.0	175.5	239.4

Household 7 (burning pallet wood) had the highest mean and maximum flue temperatures and lowest overall emissions with one outlier. However when all the appliances in the study were considered there was no significant correlation between the daily emission rates and the mean efficiency ($p=0.06$) or flue temperature ($p=0.06$). Other factors such as the appliance type, installation and fuel quality also have a significant effect on emission rates.

On average, Household 1 had the lowest flue temperatures of the households tested and this is associated with low air control settings (see section 3.2.3). This resulted in a higher operating efficiency (see section 3.2.2) but created issues with deposition of creosote in the flue (see section 3.2.7). The lower flue temperatures were probably the result of both the thermostat setting (see section 3.2.3) and the large fuel loads burned in this appliance (see section 3.2.5)

Figure 9 Flue Temperatures by Household

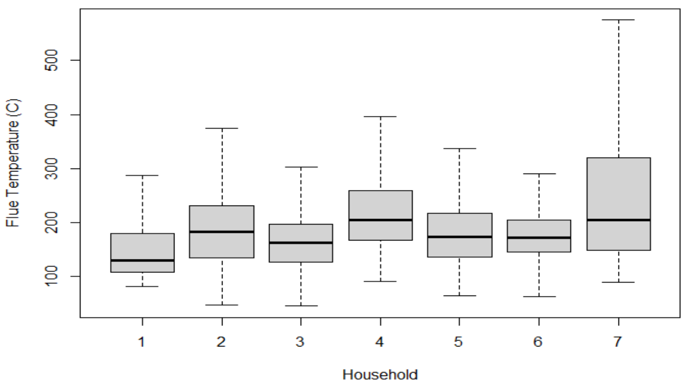
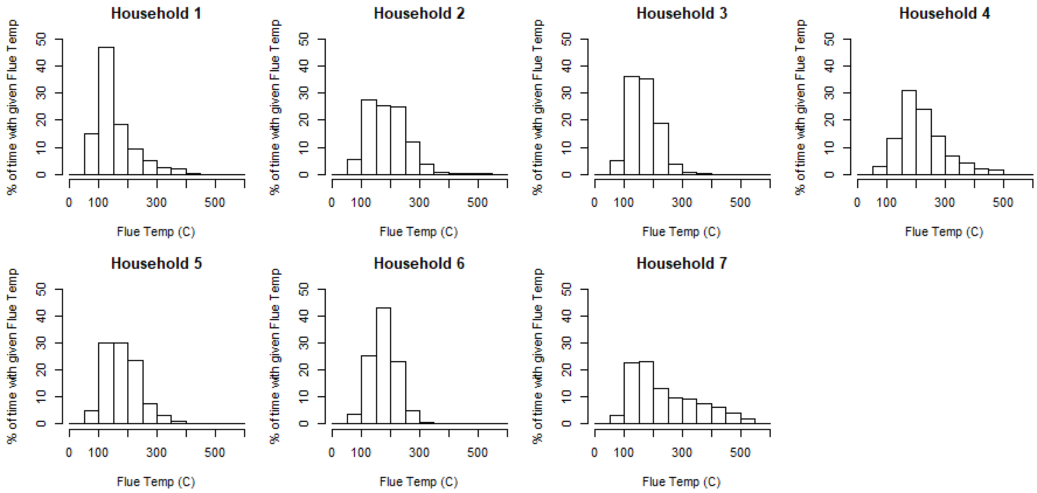


Figure 10 Flue Temperature by Household



3.2.2 Efficiency

The efficiency of each appliance was estimated at 30 second intervals from an analysis of the flue gas composition and flue temperature using the stack loss method (Ref. 9). Figure 11 shows the distribution of efficiencies obtained for all these 30 second intervals. The estimated efficiency by household is given in Table 5 and shown graphically in Figure 12. The average efficiency was 64%. Apart from the Blaze King in Household 1, the average efficiencies estimated for each heater are lower than those obtained during testing to CM-1 or AS/NZS 4012/3.

There is a significant ($p = 1.7 \times 10^{-5}$) negative correlation between efficiency and flue temperature, but flue temperature explains only some of the variation in efficiency ($R^2 = 33\%$). The degree of correlation can be seen in Figure 13.

The Blaze King was operated in a way that gave low flue temperatures which contributed to the high efficiency but caused creosote build-up in the flue (see section 3.2.7). Conversely the Pyroclassic with wetback in Household 7 was operated in a way that gave high flue temperatures and largely low emissions but at the cost of efficiency.

Overall, there was no significant correlation between the daily emission rates and the mean efficiency (p=0.06).

Figure 11 Estimated Efficiency of the Heaters during the Program

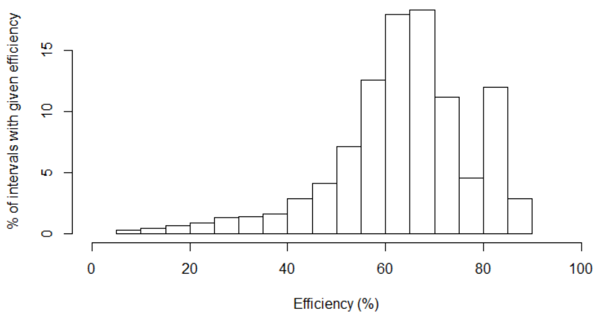


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Table 5 Estimated Efficiency by Household

	Household						
Estimated Efficiency (%)	1	2	3	4	5	6	7
	79	58	61	58	63	59	53

Figure 12 Estimated Efficiency by Household

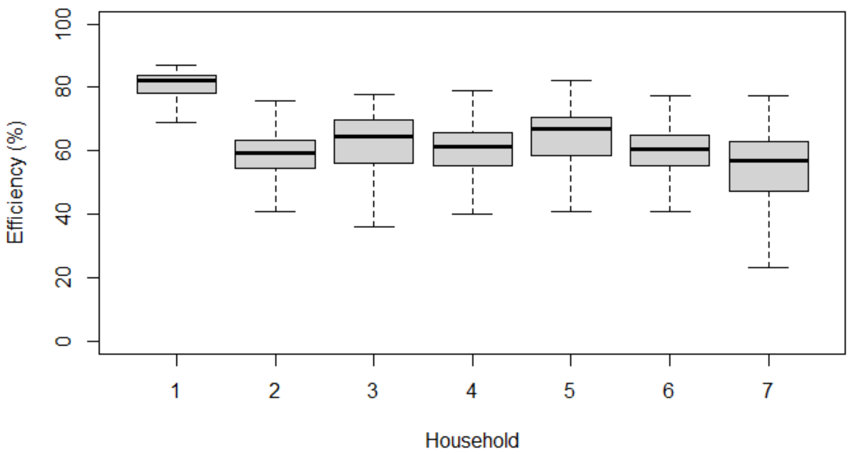
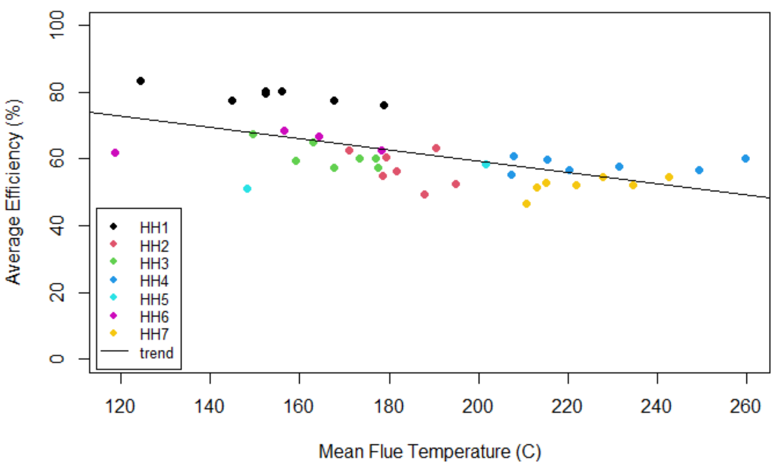


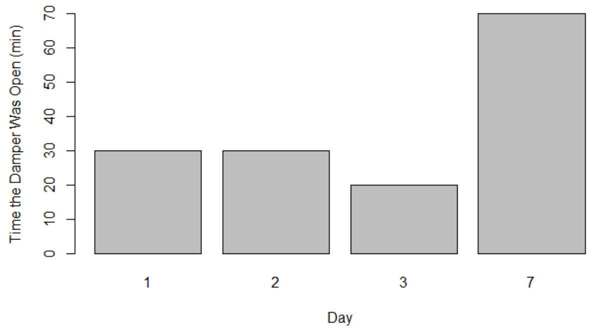
Figure 13 Correlation between Efficiency and Flue Temperature



3.2.2 Bypass Position

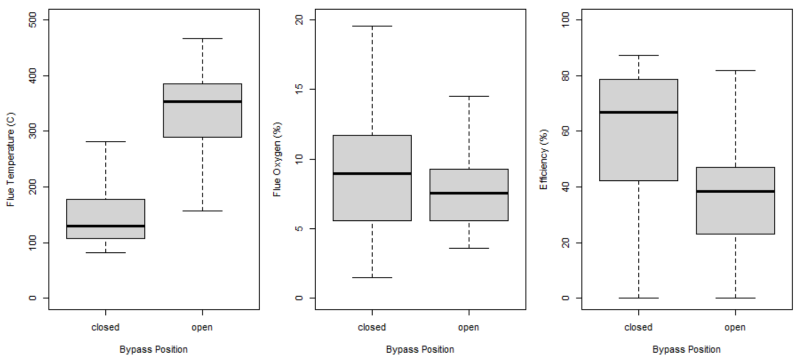
The Blaze King Chinook 30 heater in household 1 has a catalytic combustor. The combustor is enabled when the bypass is closed. The householder was asked to record the bypass position on their daily worksheets. They used the heater with the bypass open 4 times when they had to relight their fire. Short periods when the bypass door was opened for refuelling have not been included in the analysis. The bypass was open for 2.1% of the time the heater was operating. The length of time the damper was open (on each occasion it was opened) is summarised in Figure 14. The householder indicated that the damper was not opened on days 4, 5, and 6.

Figure 14 Length of time the Damper was Open



When the bypass was open, flue temperatures were significantly ($p< 10^{-16}$) higher (by 185 ^{o}C on average), flue oxygen levels were slightly lower and the efficiency was significantly ($p< 10^{-16}$) lower (by 23 %) (Figure 15). Because the damper is only open for a short time the overall efficiency of the heater is not significantly affected.

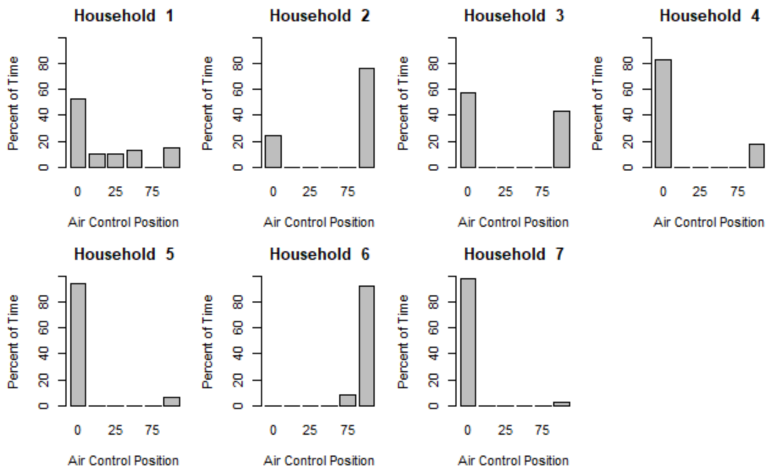
Figure 15 Effect of Bypass Position (Blaze King, Household 1)



3.2.3 Air Control

All appliances had a combustion air control, but it differed in its mode of operation depending on the appliance. The Blaze King (Household 1) had a thermostat which uses a bimetallic element to regulate the air flow. The Serene (Household 2) and Wee Rad Ultra (Household 6) have a slide which regulates the primary air supply in order to control the output. The Pyroclassic heaters (households 3, 4, 5 and 7) have a turbo control which is intended to boost the primary air on startup and reloading but otherwise remain closed. The householders were asked to record the air control position on their daily worksheets and the results are summarised in Figure 16. Households 4,5 and 7 used their Pyroclassic heater with air slide mostly closed as expected. Household 3 did not follow the same method for recoding control settings as the other household and we think they may have omitted to note some of the times when the air slide was closed.

Figure 16 Length of time the Air control was Open/Closed



The Blaze King in Household 1 was operated predominantly with its thermostat on the low setting which was associated with low flue temperatures and the associated issues (see section 3.2.7).

3.2.4 Wood Moisture

All seven households burned well-seasoned wood with a moisture content below 20% on a wet weight basis (see Appendix 1). The small number of households and limited range of wood moisture preclude any reliable analysis of the effect of wood moisture on emissions for this data set.

3.2.5 Fuel Loading

All households recorded information on the weight of wood that was burned during the sampling program. The quality of this information varied but appears to be reasonably accurate for all households.

The overall distribution of weights is shown in Figure 17, while Figure 18 shows the individual load weights for each household along with the corresponding box plot. The mean wood load over all tests was 2134 g. All the households used a range of load sizes but those used by household 1 were noticeably larger.

No correlation (p=0.3322) was found between the mean load weight and the mean emission rate for each household.

Figure 17 Weight of Fuel per Load for All Loads

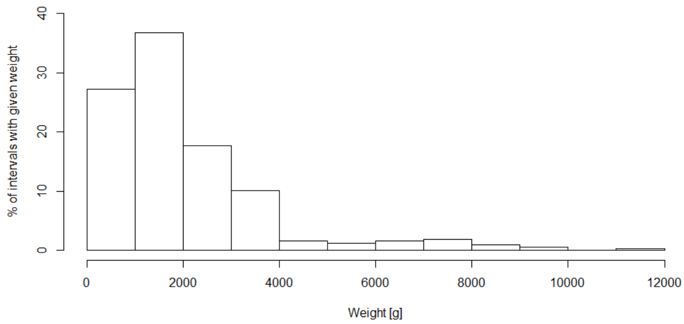
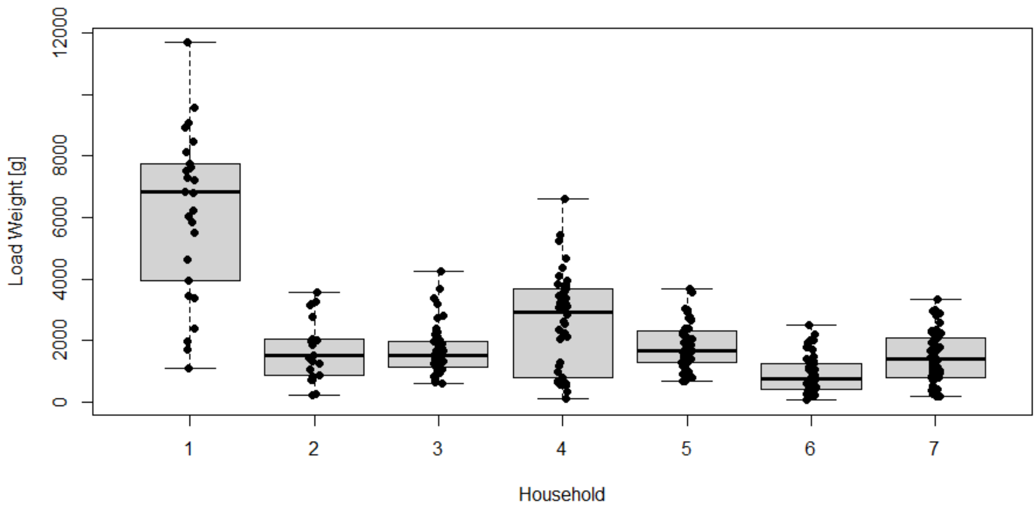


Figure 18 Weight of Fuel per Load by Household



3.2.6 Time of Day of Heater Operation

Table 6 shows the proportion of time the portable samplers were operating (flue temperature > 90 ºC), on average, over each hour of the day. This gives a good indication of when the heaters were being used. For example, the value of 94.5% at 19 indicates that during the test program the heaters were in-use with flue gases above 90 degree C, on average, 94.5% of the time between 19:00 and 20:00.

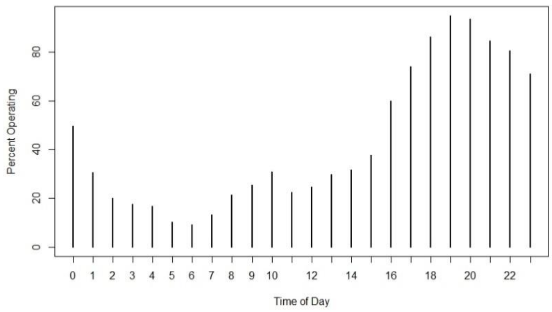
Overall, the samplers were operating and recording data 43% of the time they were installed at the participants' households. The rest of the time the samplers were on idle.

This information is shown graphically in Figure 19. The data is based on runs from all seven households.

Table 6 Relative Frequency of All Heaters Operation as a Function of Time of Day.

Time	0	1	2	3	4	5	6	7	8	9	10	11
% Operating	49.5	30.6	19.9	17.5	16.7	10.1	9.2	13.1	21.5	25.4	31.0	22.3
Time	12	13	14	15	16	17	18	19	20	21	22	23
% Operating	24.7	29.8	31.6	37.7	60.0	74.1	86.2	94.9	93.7	84.7	80.5	71.1

Figure 19 Time of Day Profiles for All Heaters Use



The same information is broken down, by household, in Figure 20

The heater in household 1 was operated throughout the day and night (the householders work from home). Overall, their heater was operating for about 66% of the time.

The householders in household 2 were back home after work in the afternoon during most the weekdays. They were mostly using their wood burner in the afternoon and evening. Overall, their heater was operating about 19% of the time.

The householders in household 3 were mostly home all day as they were working from home and with a young child, therefore they were using their wood burner all day. Overall, their heater was operating about 53% of the time.

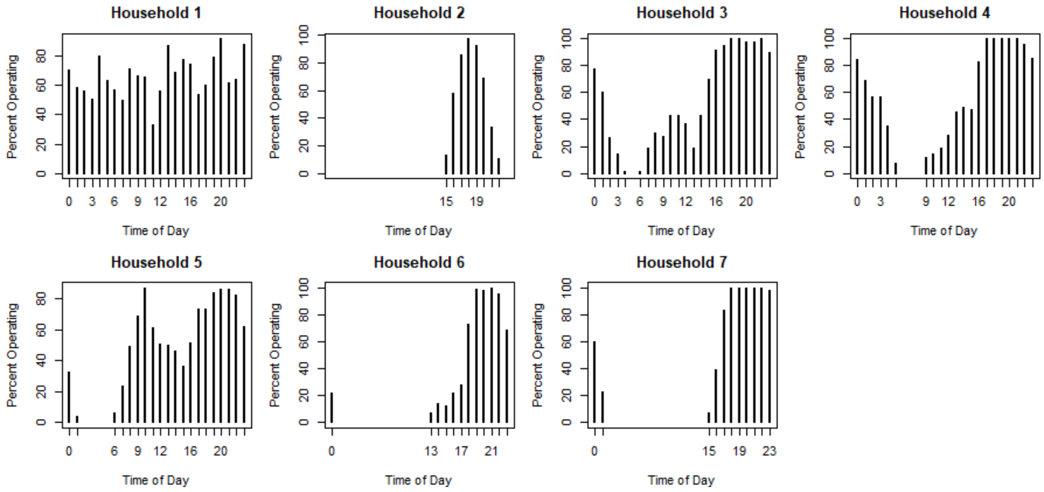
The householders in household 4 were back home after work in the afternoon most of the weekdays. They used their wood burner some mornings, and most afternoons and evenings. Overall, their heater was operating about 54% of the time.

The householders in household 5 were mostly home as they were working from home, with sick children. Overall, their heater was operating about 49% of the time.

The householders in household 6 were mostly home all day as they were working from home, however they were only using their wood burner in the evening. Overall, their heater was operating about 27% of the time.

The householders in household 7 were mostly home all day as they were working from home, however they were only using their wood burner in the afternoons. Overall, their heater was operating about 34% of the time.

Figure 20 Time of Day Profiles for Individual Households



3.2.7 Other Comments

The householders in Household 1 could smell smoke inside their house when their fire was on the low setting. This was solved by closing a skylight that had been left partially open.

Additionally, in Household 1, we noticed creosote was being dislodged from the inside of the flue when the holes were being drilled to fit the sampler probes to the flue. A build-up of residue was also evident on the outside of the flue at some locations where two flue sections joined as well as around some rivets - see photos in Figure 21. During the daily visit we also noticed water dripping down the inside of the flue when the heater was on its low setting. These issues suggest that the low flue temperatures are causing condensation in the flue.

In Household 2 and 5 we noted a small amount of water coming into the room from the flue ceiling plate and dropping onto the heater’s top plate – this may indicate that the flashing on the roof is not water-tight.

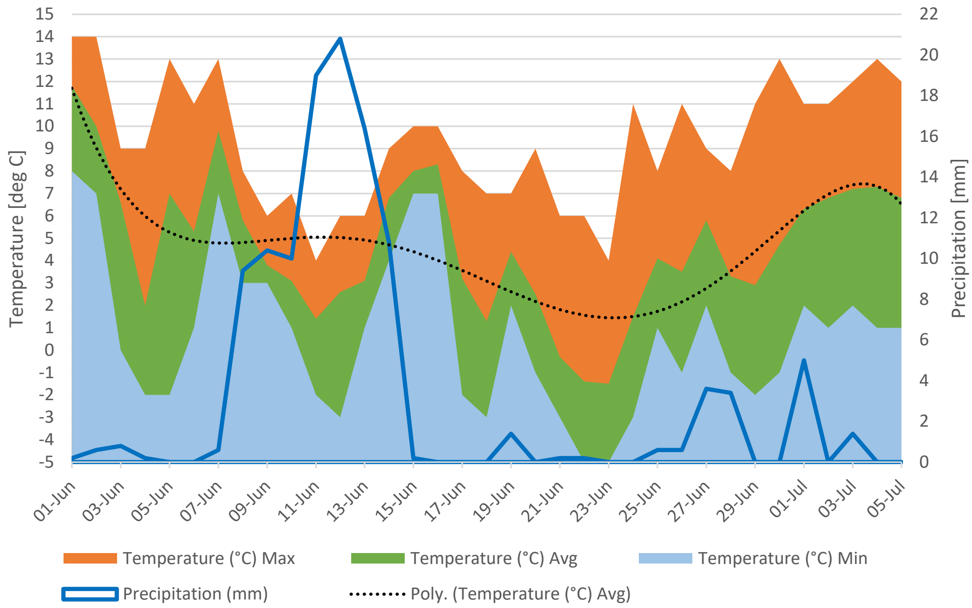
Figure 21 Household 1 Flue Showing Build-up of Creosote

3.3 Weather

The sampling program started on the 1st of June 2022 and finished on the 5th of July 2022. Arrowtown is located in the foothills of the Southern Alps. The temperatures in Arrowtown for June typically ranges between 7 °C and 0 °C. The typical probability of precipitation in June is 36 - 40%, and this consists of a small amount of rain mixed with snow [17].

During our sampling program, Queenstown Airport weather station recorded a maximum of 12 °C, a minimum of -2 °C and a total of 116 mm of rain [18]. Figure 22 shows the weather during this time. There was a period of high precipitation, rain and snow, from the 7th to the 15th of June. The coldest days were the 22nd and 23rd of June. We assume the weather in Arrowtown and 14 kilometres away at Queenstown Airport, was similar.

Figure 22 Weather Data during the Sampling Program



4.0 References

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This Report:

Report: 23/3115

Prepared by:	G Roux and W.S. Webley	W.S. Webley
Approved by:	W.S. Webley	W.S. Webley
Release Date:		28 February 2023

Appendix 1 Details of the Sampling System

APPLIED RESEARCH SERVICES LIMITED

Technical Bulletin 72

Portable Emissions Sampler

1.0 Overview

The portable emissions sampler captures particulate emissions using a method based on Oregon Method 41 (OM41), also known as the Condar Method. Barnett, S. (1985).

2.0 Principle of Operation

The sampler contains two separate analysers: a particulate sampler and a flue gas analyser. The sampler is controlled by a computer which activates the sampling pump whenever the flue temperature exceeds 100 °C and logs data whenever the pump is running.

Schematic diagrams of the two analysers are given in Figure 1 and the analysers are described below. A photograph of the sampler in use is given in Figure 3.

Figure 1 Schematic of Apparatus

Figure 1a Gas Analyser

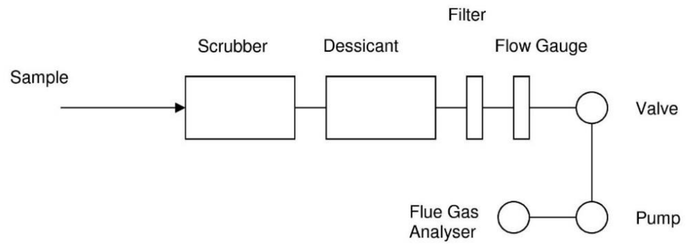
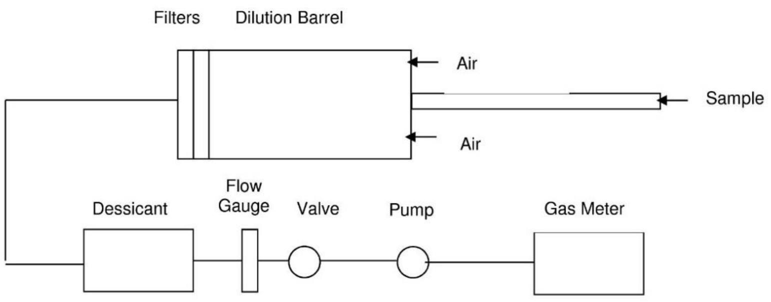


Figure 1b Particulate Sampler



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2.1 The Particulate Sampler

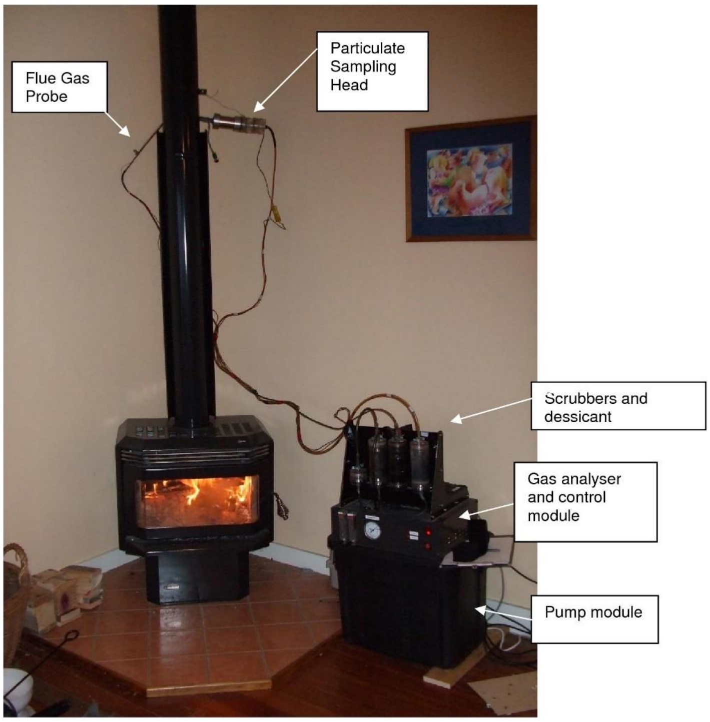
The sampling head includes a dilution system to dilute and cool the flue gas. This simulates the dilution and cooling that occurs when flue gases mix with ambient air and results in condensation of oily compounds such as poly-aromatic hydrocarbons which can then be captured on the filters.

The sampling head consists of a stainless steel dilution manifold (length 100 mm, internal diameter 49 mm) fitted with two end caps. One end cap is fitted with a short probe which is inserted into the flue so that the inlet is near the flue center. Dilution air is admitted to the manifold via 12 x 1 mm diameter holes in the face of the end cap. As with AS/NZS 4012/3 the sample is collected on two 47 mm glass fibre filters (Gelman Type A/E Cat No 61631) mounted on two filter holders fitted to the other end cap of the manifold.

2.2 The Gas Analyser

The flue gas composition is also measured and is used to calculate the total volume of gas which has passed up the flue per kg of fuel burnt. Flue gases are scrubbed and filtered before being passed to the analyser.

Figure 3 Photograph of The Sampler Installed in Home



3.0 Sample Calculations

Calculations follow the method set out in OM41. SI units have been used for clarity and calculations have been set out in what we believe to be a more readily understood form. Calculations are based on the values of flue temperature and flue oxygen level averaged over the run.

Particulate matter is collected on filters which are weighed before and after the run. Filters are held in a dessicator and weighed every 24 hours until constant weights are obtained. The deposit on the filter is calculated from the difference in filter weights.

Weight before: 0.2236 g
Weight after: 0.2357 g
Filter deposit: 0.0121 g

The volume of diluted sample drawn through the filters is determined from the difference in dry gas meter reading taken before and after the run

Gas meter before run: 128392 litres
Gas meter after run: 130024 litres
Volume of diluted gas: 1632 litres

The dilution ratio is the ratio of volumes of the diluted gas stream to the undiluted gas stream. For the runs carried out as part of the program to which this revision refers the dilution ratio was verified by comparing the results of 5 calibration runs carried out with the samplers installed in a test rig complying to the requirements of AS/NZS 4012/3.

Dilution ratio: 13.0

The flow of flue gases into the sample probe is dependent on their viscosity. The viscosity varies with their temperature in a known way – the viscosity varies as the square root of the absolute temperature. OM41 corrects for this variation using the stack correction factor (STF). Values of the STF at various temperatures are set out in the standard.

Flue Temperature: 258.57 C
STF per OM41: 0.7438
Actual Dilution Ratio for run: 17.48

The volume of the undiluted sample drawn into the manifold via the sample probe is obtained by dividing the volume of the diluted sample by the dilution ratio.

Volume of undiluted sample: 93.38 litres

The concentration of particulates in the flue gas is obtained by dividing the weight of particulates collected on the filter by the volume of the undiluted sample.

Particulate concentration: 0.0001296 g/litre

If enough air is supplied to exactly consume the wood then the volume of flue gases generated per kilogram of wood is burned is fixed by the stoichiometry of the combustion reaction. Wood is composed primarily of cellulose and its composition is relatively species independent.

Stoichiometric volume of dry flue gases per kg of wood: 5164 litre/ kg

In real life, more air is supplied for combustion than is actually required. This leads to the excess air passing into the flue gases. As a result, the volume of the flue gases is greater than it would be if only the stoichiometric amount of air was supplied. The proportion of excess air can be determined by measuring the flue oxygen concentration and the actual volume of flue gases van then be calculated. In OM41 this is done using the SDM tabulated for a given flue oxygen level.

Flue oxygen level: 15.7
SDM per OM41: 3.68
Actual volume of dry flue gases per kg of wood: 18985 litres/ kg

The emissions rate is obtained by multiplying the particulate concentration by the volume of flue gases per kg of wood.

Emissions Rate: 2.46 g/kg

4.0 Uncertainty Analysis

Table 1 gives estimated uncertainties for the sample calculations set out in Section 3.

Table 1 Estimated Uncertainties

	Values	Unit	Estimated Uncertainty	
			absolute	%
Weight of filter after run	0.2357	g	0.0001	
Weight of filter before run	0.2236	g	0.0001	
Weight deposited on filter	0.0121	g	0.0002	1.7
Gas meter after run	130024	l	0.5	
Gas meter before run	128392	l	0.5	
Volume of diluted sample	1632	l	1	0.1
Dilution Ratio	13.0			5.0
Flue Temperature	259	C	1	
STF	0.744	OM41	0.006	0.8
Temp corrected dilution ratio	17.48			5.8
Volume of undiluted sample	93.38	l		5.9
emissions concentration	0.0001296	g/l		7.5
Stoichiometric volume of dry flue gases	5164	l/kg		5.0
Flue Oxygen	15.71		0.25	
SDM	3.68	OM41	-0.30442	8.3
Actual volume of flue gases	18985	l/kg		13.3
emissions rate	2.46	g/kg		20.8

5.0 Differences from OM41

The methodology used here follows that in OM41 except that the dimensions of the sampling head are different. The portable emissions sampler used in this study uses a sampling head incorporating the same filter system as used in tests to AS/NZS 4012/3.

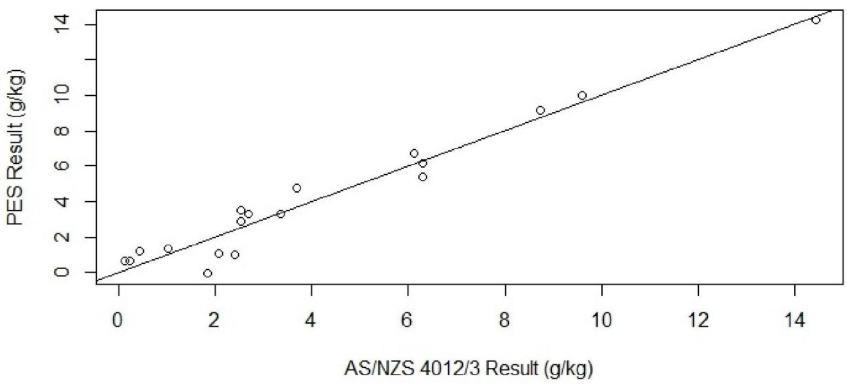
6.0 Comparison of Results Obtained with AS/NZS 4012/3

Laboratory tests of wood burners for compliance to particulate emissions standards in New Zealand are currently carried out according to methods set out in the joint Australian/ New Zealand standard AS/NZS 4012/3. The test involves capture of the entire gas stream exiting the flue which is then passed to a dilution tunnel where it is mixed with room air which provides dilution and cooling. The particulate sample is drawn from the end of the dilution tunnel. Because the velocity of gas in the dilution tunnel is more easily measured than that in the flue the amount of particulate generated is relatively easily calculated.

During the comparative tests the portable emissions sampler was set up in the test room and run at the same time as the laboratory test rig.

The graph below (Figure 2) shows the results of eighteen runs carried out on a Tropicair Duo down-draft heater under a range of 'real life' scenarios. There is a good agreement (R^2 = 0.87) between the emissions rates obtained with the portable emissions samplers (PES) and the AS/NZS 4012/3 test rig.

Figure 2 Comparison of Results Obtained with Portable Emissions Sampler and AS/NZS 4012/3



7.0 Assumptions Inherent in OM41

- The filter system collects the all the particulates in the sample. Deposition in the probe and material passing the filters is insignificant.
- The STF and SDM factors correctly represent actual behaviour.
- Calculations are based on STF and SDM factors calculated for average values of flue oxygen and flue temperature. It is assumed that these will correctly represent the actual behaviour.
- It is assumed that the volume of dry flue gases per kg of wood consumed does not vary significantly with fuel type.

The good correlation between results obtained with the portable emissions samplers and those measured using AS/NZS 4012/3 suggests that these assumptions are valid.

7.0 References

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Appendix 2 Information on Wood Burned

		Proportion	Density	Moisture	Resin Content
		% by weight	kg/m3	% wwb	%
Household 1	Gum	96.4	0.63	16.3	0.29
	Douglas fir	3.6	0.51	13.9	
Household 2	Kindling (cedar)	16.6	0.81	10.5	0.58
	Gum	49.9	0.63	13.7	
	Pine	33.5	0.49	13.6	
Household 3	Gum	35.4	0.47	19.6	0.21
	Pine	64.6	0.41	17.2	
Household 4	Gum	100.0	0.50	16.9	0.26
Household 5	Larch	100.0	0.47	19.0	0.12
Household 6	Gum	15.1	0.62	18.1	0.26
	Pine	53.0	0.47	17.1	
	Oregon	32.0	0.70	17.3	
Household 7	Pallet	100.0	0.41	16.9	0.80

The wood species was based on information supplied by each household.
The proportion is based on information recorded by the householder for each fuel load. Cardboard and firelighters have been excluded.
Moisture values are based on readings taken of a selection of pieces of each fuel type in the householder's wood pile and are expressed on a wet weight basis.
Density and resin content values are based on samples of each species taken at random from the wood pile and returned to the lab for analysis.

<u>Appendix 3 Example of Worksheet Completed by Householders</u>

Name

Address

Date

Time	What went on the fire	Weight	Air Control Setting (Front Lever) High, Medium or Low	Damper Control Setting – If applicable (Side Lever) – Open or Closed	Observations

Appendix 4 Run Data

Household	Run	Start Date	Sampler	Emissions Rate g/kg
1	a	1/06/2022	1	1.0
1	b	2/06/2022	1	0.4
1	c	3/06/2022	1	2.7
1	d	4/06/2022	1	0.5
1	e	5/06/2022	1	0.7
1	f	7/06/2022	1	4.1
1	g	8/06/2022	1	1.1
2	a	1/06/2022	2	1.3
2	b	3/06/2022	2	1.9
2	c	4/06/2022	2	1.0
2	d	5/06/2022	2	2.1
2	e	6/06/2022	2	2.1
2	f	7/06/2022	2	2.2
2	g	8/06/2022	2	1.6
3	a	9/06/2022	1	2.5
3	b	10/06/2022	1	3.0
3	c	11/06/2022	1	2.6
3	d	12/06/2022	1	1.9
3	e	13/06/2022	1	1.6
3	f	14/06/2022	1	2.6
3	g	15/06/2022	1	2.8
4	a	10/06/2022	2	1.3
4	b	11/06/2022	2	1.3
4	c	13/06/2022	2	1.7
4	d	14/06/2022	2	2.7
4	e	15/06/2022	2	3.0
4	f	16/06/2022	2	0.6
4	g	17/06/2022	2	1.6
5	a	16/06/2022	1	3.3
5	b	20/06/2022	1	1.2
5	c	22/06/2022	1	1.3
5	d	23/06/2022	1	2.1
5	e	24/06/2022	1	1.7
5	f	25/06/2022	1	1.6
5	g	26/06/2022	1	3.9
6	a	27/06/2022	1	3.7
6	b	28/06/2022	1	1.9
6	c	29/06/2022	1	4.1
6	d	30/06/2022	1	3.6
6	e	1/07/2022	1	2.8
6	f	2/07/2022	1	4.0
6	g	3/07/2022	1	2.9
7	a	29/06/2022	2	4.7
7	b	30/06/2022	2	1.0
7	c	1/07/2022	2	1.2
7	d	2/07/2022	2	1.0
7	e	3/07/2022	2	1.1
7	f	4/07/2022	2	0.5
7	g	5/07/2022	2	0.9

6.4. Kelp Forest Phase Monitoring Project

Prepared for:	Environmental Science and Policy Committee
Report No.	SPS2308
Activity:	Governance Report
Author:	Sam Thomas, Coastal Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	26 April 2023

PURPOSE

[1] This report is Phase 1 of a multi-year programme that will provide baseline knowledge and provide guidance for ongoing monitoring of Otago's coastal marine ecosystems.

[2] In Phase 1, NIWA reviewed several sources of information to select sites for passive and active monitoring of kelp forests. Monitoring will consider *Macrocystis* and *Durvillaea* habitats separately and will select multiple sites of each habitat across gradients of potential stress, particularly associated with land-use scenarios.

[3] This report provides a baseline of the Macrocystis kelp distribution in Otago and will help inform both the next phases of the kelp forest monitoring programme but also to help inform the review of ORC's Regional Plan: Coast. The Policy Team proposes to start the review in 2024/25 and notify the plan in 2025/26.

EXECUTIVE SUMMARY

[4] Kelp forests support some of the highest levels of biodiversity in New Zealand. They support marine food-webs, important recreational, commercial, and cultural fisheries, and are increasingly viewed for their pharmaceutical, nutritional and carbon capture potential. There is, however, anecdotal evidence of reductions in *Macrocystis* forests in Southern Otago and empirical evidence of retractions at the national level. Marine heatwaves are a major stressor to kelp forests globally, but local stressors such as sediment input have been shown to exacerbate the consequences of climatic events on kelp forests.

[5] NIWA applied satellite remote sensing to establish baseline information on the cover of the giant kelp *Macrocystis pyrifera* (hereafter referred to as *Macrocystis*) and key water quality parameters across regions exposed to varying land-use regimes. NIWA examined the implications of region-wide gradients of key stressors (e.g., sedimentation) on the coverage of *Macrocystis*, as well as temporal shifts in coverage as related to seasonal trends (e.g., temperature) and extreme events (e.g., marine heatwaves). Results show that water temperature is a major driver of reductions in *Macrocystis* cover as observed during two marine heatwaves (summer 2017–18 and summer 2012–22). While there was little evidence of sediment driven reductions of *Macrocystis* cover within regions, there

were major differences in *Macrocystis* coverage across regions exposed to varying sediment concentrations.

[6] Using national scale bathymetric[1] layers, NIWA examined the influence of water quality parameters on the potential depth distribution of *Macrocystis*. Results revealed that both warmer temperatures and elevated suspended sediments compress the habitable depth range for *Macrocystis* and indicate maximum depth ranges of between 25–35 m. These results are used to inform future monitoring of populations that are likely to be highly susceptible to changes in temperature and sedimentation regimes, and thus likely to provide responsive indicators of change.

[7] The assessment of gradients of sedimentation and relative land-use along the coast helped inform the relevant monitoring strategies required for each kelp species (*Durvillaea* spp. and *Macrocystis*). NIWA provided recommendations for the establishment of long-term monitoring which uses *Macrocystis* and *Durvillaea* as indicators of ecosystem health across a range of gradients of exposure to land-use pressure. This information will be used to plan field campaigns of aerial imagery mapping of discrete rocky headlands for *Durvillaea* and calibration of remote monitoring of *Macrocystis* across the Otago region.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*

2) ***Notes** that phase 1 of the kelp forest monitoring programme "*Giant Macrocystis forests; Distribution and trends for the Otago region*" has been completed.*

3) ***Notes** that phase 1 is part of a broader five-year programme that will produce a passive monitoring platform online combined with in-situ long term monitoring.*

BACKGROUND

[8] Otago Regional Council (ORC) has regulatory obligations under the Resource Management Act 1991(RMA) and the New Zealand Coastal Policy Statement (NZCPS), particularly Policy 11, to protect indigenous biological diversity in the coastal environment. This report supports ORC in meeting these obligations by assessing the status of kelp forests and informing monitoring of kelp forest habitats to enable management decisions to better include outcomes for marine ecosystems. The information will be used to inform the review of the Regional Plan: Coast, and enable data-driven decisions that identify and mitigate potential impacts caused by terrestrial land-use management regime.

[9] Kelp dominated coastal rocky reef ecosystems are critically important to New Zealand but are in decline in response to multiple stressors including marine heatwaves, and shading effects of coastal sedimentation (Tait 2019; Thomsen et al. 2019; Blain et al. 2021; Tait et al. 2021). The status of coastal reef ecosystems is often assumed rather than known because they are difficult to access, but the impacts are real – loss of productivity, broken
[10] trophic linkages and impaired ecosystem functioning. These impacts are often associated with degradation of kelp forests that underpin these ecosystems (Rogers-Bennett and Catton 2019; Tait et al. 2021).

[1] Bathymetry is the measurement of the depth of water in oceans, rivers or lakes.

[11] The biogenic habitats of large macroalgae are nurseries for fishes and invertebrates of cultural, recreational, and economic importance (Layton et al. 2020). Their productivity contributes directly to 40% of the biomass of coastal fishes (Udy et al. 2019); at stake are hundreds of millions of dollars of gross domestic product (GDP) from pāua, crayfish, and inshore fisheries. Large macroalgae are a key indicator of wider ecological health, and unlike many other ecosystem components, are conspicuous and remain fixed to a location. For these reasons they integrate and reflect many of the stressors affecting rocky reef habitats (D'Archino and Piazzi 2021).

[12] Giant kelp, *Macrocystis pyrifera* (hereafter referred to as *Macrocystis*), is one of the fastest growing photosynthetic organisms globally, and is a key contributor to carbon fixation and habitat provision for temperate marine ecosystems across a large extent of the world's temperate coastlines (Schiel and Foster 2015; Miller et al. 2018). Recent studies have revealed that *Macrocystis* and other large kelps have had retractions in the northern hemisphere (Arafeh-Dalmau et al. 2019; Rogers-Bennett and Catton 2019), often in response to combined physical and trophic interactions (Ling et al. 2009; Rogers-Bennett and Catton 2019). In southern Australia, *Macrocystis* has experienced massive retractions, and is nearing functional extinction in some regions in response to oceanographic shifts that have increased larval delivery of a key herbivorous urchin, decreased nitrogen concentrations and high seawater temperatures (Mabin et al. 2019; Butler et al. 2020). A study of the *Macrocystis* populations along the Otago coast show that a key driver of *Macrocystis* health is turbidity and reduced light availability (Tait 2019). More recent research (Tait et al. 2021) has revealed that the 2017–18 marine heatwave had significant negative effects on *Macrocystis* nationwide, including the Otago Coast, with water clarity interacting to further reduce coverage of *Macrocystis*.

[13] Datasets of Southern bull kelp, dominated by three species *Durvillaea antarctica*, *Durvillaea poha* and *Durvillaea willana* (hereafter collectively referred to as "*Durvillaea*"), are some of the largest macroalgal species and in New Zealand are represented by several native and endemic species. Like *Macrocystis*, *Durvillaea* are important contributors to a range of vital ecosystem services. Unlike *Macrocystis* however, these species inhabit rocky reefs along the coastal fringe, are tolerant of very heavy wave exposure and are therefore widely distributed along New Zealand's southern coastlines (from Wairarapa/Wellington to the Sub-Antarctic Islands). Like *Macrocystis*, *Durvillaea* have proved highly vulnerable to marine heatwaves (Tait et al. 2021; Thomsen et al. 2019, 2021). Less is known globally about the stressors affecting *Durvillaea* species, but while light can be less limiting to macroalgae higher up the shore due to exposure of sunlight at low tide, sediments can still have a negative influence on macroalgal populations in these areas (Alestra et al. 2014; Schiel and Gunn 2019).

[14] New Zealand has experienced some of its most intense marine heatwaves in its climate record in the past five years (Salinger et al. 2019) causing localized extinctions of *Durvillaea* (Thomsen et al. 2019), and declines in *Macrocystis* across mainland New Zealand (Tait et al. 2021). Land-use change associated with agriculture, forestry and urbanisation have altered the land-water interface globally, including in New Zealand, where rates of sedimentation have increased as a result (Goff 1997, Thrush et al 2004). Proximity of *Macrocystis* forests to sources of sediments greatly affects the demography of populations which exhibit a poor rate of conversion from juvenile sporophytes to adult plants reaching the surface (Tait 2019). Likewise, deposited sediments can inhibit the settlement of propagules of both *Durvillaea* and *Macrocystis*. Sediment accretion and reef burial is also possible (Tait 2019), yet these processes are some of the least understood

consequences of sediment inputs. The impacts of land-management regimes, particularly the delivery of sediments to the marine environment, requires consistent and broad-scale monitoring to understand the impacts of terrigenous sediments, and the potential management and intervention measures which will improve outcomes for marine ecosystems.

DISCUSSION

[15] The distribution of *Macrocystis* forests across the Otago region (and southern Canterbury) revealed various spatio-temporal trends. *Macrocystis* forests tended to be smaller in size and closer to shore in the northern regions (Timaru and North Otago). Further south towards the Otago Peninsula, *Macrocystis* forests increased in coverage and many large offshore forests were observed (Moeraki, Waikouaiti, and Blueskin Bay). *Macrocystis* coverage peaked in the Waikouaiti Zone (refer to report pg. 12). At the southern extent of the Otago region, small patches of *Macrocystis* were observed near Nugget Point and the mouth of the Catlins Estuary. Analysis revealed that sea surface temperature, particularly un-seasonably warm temperatures generally had a negative impact on *Macrocystis* bed coverage. These trends were the most striking for regions with the highest coverage of *Macrocystis*.

[16] Combined analysis revealed significant influences of sea surface temperature, suspended sediments, and maximum significant wave height. While several factors influence *Macrocystis* coverage, increasing temperatures (as shown by temperature anomalies and absolute temperatures) were shown to influence *Macrocystis* coverage across zones. Warm temperature anomalies during summer had a negative effect on *Macrocystis* coverage, while warm anomalies in spring and autumn had an initially positive effect, but that became increasingly negative beyond 2–3°C above average. However, during winter, warm anomalies had a positive influence on *Macrocystis* coverage.

[17] Sites with the lowest range of sediment loads (Waikouaiti and Blueskin Bay) had neutral or slightly positive relationships between *Macrocystis* cover and Total suspended sediment (TSS), while the other sites had slightly negative relationships. Although there was little evidence that temporal variation in suspended sediments within sites caused major declines in *Macrocystis* coverage, variation in sediment loading between sites had a significant influence on observed *Macrocystis* coverage. Increasing sediment loads had a negative influence on *Macrocystis* cover, but this was exacerbated by warm temperature.

[18] Using the national bathymetric grid, the cover of *Macrocystis* across the four major *Macrocystis* regions of the North Otago coast were presented across depth bins (from 2016–22). The expected trend was for exponentially decreasing coverage with increasing depth as light becomes limiting. This trend was evident at most sites, however the Moeraki region had a noticeable increase in coverage at greater depths, particularly at 10-15 m. This trend was likely driven by the distribution of rocky reef, with several offshore reefs present in this region. At the Moeraki and Waikouaiti regions there were several instances of *Macrocystis* detected in water depths of 20-30 m. No surface *Macrocystis* was detected at water depths greater than 35m.

[19] Updated analysis of *Macrocystis* coverage trends has confirmed that warm sea surface temperatures are a major threat to the stability of *Macrocystis* forests in the Otago region. Like previous studies on *Durvillaea* (Thomsen et al. 2019) and *Macrocystis* (Tait et al. 2021), this study shows that warm temperature anomalies, particularly those greater

than 3–4°C above average, cause dramatic reductions in the coverage of *Macrocystis*. Despite the severe consequences of marine heatwaves on surface cover of *Macrocystis*, including the summer 2021–22 event, mild summer seasons such as 2020–21 revealed the highest cover of *Macrocystis* over the six-year period.

[20] The study has shown some of the first evidence that the marine heatwave of summer 2021–22 caused retractions in *Macrocystis* cover. Additionally, NIWA has showed that the use of a national bathymetric layer can help identify changes in the depth range that *Macrocystis* can occupy and reveal a shallowing of the habitable depth range during warm conditions. Alongside warm temperature anomalies, NIWA has shown that reduced water clarity is an additive stressor to *Macrocystis* forests. While there was little evidence that changes in *Macrocystis* coverage were caused by temporal variations in sediments within regions, there was variation in *Macrocystis* coverage across regions exposed to varying sediment loads. NIWA presents a gradient of sediment loading, increasing from Blue Skin Bay to Timaru. Similar gradients exist for the Catlins region, with the Brighton–Taieri coast exposed to high sediment loading which decline towards the southern Catlins region.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[21] This study contributes predominately toward the *Healthy and diverse ecosystems, Effective response to climate change,* and *Healthy water, soil, and coast strategic directions.*

Financial Considerations

[22] This work is within existing budgets, and includes a five-year contract is in place for the period of this programme.

Significance and Engagement Considerations

[23] N/A

Legislative and Risk Considerations

[24] The Coastal Monitoring programme at ORC is developing, to address our legislative obligations under the RMA and other New Zealand Coastal Policy Statement.

Climate Change Considerations

[25] Understanding how Kelp Forest distribution changes in Otago's coastal marine area allows for appropriate management actions to be enacted to build resilience against climate change.

Communications Considerations

[26] Communication between key stakeholders and iwi will occur on a project-by-project basis.

NEXT STEPS

[27] To undertake ground truthing and validation of baseline data gathered by satellite and image monitoring. NIWA will then synthesize the outcomes from the in-situ monitoring to enable development of an online platform to passively monitor giant kelp and explore the potential of developing a similar platform for southern bull kelp. This online platform will be combined with long term monitoring of selected representative sites at an appropriate timescale.

[28] This kelp forest report will steer the next phase of the kelp forest monitoring programme which is ground truthing and validating the data with subtidal monitoring using remote operated vehicles (ROVs) and divers. The data gathered during this 5-year programme will inform the coast plan review and also set up a monitoring programme for kelp in Otago an important ecosystem Otago's coastal marine area.

[29] The coastal work programme over the next few years will include surveying of Macrocystis populations on deeper rocky reefs at several locations using Remote Operated Vehicles (ROV), drop-cameras and where possible SCUBA (Self Contained Underwater Breathing Apparatus) divers should occur help understand the abundance of deeper-living populations. These methods will also be used at an equal number of shallow reefs adjacent to these deep sites to establish relationships between the two habitats. These measurements will identify uncertainties surrounding passive monitoring methods (i.e., satellites) in assessing Macrocystis populations in deeper habitats. Remote sensing has revealed several areas where Macrocystis populations are sporadically present in deeper water. Shifting light availability and increasing frequency of heat-wave events present the greatest threat to Macrocystis populations (Tait et al. 2021) and plants at the limits of their depth distribution will likely be the most responsive to subtle water quality shifts. Therefore, establishing in-situ validation and calibration of in-situ populations in several candidate deep areas (Figure 4-2) to determine depth limitations of Macrocystis and fine-tune remotely sensed metrics of ecosystem health. Georeferenced drop-camera, ROV and SCUBA diver methods will be used to align observations of Macrocystis density at the seafloor with satellite observations to examine the accuracy of satellite-based detection methods.

ATTACHMENTS

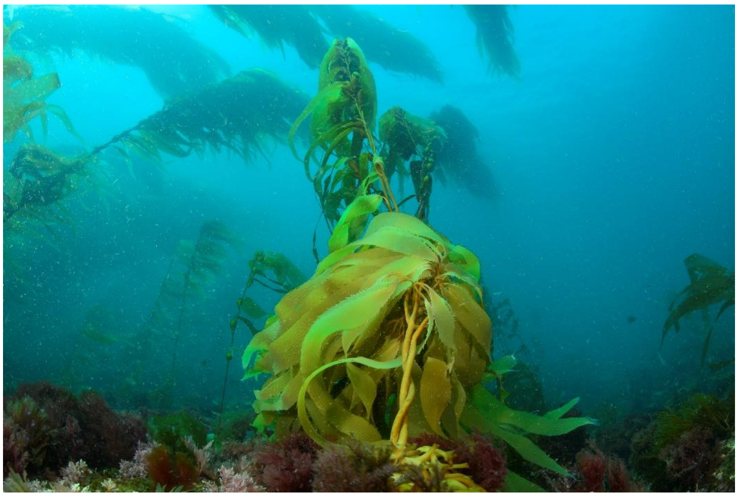
1. Giant Macrocystis Forests - NIWA Report [**6.4.1** - 44 pages]

Giant Macrocystis forests

Distribution and trends for the Otago region

Prepared for Otago Regional Council

August 2022



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Executive summary

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Otago Regional Council (ORC) has regulatory obligations under the Resource Management Act 1991 and the New Zealand Coastal Policy Statement, Policy 11, to protect indigenous biological diversity in the coastal environment. The purpose of this report is to support ORC in meeting these obligations by assessing the status of kelp forests and informing monitoring of kelp forest habitats that will enable management decisions to better include outcomes for marine ecosystems. This information will be used to inform an effective coastal plan and enable data-driven decisions that identify and mitigate potential impacts caused by terrestrial land-use management regimes.

Here, I apply satellite remote sensing to establish baseline information on the cover of the giant kelp *Macrocystis pyrifera* (hereafter referred to as *Macrocystis*) and key water quality parameters across regions exposed to varying land-use regimes. I examine the implications of region-wide gradients of key stressors (e.g., sedimentation) on the coverage of *Macrocystis*, as well as temporal shifts in coverage as related to seasonal trends (e.g., temperature) and extreme events (e.g., marine heatwaves). Results show that water temperature is a major driver of reductions in *Macrocystis* cover as observed during two marine heatwaves (summer 2017–18 and summer 2012–22). While there was little evidence of sediment driven reductions of *Macrocystis* cover within regions, there were major differences in *Macrocystis* coverage across regions exposed to varying sediment concentrations.

Using national scale bathymetric layers, I examined the influence of water quality parameters on the potential depth distribution of *Macrocystis*. Results revealed that both warmer temperatures and elevated suspended sediments compress the habitable depth range for *Macrocystis* and indicate maximum depth ranges of between 25–35 m. These results are used to inform future monitoring of populations that are likely to be highly susceptible to changes in temperature and sedimentation regimes, and thus likely to provide responsive indicators of change.

Assessment of gradients of sedimentation and relative land-use informed monitoring strategies for kelp species (*Durvillaea* spp. and *Macrocystis*). I provide recommendations for the establishment of long-term monitoring which uses *Macrocystis* and *Durvillaea* as indicators of ecosystem health across gradients of exposure to land-use pressure. This information will be used to plan field campaigns of aerial imagery mapping of discrete rocky headlands for *Durvillaea* and calibration of remote monitoring of *Macrocystis* across the Otago region.

1 Introduction

Kelp dominated coastal rocky reef ecosystems are critically important to Aotearoa New Zealand but are in decline in response to multiple stressors including marine heatwaves, and shading effects of coastal sedimentation (Tait 2019; Thomsen et al. 2019; Blain et al. 2021; Tait et al. 2021). The status of coastal reef ecosystems is often assumed rather than known because they are difficult to access, but the impacts are real – loss of productivity, broken trophic linkages and impaired ecosystem functioning. These impacts are often associated with degradation of kelp forests that underpin these ecosystems (Rogers-Bennett and Catton 2019; Tait et al. 2021).

The biogenic habitats of large macroalgae are nurseries for fishes and invertebrates of cultural, recreational, and economic importance (Layton et al. 2020). Their productivity contributes directly to 40% of the biomass of coastal fishes (Udy et al. 2019); at stake are hundreds of millions of dollars of gross domestic product (GDP) from pāua, kōura, and inshore fisheries. Large macroalgae are a key indicator of wider ecological health, and unlike many other ecosystem components, are conspicuous and remain fixed to a location. For these reasons they integrate and reflect many of the stressors affecting rocky reef habitats (D'Archino and Piazzi 2021).

Giant kelp, *Macrocystis pyrifera* (hereafter referred to as *Macrocystis*), is one of the fastest growing photosynthetic organisms globally, and is a key contributor to carbon fixation and habitat provision for temperate marine ecosystems across a large extent of the world's temperate coastlines (Schiel and Foster 2015; Miller et al. 2018). Recent studies have revealed that *Macrocystis* and other large kelps have had retractions in the northern hemisphere (Arafeh-Dalmau et al. 2019; Rogers-Bennett and Catton 2019), often in response to combined physical and trophic interactions (Ling et al. 2009; Rogers-Bennett and Catton 2019). In southern Australia, *Macrocystis* has experienced massive retractions, and is nearing functional extinction in some regions in response to oceanographic shifts that have increased larval delivery of a key herbivorous urchin, decreased nitrogen concentrations and high seawater temperatures (Mabin et al. 2019; Butler et al. 2020). A study of the *Macrocystis* populations along the Otago coast show that a key driver of *Macrocystis* health is turbidity and reduced light availability (Tait 2019). More recent research (Tait et al. 2021) has revealed that the 2017–18 marine heatwave had significant negative effects on *Macrocystis* nationwide, including the Otago Coast, with water clarity interacting to further reduce coverage of *Macrocystis*.

Southern bull kelp, dominated by three species *Durvillaea antarctica*, *Durvillaea poha* and *Durvillaea willana* (hereafter collectively referred to as "*Durvillaea*"), are some of the largest macroalgal species and in New Zealand are represented by several native and endemic species. Like *Macrocystis*, *Durvillaea* are important contributors to a range of vital ecosystem services. Unlike *Macrocystis*, however, these species inhabit rocky reefs along the coastal fringe, are tolerant of very heavy wave exposure and are therefore widely distributed along New Zealand's southern coastlines (from Wairarapa/Wellington to the Sub-Antarctic Islands). Like *Macrocystis*, *Durvillaea* have proved highly vulnerable to marine heatwaves (Tait et al. 2021; Thomsen et al. 2019, 2021). Less is known globally about the stressors affecting *Durvillaea* species, but while light can be less limiting to macroalgae higher up the shore, sediments can still have a negative influence on macroalgal populations (Alestra et al. 2014; Schiel and Gunn 2019).

Macrocystis and *Durvillaea* both occur throughout the Otago Region. However, the Otago Peninsula represents a key breakpoint for populations of these species, a product of the protection that Otago Peninsula provides from large swells originating in the Southern Ocean. *Macrocystis* forests flourish along the coast north of the Otago Peninsula thanks to the protection from a large proportion of southerly swells (Tait 2019), while *Durvillaea* dominates the highly exposed headlands and rocky reef south of the Otago Peninsula.

New Zealand has experienced some of its most intense marine heatwaves in its climate record in the past five years (Salinger et al. 2019) causing localized extinctions of *Durvillaea* (Thomsen et al. 2019), and declines in *Macrocystis* across mainland New Zealand (Tait et al. 2021). Rapid rates of land-use change associated with agriculture and urbanisation have dramatically altered the land-water interface globally, including in New Zealand, where rates of sedimentation have increased as a result (Goff 1997). Proximity of *Macrocystis* forests to sources of sediments greatly affects the demography of populations which exhibit a poor rate of conversion from juvenile sporophytes to adult plants reaching the surface (Tait 2019). Likewise, deposited sediments can inhibit the settlement of propagules of both *Durvillaea* and *Macrocystis*. Sediment accretion and reef burial is also possible (Tait 2019), yet these processes are some of the least understood consequences of sediment inputs. The impacts of land-management regimes, particularly the delivery of sediments to the marine environment, requires consistent and broad-scale monitoring to understand the impacts of terrigenous sediments, and the potential management and intervention measures which will improve outcomes for marine ecosystems. Otago’s coastline is home to a wide range of diverse and unique ecosystems. These ecosystems are biodiversity hotspots with deep sea canyons, bryozoan reefs, rhodolith beds, gravel/boulder fields and kelp forests. This diversity of habitats and the nutrient rich currents such as the Southland and Sub-Antarctic currents create the conditions that make Otago’s marine life highly diverse with many iconic species (e.g., pāua, kōura, blue cod, sperm whales, albatross, yellow eyed penguins, and sea lions). Among these ecosystems, the importance of kelp forests along Otago’s Coast is reflected in their designation as ‘marine significant ecological areas’ in Department of Conservation (2010).

Otago Regional Council (ORC) has regulatory obligations under the Resource Management Act 1991 (RMA) and the New Zealand Coastal Policy Statement, Policy 11, to protect indigenous biological diversity in the coastal environment. Regional councils must provide for the preservation of natural character (which includes an ecological element) (RMA, Section 6a) and protection of indigenous vegetation and fauna (RMA, Section 6c). Otago’s jurisdiction (Regional Policy Statement and Regional Plan: Coast) runs from mean high-water spring (MHWS) out to 12 nautical miles. Our proposal is to support ORC in meeting these obligations by mapping and monitoring kelp forest habitats/ecosystems. This will provide information for the creation of an effective coastal plan and enable informed management decisions to identify and mitigate the impacts of potential stressors on kelp forests such as sedimentation from land.

1.1 Purpose of this report

This report represents “Phase 1” of a multi-year programme that will provide baseline knowledge and provide guidance for ongoing monitoring of Otago’s coastal marine ecosystems. In Phase 1, I will review several sources of information to select sites for passive and active monitoring. Monitoring will consider *Macrocystis* and *Durvillaea* habitats separately and will select multiple sites of each habitat across gradients of potential stress, particularly associated with land-use scenarios. The sources of information I will utilise include:

- technical reports and grey literature (e.g., reports for regional councils)
- peer-reviewed scientific literature
- satellite information.

As part of the review, I will establish qualitative and quantitative information about the abundance, distribution, and status of *Macrocystis*, the relative status of terrestrial catchments, and broad estimates of water quality parameters across several regions of the Otago Coast. Moderate resolution marine bathymetry will also be incorporated to explore the depth distribution in regions exposed to varying turbidity. This will provide key information to inform upcoming in situ monitoring campaigns.

I will use multiple satellite platforms to detect and quantify *Macrocystis* forests across the Otago region using methods developed by NIWA (Tait et al. 2021). Passive remote sensing has been widely used for monitoring marine ecosystems (Bell et al. 2020; Mora-Soto et al. 2020) and the widely accepted approach generally computes vegetation indices based on measurements of near infrared electromagnetic radiation (ideally at red edge bands; Timmer et al. 2022). These indices detect vegetation not occluded by overlying water, giving a direct measurement of only the floating portion of macroalgal canopies. Because the approach is limited to the detection of surface canopies, these datasets are unable to integrate the full population dynamics of *Macrocystis* and give no insight into the presence of subsurface *Macrocystis* forests.

ORC wish to establish an environmental baseline for these key components of their rocky reef ecosystems. Here, I review information about *Macrocystis*-dominated coastal marine ecosystems in Otago, provide updated time-series analysis with satellite imagery and identify the influence of water quality parameters on kelp forest coverage. Using this analysis I will provide recommendations on the monitoring approach for the next phase of this project, including identifying key populations, regions, and methods that will help calibrate and validate remotely sensed metrics.

2 Methods

Macrocystis inhabits subtidal reefs down to approximately 20–25 m depth in the Otago region (Tait 2019). While *Macrocystis* populations that inhabit shallow depths (e.g., 5–10 m) are regularly visible from aerial or satellite imagery, deeper populations may not be. In this study I examine the coverage of *Macrocystis* broadly across all depths, however, I also explore the detection of surface canopies at different depths (as defined by a national bathymetric dataset; NIWA; Figure 2-1). I explore the variability of the coverage of *Macrocystis* across depth ranges to help inform in situ validation campaigns.

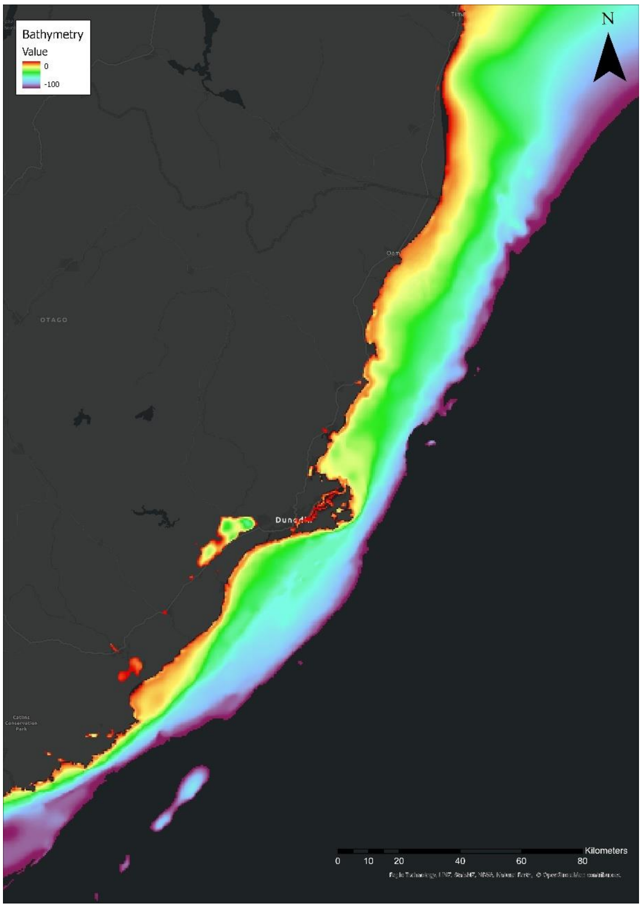

Figure 2-1: Bathymetry (m) of the coastal Otago region. Bathymetric layer is masked to display depths from 0 to100m.

Durvillaea inhabit exposed rocky reef platforms in the intertidal and shallow subtidal zone. Several years of combined in situ and aerial monitoring on several headlands near the Otago Harbour have been completed on behalf of Port Otago Ltd (Tait 2020). These will form the basis of a 25-year programme to monitor these habitats to determine negative consequences of sediment disposal at the Heyward dredge spoil grounds (offshore from Hayward Point; Tait 2020). Although satellite-based remote sensing of these populations is challenging due to the narrow zone inhabited by these species, I will use existing data to provide guidance on the design of a monitoring programme for these habitats, particularly relating to the Catlins region.

I explore the distribution of *Macrocystis* with the aid of several datasets, particularly aerial and in situ datasets collected on behalf of Port Otago Ltd during the “Project Next Generation” capital dredging programme (Tait 2018), and for consenting of long-term maintenance dredging (Tait 2020). I present information collected during these monitoring campaigns for Port Otago to summarise the best available knowledge of these marine forests, provide guidance for ongoing monitoring and to provide context for remote monitoring techniques. The methodology implemented for these surveys can be found in Tait (2018) and Tait (2020). Furthermore, I leverage remote sensing techniques developed by Tait et al. (2021) to examine trends in *Macrocystis* cover from 2016 to 2022.

2.1 Catchment land-use and study regions

Broadly defined terrestrial habitat classes were downloaded from (https://lris.scinfo.org.nz/layer/95415-basic-ecosystems/). The data provide high resolution (e.g., 15 m^2) estimates of land-use based on satellite products integrated between 2002–12. The 17 habitat classes defined in the original datasets (Dymond et al. 2012) were then collapsed into eight land-use types including: urban; coastal ecosystems; alpine ecosystems; water (fresh); agriculture; tussock/grassland/scrubland; exotic forest; and native forest. Each marine region was chosen based on natural breaks such as headlands and exposure to terrestrial catchments (Figure 2-2). The study zones used to assess regional cover of *Macrocystis* were chosen based on natural geological breaks and exposure to various terrestrial and freshwater catchments.

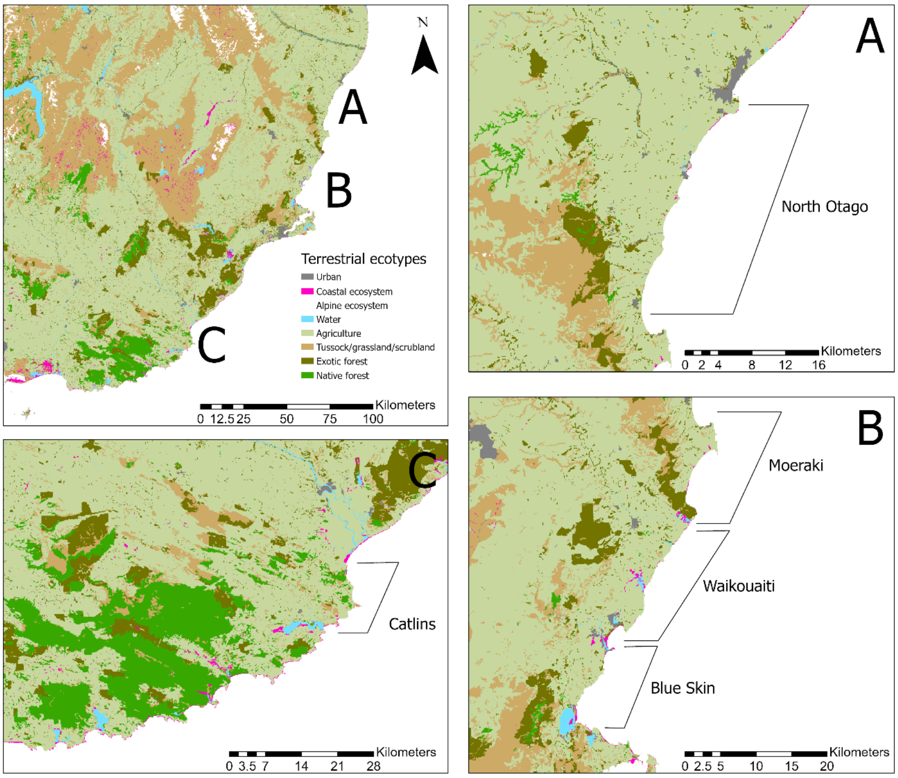

Figure 2-2: Terrestrial land-use types and ecosystems across the Otago region. Locations and extents of regions used to estimate *Macrocystis* coverage are shown in each subregion (A, B, and C).

2.2 Remote detection of *Macrocystis* canopies

Surface canopies of *Macrocystis* were assessed using Sentinel-2 satellite imagery (resolution = 100 m^2) between December 2015 and May 2022 (Copernicus Sentinel-2A data 2015–2022). Six focal regions spanning the Southern Canterbury[1] and Otago coastline were chosen, relating to key populations of *Macrocystis* (Hay 1990) and geological breaks. *Macrocystis* cover (m^2) was calculated from the number of pixels with detectable vegetation multiplied by the pixel area (100 m^2). Data were filtered, masked, and downloaded using Google Earth Engine (Gorelick et al. 2017). Although the timing of satellite capture was not synced to tidal cycles (with a tidal range of ca. 2 m in most of our study region), with potential implications for the visible extent of canopies, remote sensing studies of *Nereocystis luetkeana* (Finger et al. 2021) and *Macrocystis* (Butler et al. 2020) show that variation in coverage was not particularly sensitive to tidal height.

The Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) were calculated from the visible light and "red-edge" (Timmer et al. 2022) bands of the

[1] Timaru, is within the jurisdiction of Environment Canterbury. However, populations of *Macrocystis* occur at this location and are exposed to generally high sediment loads. Including this site in this analysis provides a useful comparison to the Otago region.

Sentinel-2 constellation. Specifically, the bands B3 (559.8 nm) and B8 (832.8 nm) were used to calculate NDWI and B4 (664.6 nm), and B5 (710.0 nm) was used to calculate the "red-edge" vegetation index. To differentiate *Macrocystis* from other features, a series of masking and filtering procedures was performed. First, monthly near cloud-free images were selected by using quality control bands (Sentinal-2 QA band 60). The acceptable percentage of cloud cover was set to 10%. The coastline and offshore islands were masked by an elevation layer to remove all land-based pixels. The thresholds of the NDVI were set to >0.01 slightly more conservative than the threshold set for detection of *Macrocystis* by Mora-Soto et al. (2020), but less than thresholds for seagrass (0.2; Calleja et al. 2017), and the threshold of NDWI was set to <0.2 based on detection results of well-studied forests (Tait 2019). Finally, the monthly cover (when appropriate imagery was available) of *Macrocystis* was estimated within each of six polygons which cover the entirety of the six distinct areas (Figure 2-2; note, figure excludes the Timaru region).

Kelp detection results were tested against in situ subtidal densities of *Macrocystis* (Tait 2019). In situ subtidal population surveys (Tait 2019) partially spanned the satellite time-series and allowed near-direct comparisons. I compare the densities of mature *Macrocystis* measured at eight subtidal sites at 8–11 m depth to satellite estimated coverage in a 100 × 100 m polygon centred at each subtidal site. Comparisons between subtidal densities of *Macrocystis* and remote estimates revealed a strong positive linear relationship, but also some variation between subtidal densities and the coverage of surface canopies (Figure 2-3).

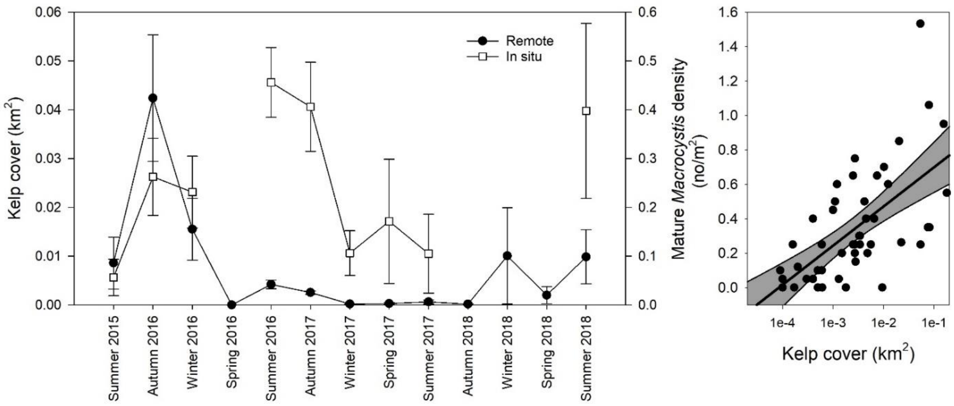

Figure 2-3: Timeseries of subtidal *Macrocystis* densities in situ (Tait 2019) and *Macrocystis* coverage at the same locations, as estimated by remote sensing (A) and the relationship between in situ densities and remotely estimated coverage (B).Linear regression (B) had a significant positive slope (t= 5.8, $p<0.0001$) and reasonable fit ($R^2 = 0.34$). Kelp cover x-axis log transformed (B).Although the method does not provide a specific canopy area per pixel, instead assuming 100% canopy coverage within pixels, similar NDVI based vegetation detection methods have been shown to provide an effective proxy for *Macrocystis* extent and abundance (Cavanaugh et al. 2010; Nijland et al. 2019). This provides a standardized method for identifying the presence and relative extent of *Macrocystis* forests to identify spatio-temporal trends in relation to key environmental parameters (Butler et al. 2020).

2.3 Satellite derived water quality parameters

Key metrics of water quality, particularly those relating to water temperature, water visibility and light availability, were extracted from SCENZ (Seas, Coasts and Estuaries, New Zealand) using novel algorithms specifically tuned for the New Zealand coastal region (Pinkerton et al. 2021). Here I used the chlorophyll-*a*, KPAR (Kd for Photosynthetically Active Radiation [PAR] wavelengths), total suspended solids (TSS) and sea surface temperature (SST). Each parameter was extracted across polygons 1 × 10 km wide placed c. 1 mkm from the coast for each region. Monthly means were extracted from SCENZ from 2002–20 for each pixel within the coastal polygons and the mean calculated for each polygon (i.e., averaged across all pixels).

2.3.1 Sea surface temperature

SST time-series were obtained from the MODIS-Aqua measurements using the SeaDAS v7.2 default 'sst' product which is derived from measurements of long-wave (11–12 µm) thermal radiation (NASA 2018). SST products at 1 km were subsampled to 500 m to improve resolution of the narrow channels over time using bilinear interpolation. Accuracy of SST is likely to be high; Pinkerton (2017) found that, in a similar New Zealand region (Manukau Harbour), these SST observations closely followed in situ measurements of surface temperature (R^2 = 0.924, n = 172). Further validation came from a comparison between MODIS-Aqua SST and OISST (Optimum Interpolation Sea Surface Temperature, version 2, Reynolds et al. 2002) for the New Zealand coast (Pinkerton et al. 2019; r^2 = 0.972, n = 256,687).

2.3.2 Chlorophyll-*a*

Chlorophyll-*a* concentration (chl-a) was estimated using satellite measurements of ocean colour from the Moderate Resolution Imaging Spectrometer on the Aqua satellite (MODIS-Aqua)—owned and operated by the US National Aeronautics and Space Administration (NASA 2018). I used the Quasi-Analytical Algorithm (QAA) algorithm (Lee et al. 2002, 2009) to estimate particulate backscatter at 555 nm [bbp(555)] and phytoplankton absorption at 488 nm [aph (488)]. Phytoplankton absorption was converted to an estimate of chl-*a* using the chl-specific absorption coefficient, $aph^*(488)$. The value of $aph^*(488)$ can vary seasonally and spatially, relating to different phytoplankton species (with varying cell physiology and pigments), different phytoplankton cell sizes, and the light environment (Kirk 2011). Here, I used an average of values found for oceanic phytoplankton (Bricaud et al. 1995; Bissett et al. 1997), and measurements in the lower reaches of New Zealand rivers and estuaries. I blended the QAA-chl-*a* and the MODIS-default chl-*a* product (NASA, 2018) using a logistic-scaling of bbp(555) (Pinkerton et al. 2018).

2.3.3 Sediment loading

The diffuse downwelling attenuation coefficient in the Photosynthetically Available Radiation (PAR range, 400–700 nm), K_d (m^{-1}) was used as our measure of water clarity. Values of K_d were estimated from MODIS-Aqua measurements of ocean colour, processed to inherent optical properties using the QAA algorithm (Lee et al. 2002, 2009) following the methodology of Pinkerton et al. (2018). From these IOPs, I estimated the diffuse attenuation coefficient in the PAR range as Lee et al. (2005). The satellite-derived attenuation coefficient was mapped at a nominal resolution of 500 × 500 m and projected to a transverse Mercator grid. The temporal resolution of the product for the study region is 1–2 measurements daily. Values of K_d were extracted from the dataset around *Macrocystis* forests and averaged monthly to provide a dataset with low quantities of missing data (Pinkerton et al. 2018).

2.4 Data analysis

Monthly estimates of *Macrocystis* coverage from five polygons within each region (Timaru, North Otago, Moeraki, Waikouaiti, Blue Skin, and Catlins) were averaged and aligned with monthly means of SST, TSS, K_d, and chl-a estimated at the zone level (12 zones within four regions). Given variation in cloud cover during satellite passes, variation in imagery availability resulted in variable sample numbers across regions.

The effects of monthly maximum SST, temperature anomaly, water clarity (as defined by the light attenuation coefficient K_d), TSS, and chl-a concentration (as a surrogate for nutrient availability) on *Macrocystis* cover were analyzed with Generalized Additive Models (GAMs) using the "R" package "mgcv." Assumptions of normality (Q-Q plot), homogeneity of variance (Levene's Test), as well as "concurvity" for general additive model analysis (an estimate of redundancy among explanatory variables) were used to check that model assumptions were met. GAM models were fitted with "cr" (cubic regression) splines, using a k-value of six (i.e., the number of "knots" denoting the complexity of the non-linear fit), and the distribution family gaussian. Selection procedures were implemented to penalize and remove factors with poor explanatory power. The final model included mean monthly SST anomalies, K_d, TSS, chl-*a*, maximum significant wave height and the two-way interaction between water clarity and temperature anomalies.

3 Results

3.1 Catchment land-use

The Timaru region (not shown) was dominated by urban and agricultural habitats but is also north of several major rivers (e.g., Waitaki), the outputs of which are transported northwards via the Southland Current (Sutton 2003). The North Otago region is also dominated by agriculture, and urban areas, but has smaller freshwater catchments than the Timaru region (Figure 2-2 A). The Moeraki region, dominated by the Moeraki Peninsula, has a high proportion of exotic forests and few major rivers (Figure 2-2 B). The Waikouaiti region is further into the lee of the Otago Peninsula, the land-use is dominated by agriculture and the three nearby major freshwater catchments (Shag, Pleasant, Waikouaiti) have some regions of intact wetland habitats (Figure 2-2 B). The Blue Skin region is well within the lee of the Otago Peninsula, with a catchment of land-use dominated by agriculture, exotic forest, native forest, and scrubland (Figure 2-2 B). The Catlins region is more exposed than the other regions due to the prevailing south-westerly wind and swell, but in the lee of small and large headlands (e.g., Nugget Point) populations of *Macrocystis* exist. The land-use of the Catlins includes the greatest native forest coverage of all regions (Figure 2-2 C). At the northern extent of the Catlins, one of New Zealand's largest rivers, the Clutha River, reaches the coast. The Clutha River and the gradient of native forest cover further south are expected to create a natural gradient of sediment exposure from north to south.

3.2 In situ data and aerial imagery

Aerial imagery collected during early April 2016 and late March 2017 showed extensive *Macrocystis* forests covering a large proportion of the coastline from Cornish Head to Shag Point. Classification of *Macrocystis* using colour matching algorithms were used on raw orthomosaic images (Figure 3-1). Overall patterns revealed the occurrence of large continuous patches of *Macrocystis* in the southern extent through to Bobby's Head (small rocky outcrop approximately in the centre of the zone), but north of this point are increasingly dominated by smaller patchy *Macrocystis* forests.

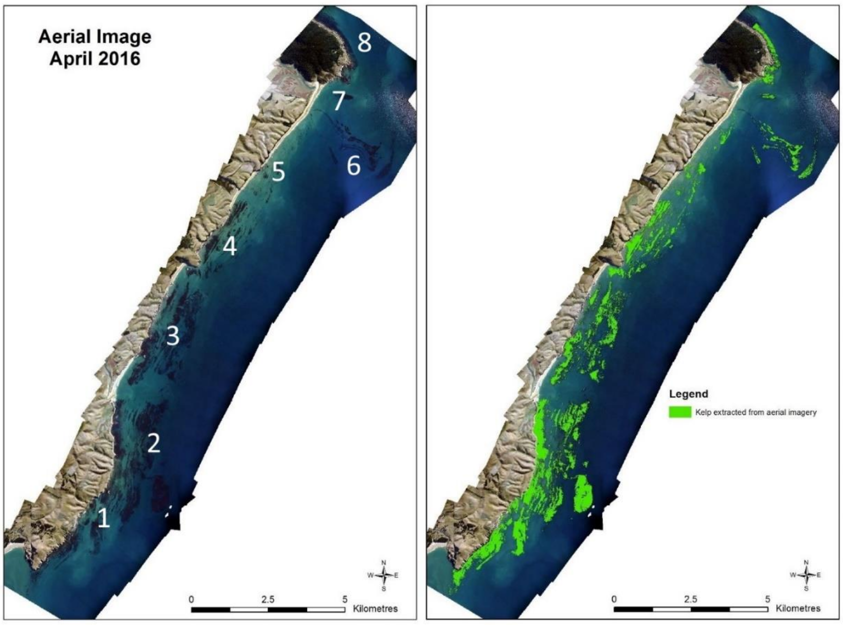

Figure 3-1: Aerial mosaic of *Macrocystis* cover from Cornish Head in the south to Shag Point in the north. Numbers indicate regions where total coverage of *Macrocystis* was summed (see Table 3-1).

Table 3-1: Total area of floating *Macrocystis* identified with colour matching extractions during April 2016 and March 2017 and differences between years (as hectares and % cover). Total area shown in hectares (10,000 m^2) and aerial imagery for two regions (2 and 6) was incomplete for the March 2017 sampling.

Region	Total area 10,000 m^2 (April 2016)	Total area 10,000 m^2 (March 2017)	Change 2016–17 (10,000 m^2)	Change 2016–17 (%)
1	233.5	85.1	-148.4	-64%
2	138.7	35.0	-103.7	-75%
3	116.8	127.3	10.6	9%
4	85.3	30.6	-54.7	-64%
5	23.8	12.4	-11.5	-48%
6	39.9	2.7	-37.2	-93%
7	11.6	3.5	-8.0	-69%
8	16.8	10.0	-6.8	-41%
TOTAL	666.4	306.6	-359.7	-54%

Relative changes in broad-scale *Macrocystis* coverage estimated by aerial imagery showed that April 2016 had far greater surface *Macrocystis* abundance than March 2017 (Table 3-1). Only region 3 showed a positive gain in *Macrocystis* cover from April 2016 to March 2017 (increase by 9%). All other sites (excluding those for which an overlapping image was not captured in March 2017), show a 41–69% decline in surface *Macrocystis* coverage. Although it is possible that extraction of colour signals associated with *Macrocystis* was affected in the nearshore due to higher turbidity, there was a noticeable reduction in *Macrocystis* bed size across the onshore to offshore turbidity gradient from 2016 to 2017.

3.3 Satellite estimates of *Macrocystis* cover and water quality

3.3.1 Regional trends in *Macrocystis* cover and water quality

Comparisons between aerial imaging (manned fixed-wing aircraft) taken in April 2016 over the region from Karitane to Shag Point and satellite images over the same region revealed very close overlap in *Macrocystis* coverage (Figure 3-2). Although the coverage calculated from aerial imagery was higher (666 ha) than satellite estimates (402 ha), all the major *Macrocystis* forests were well described by the lower resolution satellite images. Disagreement in the final values is largely a result of the higher resolution of aerial imaging, the selection of low tide conditions, and variability in the visibility of *Macrocystis* below the surface.

Remotely sensed water quality products, particularly those relating to water clarity, varied considerably between regions (Figure 3-3). PAR attenuation (K_d) was very high in the Timaru region and was elevated in the North Otago and Catlins regions but was far lower and less variable in the Moeraki, Waikouaiti and Blue Skin Bay regions. Mean SST was relatively similar between regions, although Timaru and the Catlins experienced a greater range of temperatures. TSS were notably higher in the Timaru region compared to all other regions, although both North Otago and the Catlins regions both had elevated TSS compared to Moeraki, Waikouaiti and Blue Skin Bay. Chl-*a* showed a similar trend, but the differences between sites was less pronounced.

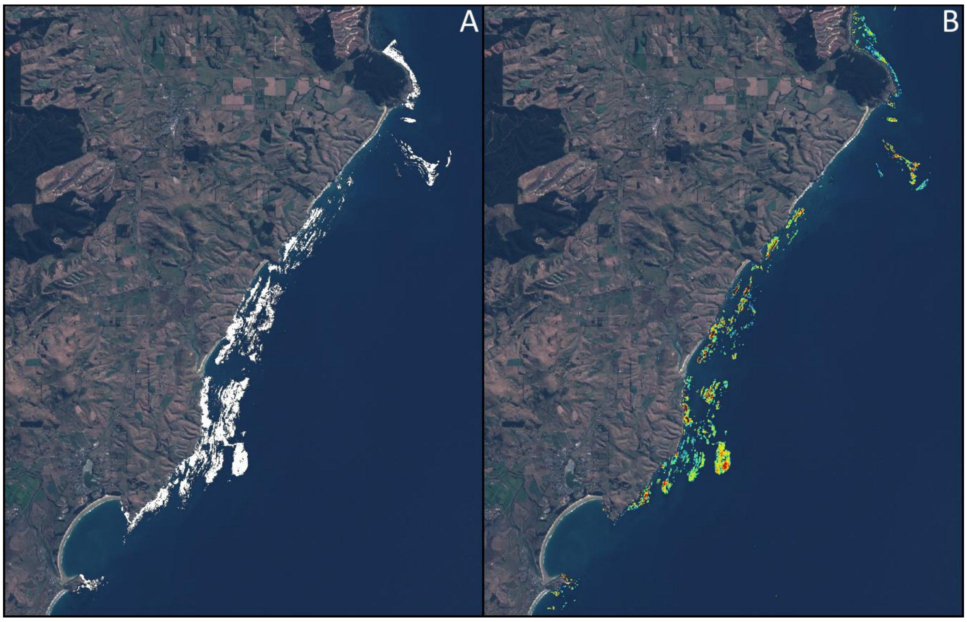

Figure 3-2: Coverage of *Macrocystis* between Karitane and Shag Point determined by aerial imagery (A) and satellite imagery (B). Aerial imagery was analysed using machine learning techniques, while satellite imagery is filtered using vegetation indices that rely on "red-edge" wavelengths.

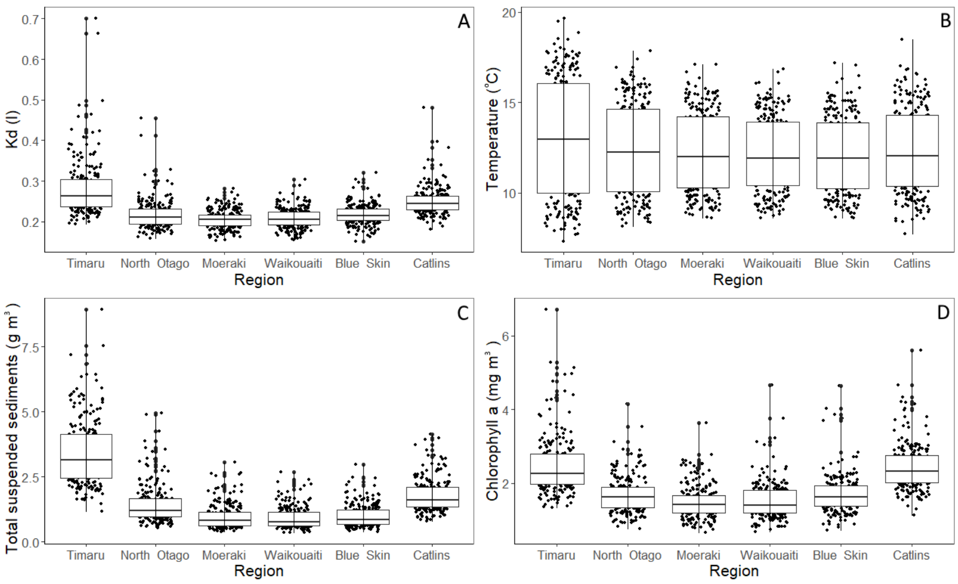

Figure 3-3: Regional variation in remotely sensed water quality products from 2002–20 across the six study regions. Water quality products include K_d (A) or light attenuation (where higher values equal reduced clarity), sea surface temperature (B), total suspended solids (C), and chlorophyll-*a* (D).

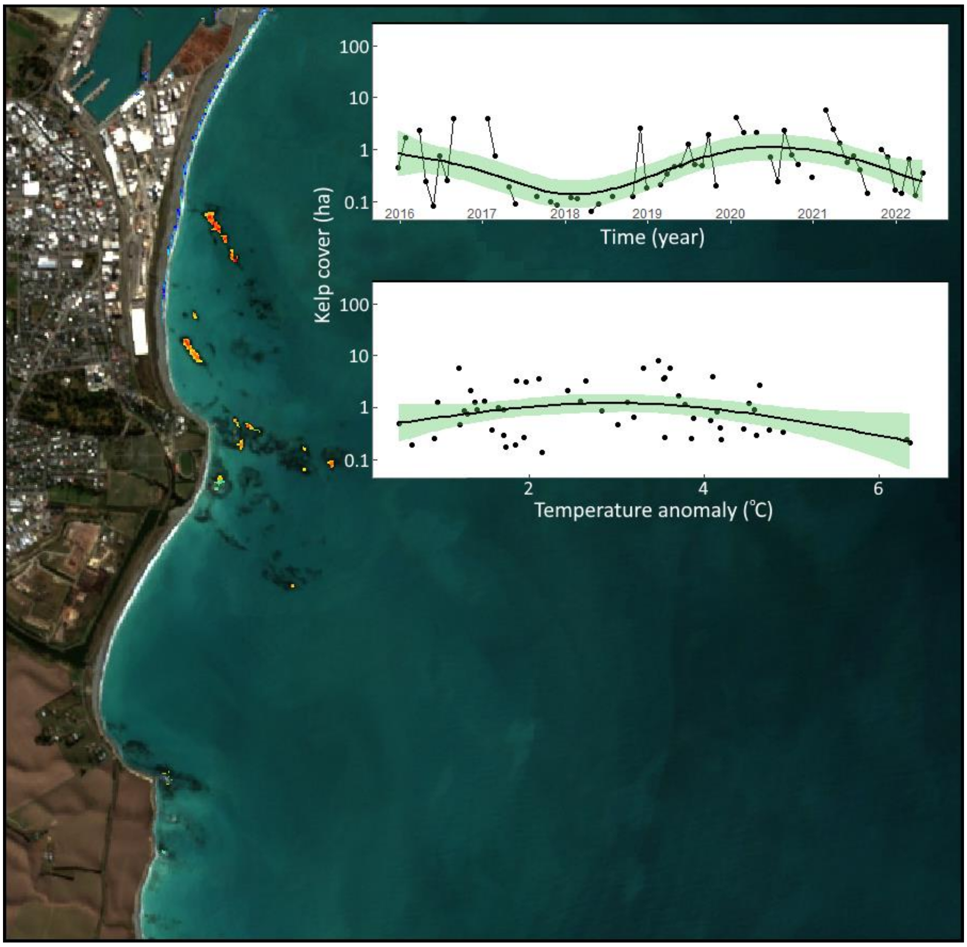

Figure 3-4: Satellite image of *Macrocystis* cover in the Timaru region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in sea surface temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

Macrocystis in the Timaru region was limited to a small number of patches surrounding Patiti Point and Jacks Point (Figure 3-4). This region is exposed to high levels of sedimentation and had low coverage of *Macrocystis*. Both low and high temperature anomalies show a negative impact on the coverage of *Macrocystis*. This region experienced the greatest extremes at each end of the temperature range.

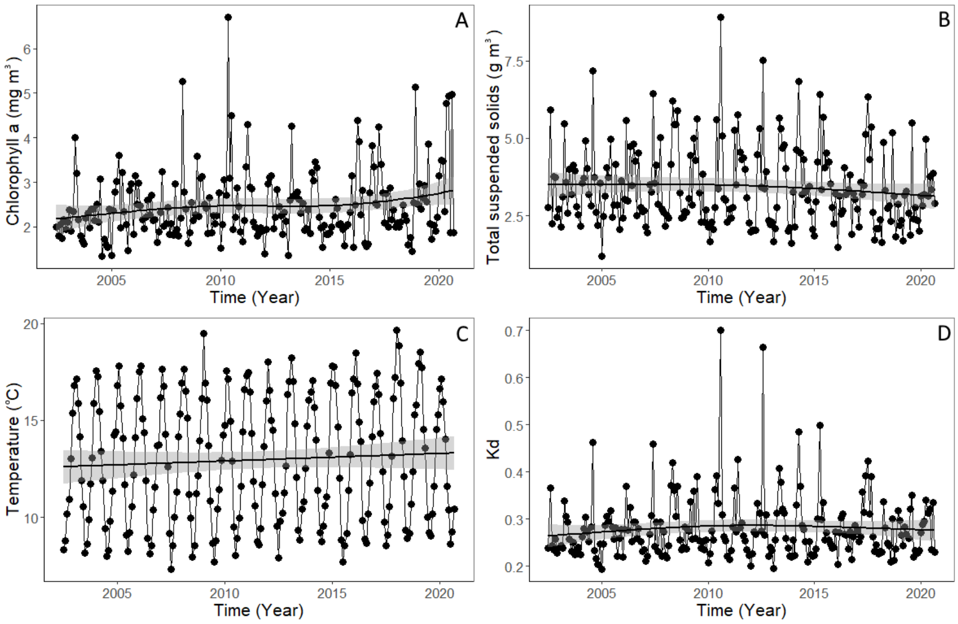

Figure 3-5: Remotely sensed water quality parameters for the Timaru region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and K_d or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll a, TSS, sea surface temperature, and K_d (Figure 3-5) for the Timaru region showed a significant trend of increasing chlorophyll-*a* concentrations over time (t = 2.5, p = 0.014). Trends for TSS, SST, and K_d were neutral with no significant changes over time.

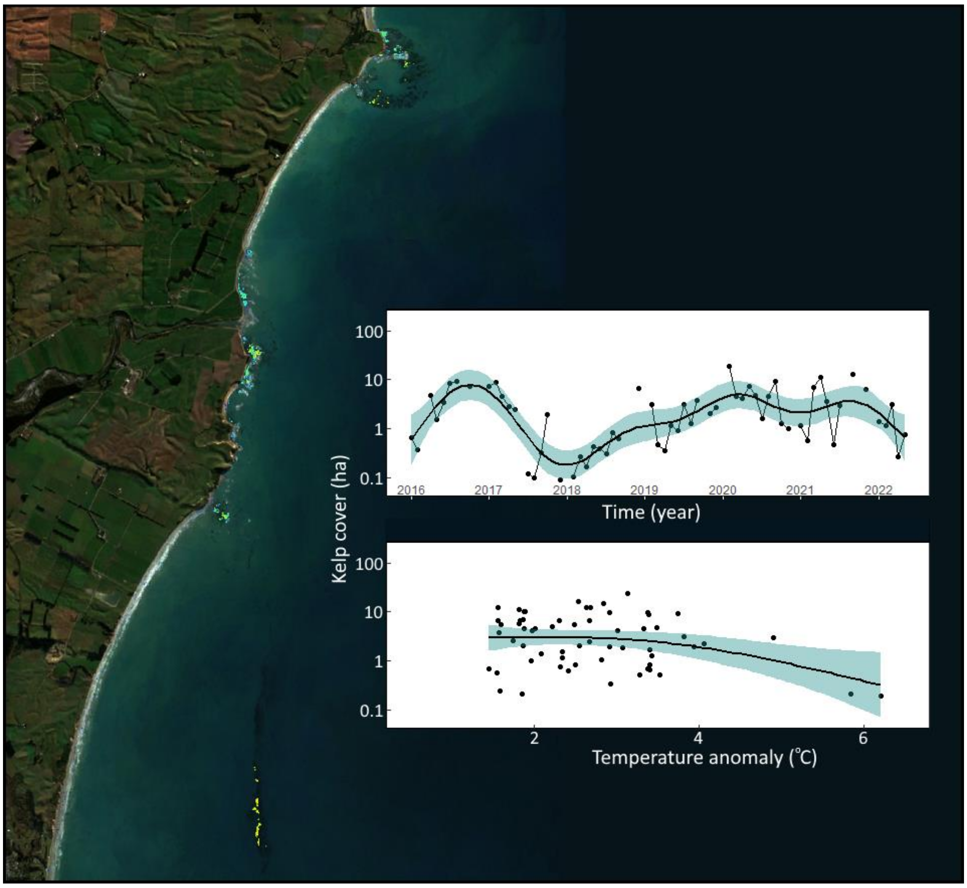

Figure 3-6: Satellite image of *Macrocystis* cover in the North Otago region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in sea surface temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

North Otago *Macrocystis* forests were generally characterised by nearshore populations that are exposed to high sediment loads (Figure 3-6). There was a stretch of offshore reef north of the Moeraki Peninsula with detectable *Macrocytsis*, however, this population was frequently not detectable from satellite imagery. The most extreme temperature anomalies had a major influence on *Macrocystis* coverage in this region.

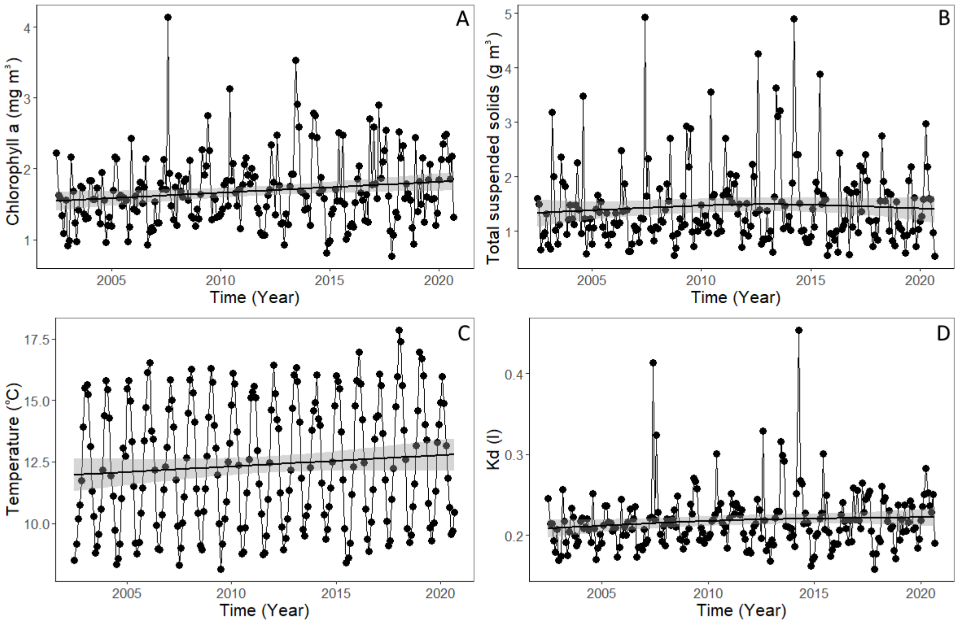

Figure 3-7: Remotely sensed water quality parameters for the North Otago region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and K_d or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll-*a*, TSS, sea surface temperature, and K_d (Figure 3-7) for the North Otago region showed a trend of increasing chlorophyll-a concentrations over time (t = 2.4, p = 0.016), and near significant increases in K_d (t = 1.6, p = 0.1). Trends for TSS and SST were neutral with no significant changes over time.

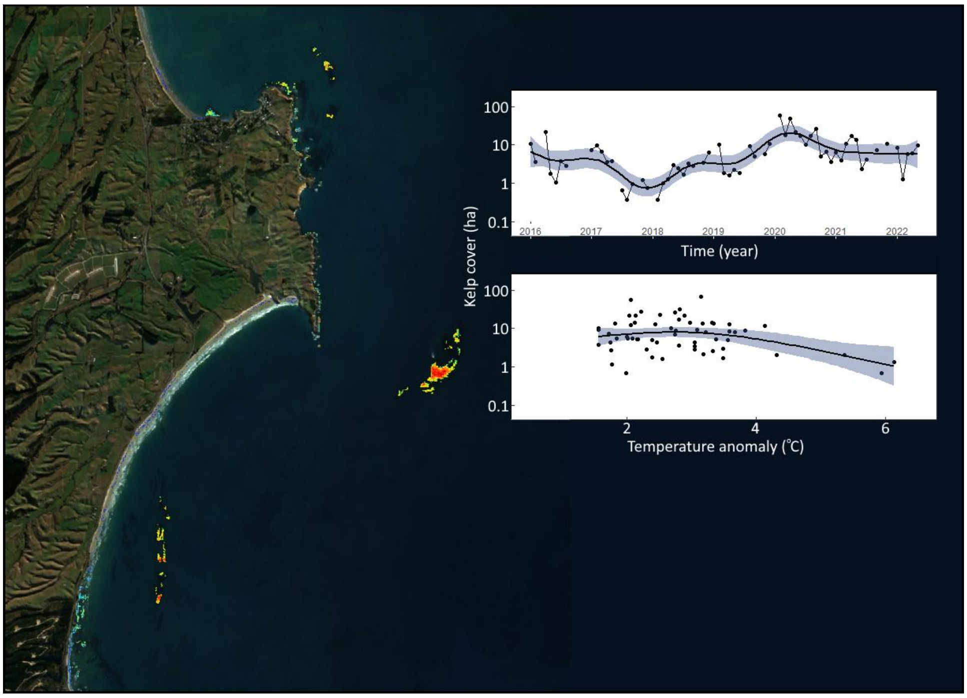

Figure 3-8: Satellite image of *Macrocystis* cover in the Moeraki region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in sea surface temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

Macrocystis forests surrounding the Moeraki Peninsula were described by several small forests near the northern tip of the Moeraki Peninsula, some offshore reef south of the Peninsula, and a very large population ("Fish Reef") well offshore from the southern end of the Peninsula (Figure 3-8). The Moeraki region had some of the highest monthly totals of *Macrocystis* coverage and were dominated by healthy coverage at the "Fish Reef" site. Warm temperature anomalies had a large influence on coverage at this site.

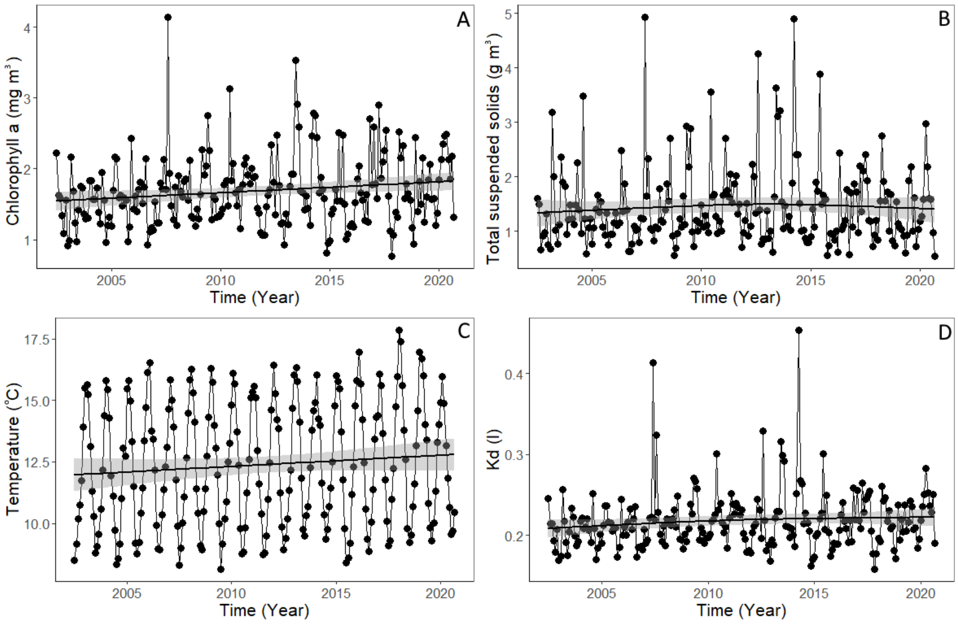

Figure 3-9: Remotely sensed water quality parameters for the Moeraki region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and K_d or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll-*a*, TSS, sea surface temperature, and K_d (Figure 3-9) for the Moeraki region showed a significant trend of increasing K_d ($t = 2.1$, $p = 0.036$) and strong trend of increasing SST ($t = 1.8$, $p = 0.08$) over time. Neutral trends for TSS and chlorophyll-*a* were observed.

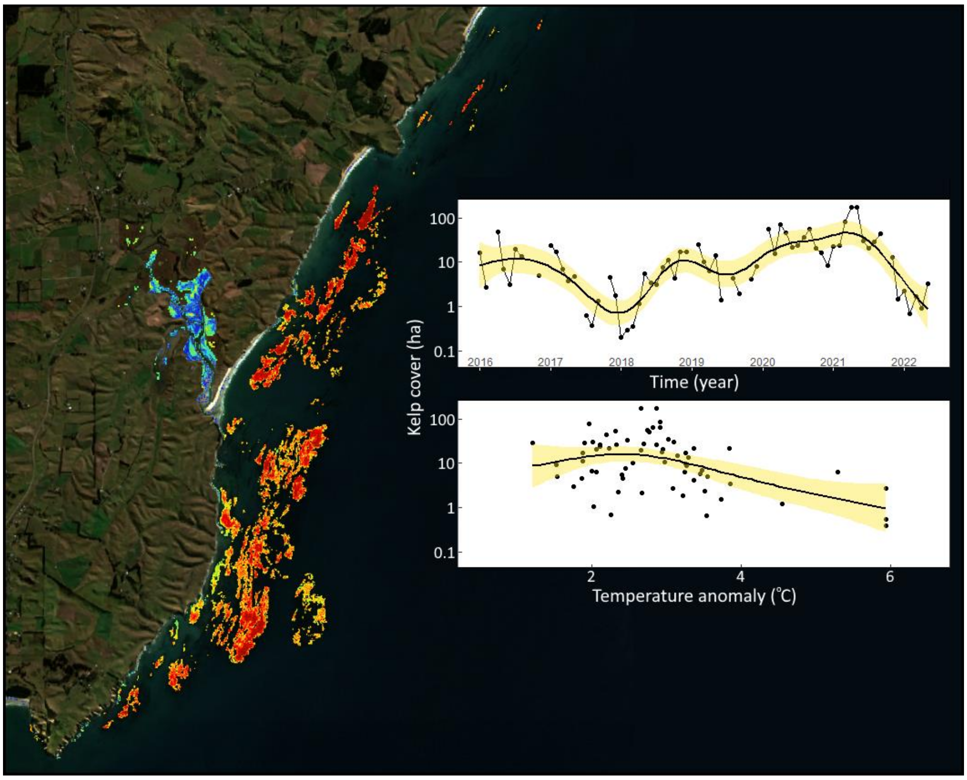

Figure 3-10: Satellite image of *Macrocystis* cover in the Waikouaiti region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

Macrocystis populations in the Waikouaiti zone were the greatest of any region on the Otago Coast, and possibly represent the biggest populations in New Zealand (Figure 3-10). The forests surrounding Cornish Head are large and extend well offshore. Like other regions, the Waikouaiti region was affected by warm temperature anomalies, but seem to hold up well to minor anomalies (e.g., some of the highest coverage seen during months c. 2°C warmer than the 20-year average).

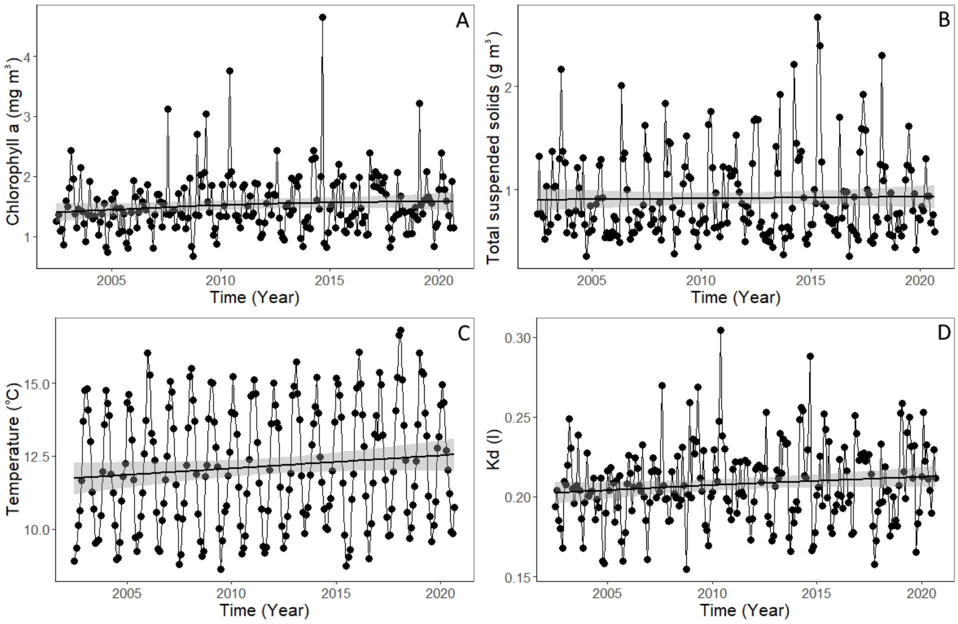

Figure 3-11: Remotely sensed water quality parameters for the Waikouaiti region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and K_d or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll-*a*, TSS, sea surface temperature, and K_d (Figure 3-11) for the Waikouaiti region showed near significant trends for K_d (t = 1.8, p = 0.08) and SST (t = 1.7, p = 0.09). Neutral trends for chlorophyll-*a* and TSS were observed.

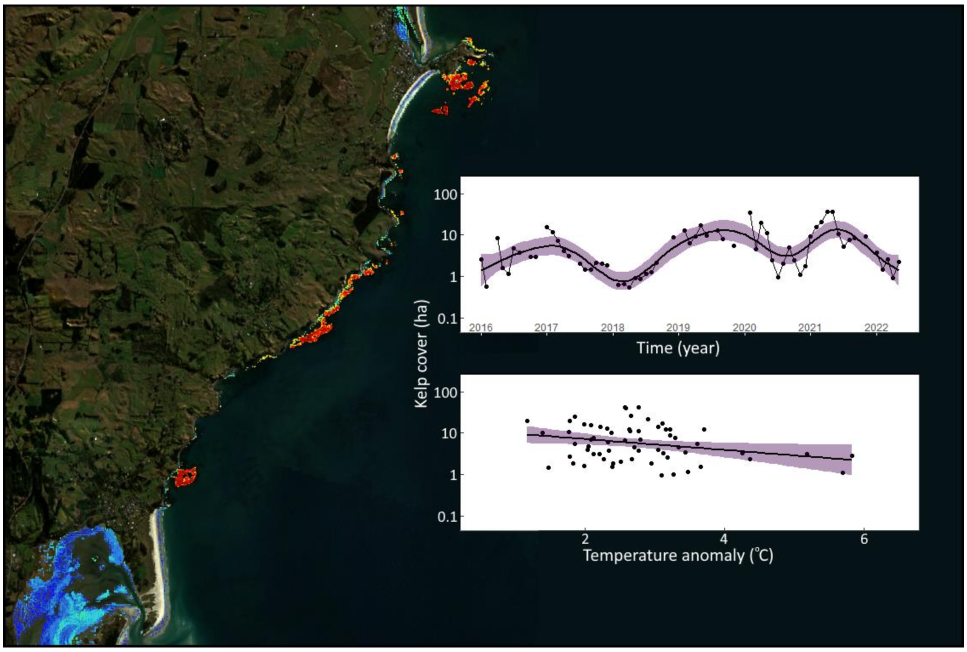

Figure 3-12: Satellite image of *Macrocystis* cover in the Blue Skin region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in sea surface temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

The Blue Skin Bay Zone had some *Macrocystis* forests extending slightly offshore at the Karitane Peninsula, but the *Macrocystis* populations were largely defined by nearshore populations (Figure 3-12). However, there was relatively high coverage of *Macrocystis* across this region and it was generally similar to the Moeraki region in total coverage. Warm temperature anomalies had a weaker negative effect on coverage than at some other locations.

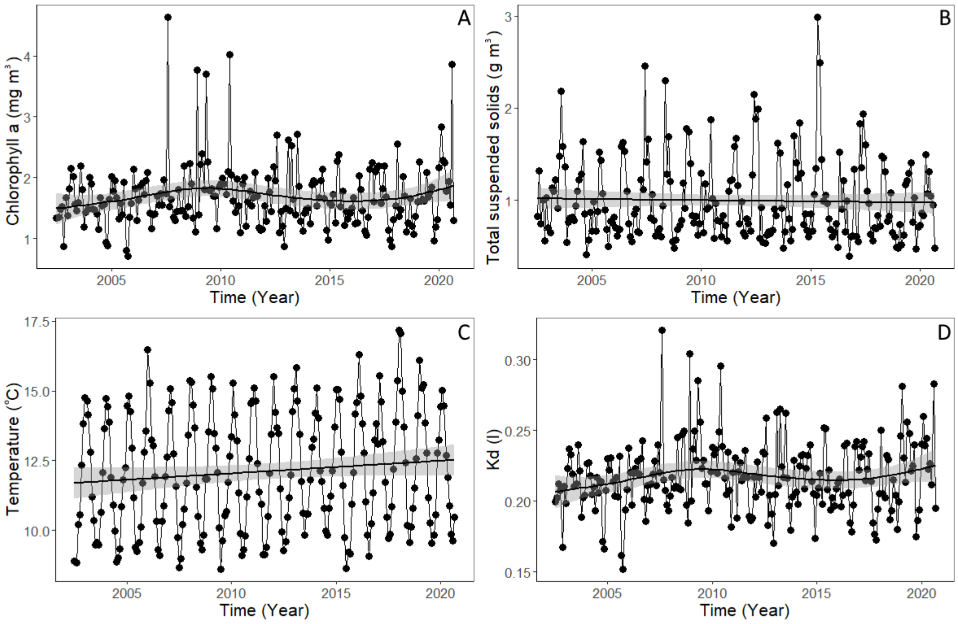

Figure 3-13: Remotely sensed water quality parameters for the Blue Skin region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and K_d or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll-*a*, TSS, sea surface temperature, and K_d (Figure 3-13) for the Blue Skin region showed a near significant trend of increasing SST ($t = 1.7$, $p = 0.09$) over time. Neutral trends for TSS, chlorophyll-*a*, and K_d were observed.

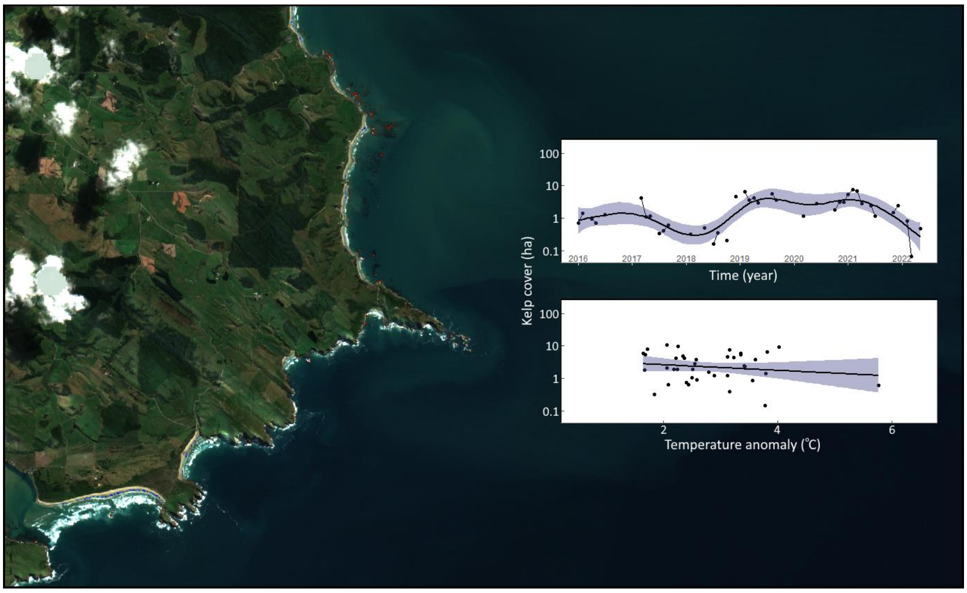

Figure 3-14: Satellite image of *Macrocystis* cover in the Catlins region including a timeseries of *Macrocystis* coverage and the influence of sea surface temperature anomalies on coverage. Temperature anomalies represent the monthly difference in sea surface temperature to a 20-year timeseries for that location. Trends are plotted using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

Macrocystis forests in the Catlins region were described by only a few locations north of Nugget Point, and just inside the mouth of the Catlins Estuary, where exposure to Southern Ocean swells are reduced (Figure 3-14). These forests were generally small but were often greater in coverage than those observed in Timaru. Warm temperature anomalies had the least influence in the cooler southern region.

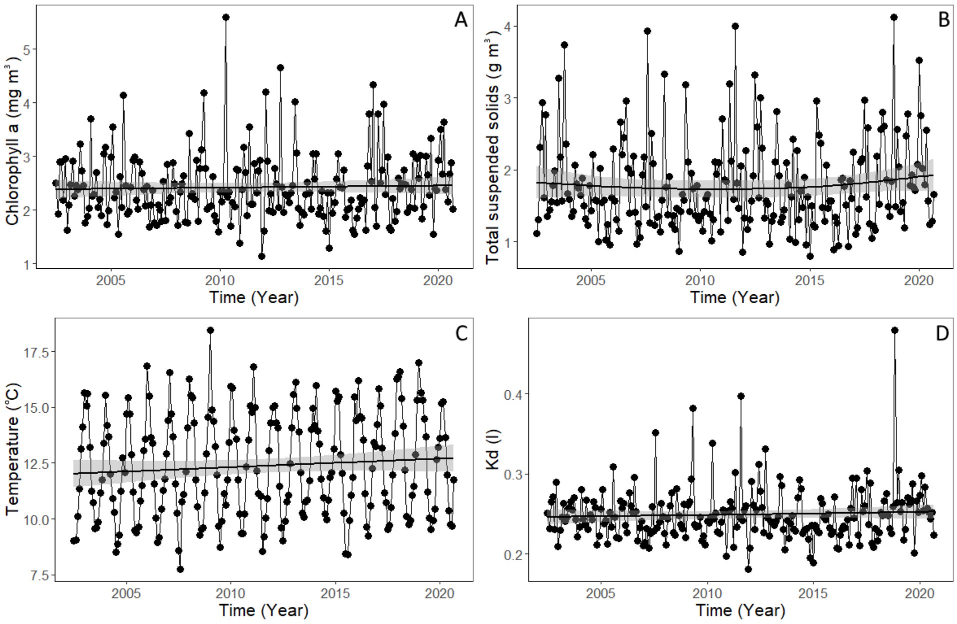

Figure 3-15: Remotely sensed water quality parameters for the Catlins region. Water quality products include chlorophyll-*a* (A), total suspended solids (B), sea surface temperature (C), and Kd or light attenuation (where higher values equal reduced clarity) (D).

Remotely sensed estimates of four water quality products chlorophyll-*a*, total suspended solids, sea surface temperature, and K_d (Figure 3-15) for the Catlins region showed no meaningful trends in remotely sensed water quality parameters.

3.3.2 Summary of *Macrocystis* cover in the Otago region

Overall, the distribution of *Macrocystis* forests across the Otago region (and southern Canterbury) revealed various spatio-temporal trends. *Macrocystis* forests tended to be smaller in size and closer to shore in the northern regions (Timaru Figure 3-4, and North Otago Figure 3-6). Further south towards the Otago Peninsula, *Macrocystis* forests increased in coverage and many large offshore forests were observed (Moeraki Figure 3-8, Waikouaiti Figure 3-10, and Blue Skin Figure 3-12). *Macrocystis* coverage peaked in the Waikouaiti Zone. At the southern extent of the Otago region, small patches of *Macrocystis* were observed near Nugget Point and the mouth of the Catlins Estuary (Figure 3-14). Analysis revealed that sea surface temperature, particularly un-seasonably warm temperatures generally had a negative impact on *Macrocystis* bed coverage. These trends were the most striking for regions with the highest coverage of *Macrocystis* (Figure 3-8; Figure 3-10; Figure 3-12).

3.4 Analysis of trends

Combined analysis revealed significant influences of sea surface temperature, suspended sediments, and maximum significant wave height (Table 3-2). While several factors influence *Macrocystis* coverage, increasing temperatures (as shown by temperature anomalies and absolute temperatures) were shown to influence *Macrocystis* coverage across zones (Figure 3-16; Figure 3-17). Warm temperature anomalies during summer had a negative effect on *Macrocystis* coverage, while warm anomalies in spring and autumn had an initially positive effect, but increasingly negative beyond 2–3°C above average. However, during winter, warm anomalies had a positive influence on *Macrocystis* coverage.

Table 3-2: Influence of key parameters on *Macrocystis* coverage as estimated by General Additive Models (GAMs). Overall model (n = 165) has an adjusted r^2 of 0.53, with 57% deviance explained. Significant terms highlighted in bold/italics.

Smooth terms	Edf	Ref.df	F	P-value
SST anomaly * TSS	9.4	27	**1.2**	**<0.0001**
SST anomaly	0.9	9	**0.8**	**0.0002**
TSS	0.9	9	**1.0**	**<0.0001**
Max HS	3.2	9	**1.0**	**0.02**

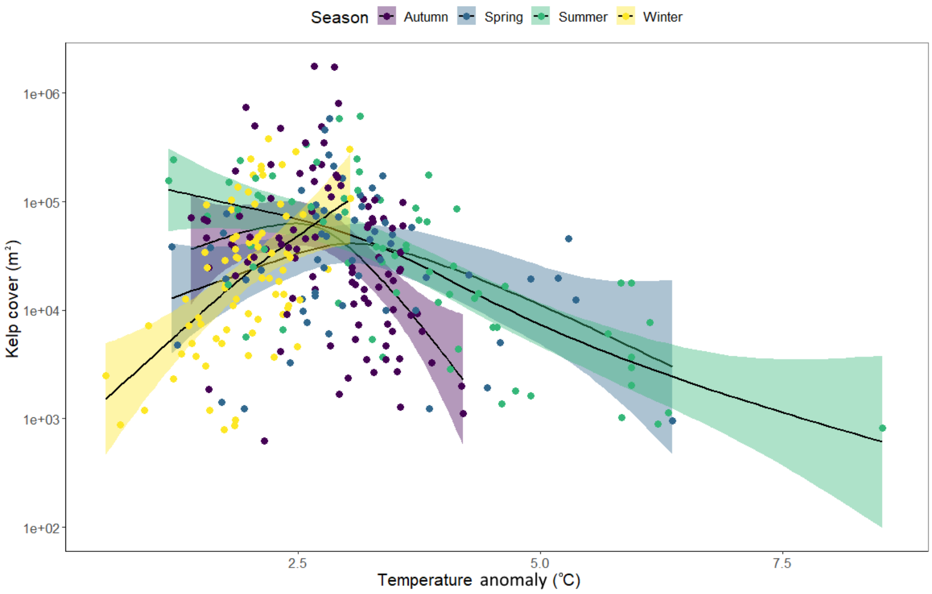

Figure 3-16: Influence of sea surface temperature anomalies on Macrocystis cover between 2016 and 2022. Trends are plotted separately for each season using General Additive Models (GAMs). Y-axis is a logarithmic scale.

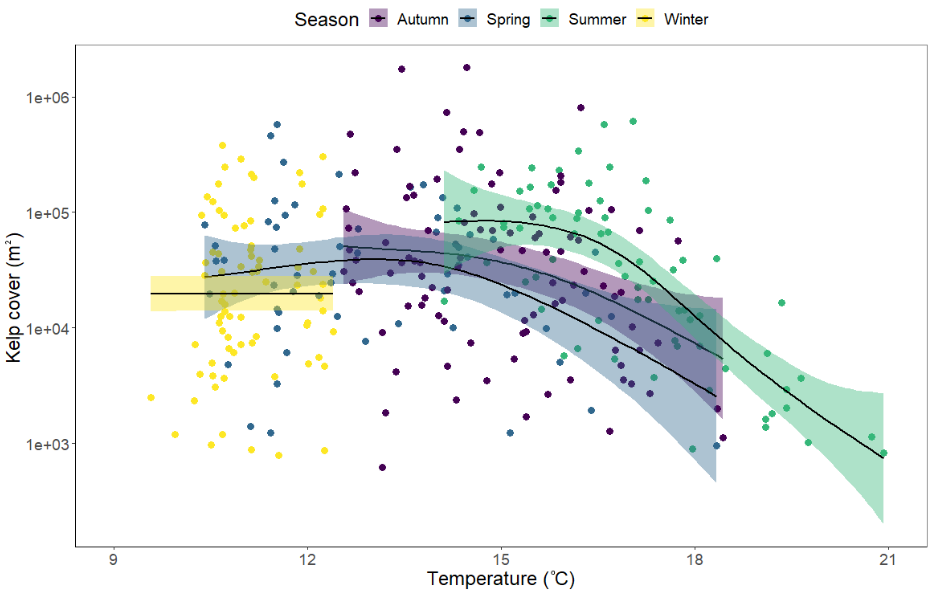

Figure 3-17: Influence of sea surface temperature anomalies on *Macrocystis* cover between 2016 and 2022. Trends are plotted separately for each season using General Additive Models (GAMs). Y-axis is a logarithmic scale.

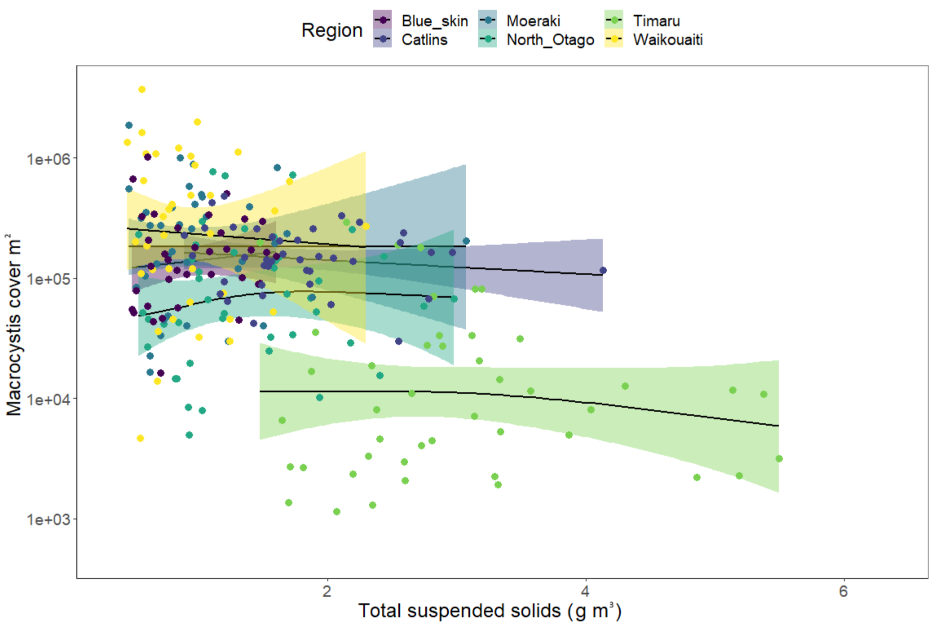

Figure 3-18: Influence of sediment loads as determined by the particulate backscatter at 555 nm (BBP) on *Macrocystis* coverage as separated by region. Trends are plotted separately for each region combined using General Additive Models (GAMs). Y-axis is plotted as a logarithmic scale.

Sites with the lowest range of sediment loads (Waikouaiti and Blue Skin Bay) had neutral or slightly positive relationships between *Macrocystis* cover and TSS, while the other sites had slightly negative relationships (Figure 3-18). Although there was little evidence that temporal variation in suspended sediments within sites caused major declines in *Macrocystis* coverage, variation in sediment loading between sites had a significant influence on observed *Macrocystis* coverage (Figure 3-18). Increasing sediment loads had a negative influence on *Macrocystis* cover, but this was exacerbated by warm temperature (Figure 3-19).

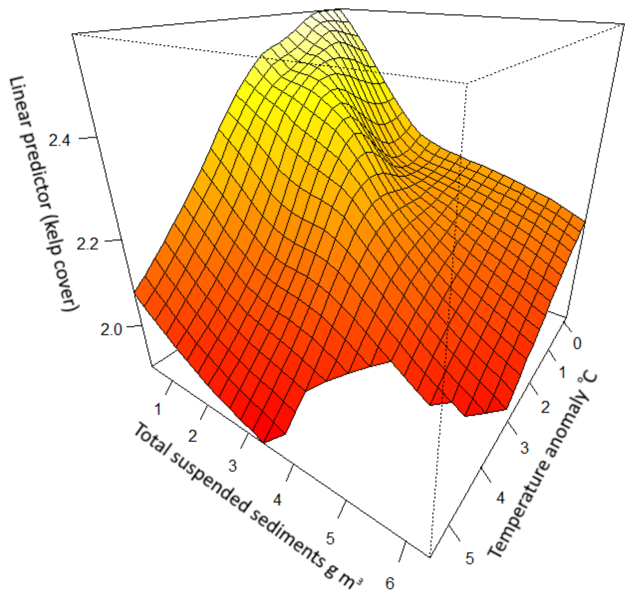

Figure 3-19: Interactive effects of TSS and temperature anomalies on *Macrocystis* cover as determined by generalised additive models (GAM).

Using the national bathymetric grid, the cover of *Macrocystis* across the four major *Macrocystis* regions of the North Otago coast were presented across depth bins (from 2016–22). The expected trend was for exponentially decreasing coverage with increasing depth as light becomes limiting. This trend was evident at most sites, however, the Moeraki region had a noticeable increase in coverage at greater depths, particularly at 10-15 m (Figure 3-20). This trend was likely driven by the distribution of rocky reef, with several offshore reefs present in this region. At the Moeraki and Waikouaiti regions there were several instances of *Macrocystis* detected in water depths of 20-30 m. No surface *Macrocystis* was detected at water depths greater than 35 m.

Analysis revealed that increasing temperature anomalies affected *Macrocystis* coverage at all depths and point to a shallowing of the possible habitable depth range of *Macrocystis* (Table 3-3). In addition, elevated sediment loads caused a similar shallowing of depth ranges (Table 3-3).

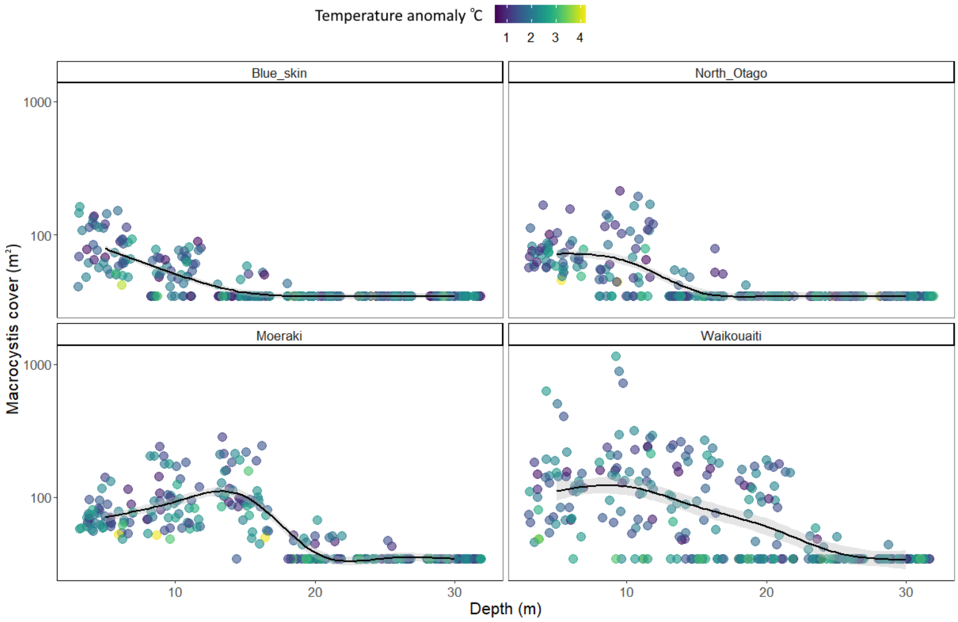

Figure 3-20: ***Macrocystis*** **cover across depths between 2016 and 2022.** Sea surface temperature anomalies during each month sampled are presented as a colour scale, with yellow points showing warm anomalies and purple points showing cool anomalies. Y-axis is cube root transformed. Depth estimates are binned into 5m categories, and the points are "jittered" within these bins for visualisation.

Table 3-3: **Influence of key parameters on** ***Macrocystis*** **coverage at multiple depths as estimated by General Additive Models (GAMs).** Overall model (n = 894) has an adjusted r^2 of 0.44, with 64% deviance explained. Significant terms highlighted in bold/italics.

Smooth terms	Edf	Ref.df	F	P-value
Temperature * Depth	15.7	29	**6.7**	**<0.0001**
Temperature anomaly	3.3	9	**1.9**	**0.0003**
Sediment load	3.8	9	**1.4**	**0.006**

4 Summary and recommendations

4.1 Status of *Macrocystis*

Updated analysis of *Macrocystis* coverage trends has confirmed that warm sea surface temperatures are a major threat to the stability of *Macrocystis* forests in the Otago region. Like previous studies on *Durvillaea* (Thomsen et al. 2019) and *Macrocystis* (Tait et al. 2021), this study shows that warm temperature anomalies, particularly those >3–4°C, cause dramatic reductions in the coverage of *Macrocystis*. Despite the severe consequences of marine heatwaves on surface cover of *Macrocystis*, including the summer 2021–22 event, mild summer seasons such as 2020–21 revealed the highest cover of *Macrocystis* over the 6-year period.

Here, I show some of the first evidence that the marine heatwave of summer 2021–22 caused retractions in *Macrocystis* cover. Additionally, I show that the use of a national bathymetric layer can help us identify changes in the depth range that *Macrocystis* can occupy and reveal a shallowing of the habitable depth range during warm conditions.

Alongside warm temperature anomalies, I show that reduced water clarity is an additive stressor to *Macrocystis* forests. While there was little evidence that changes in *Macrocystis* coverage were caused by temporal variations in sediments within regions, there was variation in *Macrocystis* coverage across regions exposed to varying sediment loads. I present a gradient of sediment loading, increasing from Blue Skin Bay to Timaru. Similar gradients exist for the Catlins region, with the Brighton–Taieri coast exposed to high sediment loading which decline towards the southern Catlins region (Figure 4-1).

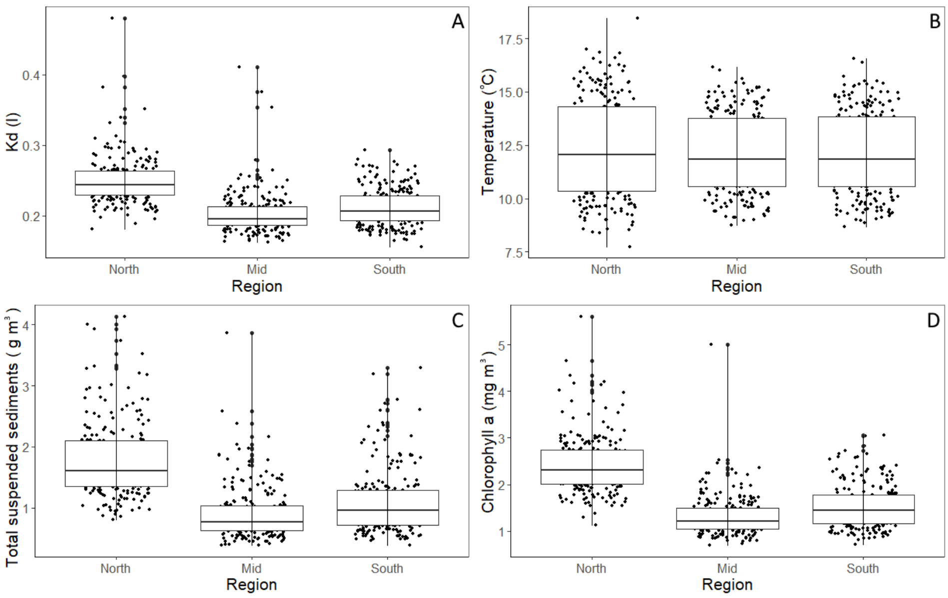

Figure 4-1: Remotely sensed water quality products averaged for three zones within the Catlins region, north (near the mouth of the Clutha River), mid (near the Catlins Estuary), and south (near Wapiti (Chaslands) River). Water quality products include Kd (A) or light attenuation (where higher values equal reduced clarity), temperature (B), total suspended solids (C), and chlorophyll-*a* (D).

4.2 Future monitoring

To help understand the abundance of deeper-living populations I propose surveying *Macrocystis* populations on deeper rocky reefs at several locations using Remote Operated Vehicles (ROV), drop-cameras and where possible SCUBA (Self Contained Underwater Breathing Apparatus) divers. These methods will also be used at an equal number of shallow reefs adjacent to these deep sites to establish relationships between the two habitats. These measurements will identify uncertainties surrounding passive monitoring methods (i.e., satellites) in assessing *Macrocystis* populations in deeper habitats.

Remote sensing has revealed several areas where *Macrocystis* populations are sporadically present in deeper water. Shifting light availability and increasing frequency of heat-wave events present the greatest threat to *Macrocystis* populations (Tait et al. 2021) and plants at the limits of their depth distribution will likely be the most responsive to subtle water quality shifts. Therefore, I propose establishing in situ validation and calibration of in situ populations in several candidate deep areas (Figure 4-2) to determine depth limitations of *Macrocystis* and fine-tune remotely sensed metrics of ecosystem health.

I propose using georeferenced drop-camera, ROV and SCUBA diver methods to align observations of *Macrocystis* density at the seafloor with satellite observations to examine the accuracy of satellite-based detection methods.

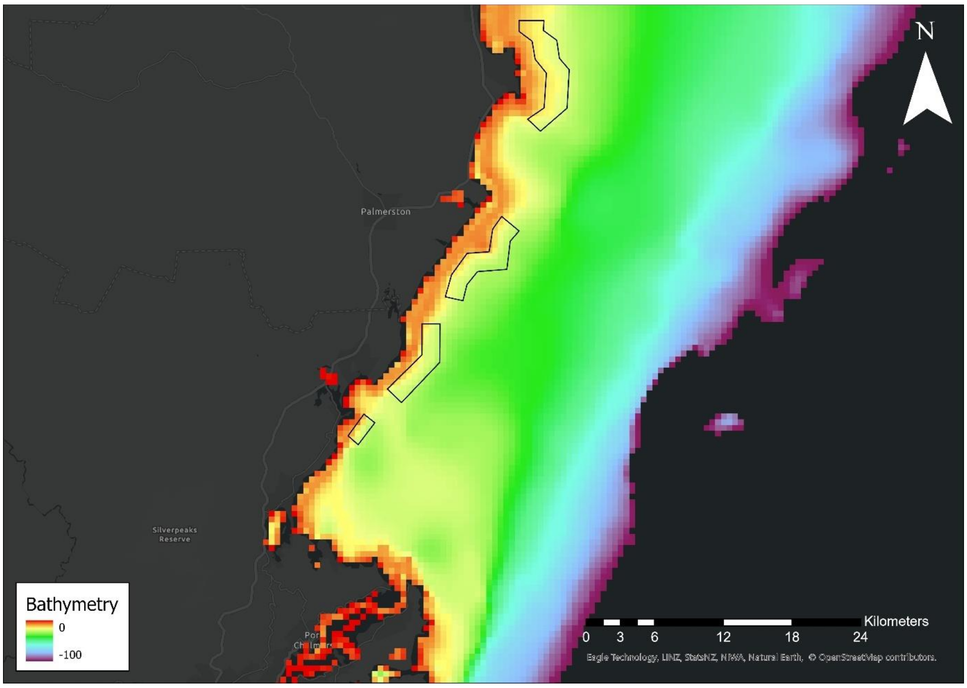

Figure 4-2: Bathymetry of the Otago Coast from the Otago Peninsula to the Moeraki Peninsula. Candidate regions for in situ validation of deep populations of *Macrocystis* shown by black polygons.

Although monitoring of *Durvillaea* along some of the northern Otago coastline only began in 2018, there was some evidence that measurements taken during the heatwave affected summer of 2017–18 were lower than the following, non-heat-wave years (Tait 2020). Further evidence is required to understand the consequences of warm water temperatures on *Durvillaea* populations. I propose establishing high-resolution aerial imagery of *Durvillaea* populations in four zones representing a gradient of exposure to discharges from the Clutha River, and gradients of terrestrial land-uses (particularly the relative proximity to agriculture, exotic forests, and native forests) (Figure 4-3). I propose aerial surveys of at least one headland or rocky reef platform in each of the four regions to establish baseline information about *Durvillaea* populations and set up a programme that will help identify sediment related stress on these populations.

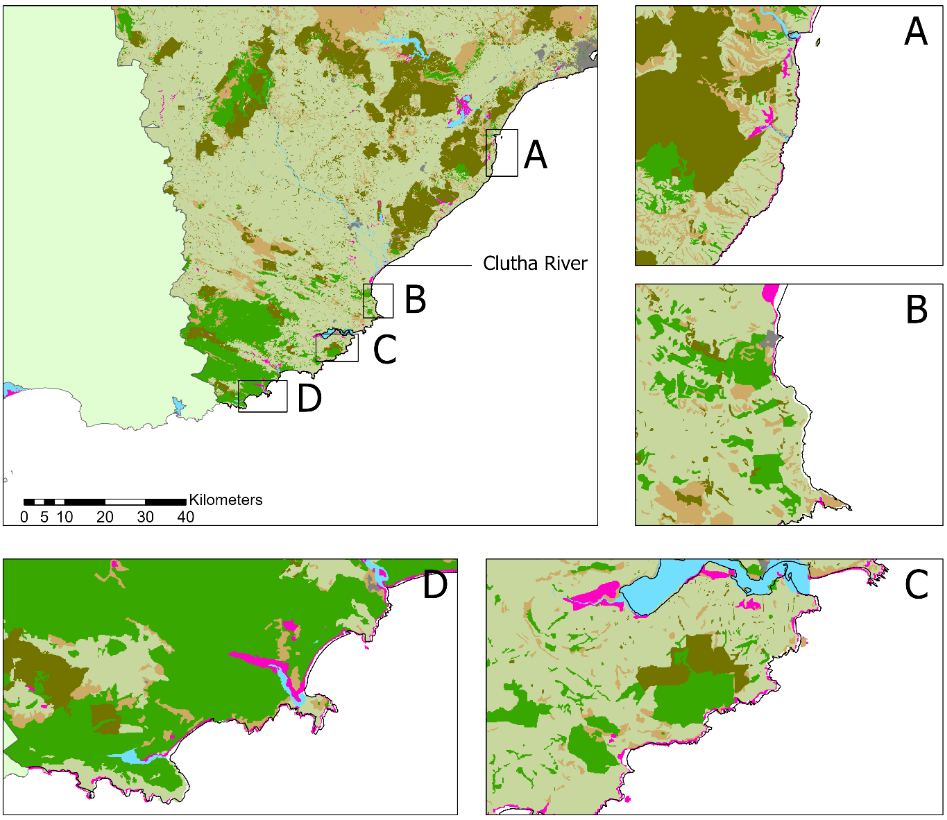

Figure 4-3: Candidate regions of coastal *Durvillaea* habitats for high-resolution aerial monitoring. Inset maps show regions of high sediment exposure and low native forest coverage (A); high sediment exposure and moderate native forest cover (B); moderate sediment exposure and moderate native forest cover; and moderate sediment exposure and high native forest cover (D).

5 Acknowledgements

I thank Rebecca McGrouther and Port Otago Ltd. for funding data collection in the Blue Skin Bay and Waikouaiti regions and for providing permission to use the data in this report, Steve Copson for collection of aerial imagery along the Waikouaiti Coast, and Jochen Bind, Stephanie Mangan for assistance analysing aerial and satellite imagery and the SCENZ team (Matt Pinkerton, Mark Gall, Simon Wood and Tilman Steinmetz) for access to satellite-derived water quality products. Thanks to Chris Woods for his constructive reviews of this report.

6 Glossary of abbreviations and terms

CHL	Chlorophyll-*a*: concentrations of phytoplankton as detected by earth-observation satellites. Expressed as milligrams per metre cubed.
GAM	General Additive Model: Statistical analysis of multiple parameters on a single response variable. Unlike general linear models (GLMs), GAMs allow for non-linear trends to be fitted.
Kd or KPAR	Attenuation coefficient for light: low Kd values represent clear water while high values represent turbid water. Expressed as the proportional reduction in light per m of water depth.
NDVI	Normalised Difference Vegetation Index: multi-band index used to define photosynthetic vegetation.
NDWI	Normalised Difference Water Index: multi-band index used to define water bodies.
NIR	Near Infrared Radiation: The radiation wavelengths greater than visible red light. These wavelengths are highly informative of vegetation health.
PAR	Photosynthetically Active Radiation: wavelengths of light required for photosynthetic organisms.
SST	Sea surface temperature: temperature at the sea surface as measured by earth-observation satellites. Expressed as degrees Celsius.
TSS	Total Suspended Solids: suspended sediments (non-biological) within the water column. Expressed as grams per metre cubed.

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6.5. Regional Threat Lists for Species in Otago

Prepared for: Environmental Science and Policy Comm

Report No. SPS2307

Activity: Governance Report

Author: Scott Jarvie, Scientist - Biodiversity

Endorsed by: Anita Dawe, General Manager Policy and Science

Date: 26 April 2023

PURPOSE

[1] This paper sets out work currently underway in the biodiversity area at ORC. It overviews the development of regional threat classifications, provides examples from other regions where regional conservation statuses have added values to national assessments, and includes details of the first regional conservation status undertaken for a species group (reptiles) in the Otago region.

EXECUTIVE SUMMARY

[2] This report details the first regional conservation status assessment for a species group in Otago. Following standardised methodology, the regional threat status of all reptile species that occur in Otago was assessed.

[3] A total of 34 reptile species were identified as present in Otago, including 18 skinks, 13 geckos, two marine reptiles (both sea turtles), and tuatara. Of the native reptile species that are resident in Otago (found in the region year-round), 31 of the 32 (97%) species were assessed as regionally threatened or regionally at risk.

[4] The information in the report will inform biodiversity and biosecurity management in the Otago region.

RECOMMENDATION

That the Environmental Science and Policy committee:

1) ***Notes** this report.*

BACKGROUND

[5] Threat classifications play an important role in monitoring biodiversity and biosecurity. The New Zealand Threat Classification System (NZTCS) is a tool used to assign a threat status to candidate species in Aotearoa New Zealand at a national scale. The NZTCS scores species against criteria based on an understanding of population state, size, and trend, while considering population status, impacts of threat, recovery potential, and taxonomic certainty. The Department of Conservation | Te Papa Atawhai (DOC) administers the NZTCS in Aotearoa New Zealand, with national assessments used to inform conservation action, target resources, and monitor biodiversity trends and conservation effectiveness.

[6] While DOC is tasked with managing indigenous species nationally, regional and district councils have statutory obligations to maintain indigenous biodiversity under the

Resource Management Act 1991 (RMA), including to manage the habitats of threatened taxa (plural for taxonomic classifications, e.g., family, genus, species, etc). The need for regional threat classifications to help local authorities manage and protect biodiversity within their regions has been identified as a high priority for regional councils. Knowledge of the threat species present at a site is of particular importance for both RMA consenting processes and conservation planning such as that associated with pest control programmes for biodiversity restoration purposes. Development proposal assessments often focus on nationally threatened species; however, the development proposal can be in an area that provides habitat to the only known regional population of a species or the type locality of a species. This knowledge gap contributes to the ongoing biodiversity loss in Aotearoa New Zealand.

[7] Regional council ecologists have worked with DOC to develop a standardised methodology for the development of regional threat classifications. This methodology uses national criteria where appropriate but takes the size of each region into account for some of the decision-making. Regional threat classifications for native flora and fauna will complement the existing NZTCS.

[8] Regional conservation statuses have so far been developed by the Greater Wellington Regional Council and Auckland Council, providing benefit to their regions. An example for statutory advice and guidance has been a consent proposal to mitigate the impacts of dredging in Wellington Harbour. This mitigation focused initially on nationally threatened species not present in the area, but recognition of regionally threatened species has resulted in future mitigation proposals providing a greater benefit to regional biodiversity (i.e., where the impact is occurring).

[9] The regional conservation statuses can also be used to help guide decisions on where local authorities spend funding on pest control and/or biodiversity management programmes. Information regarding the species present, as well as their threat status can aid decision-making processes regarding priority sites and guiding management actions to ensure appropriate activities are part of the site restoration programme. For example, if spotless crake are present in only one wetland in part of the region (even though the species may be less rare in other parts of the country), that knowledge can guide appropriate protection, conservation funding and actions.

DISCUSSION

REGIONAL CONSERVATION STATUS OF REPTILES IN OTAGO

[10] The first regional conservation status has recently been undertaken in the Otago region. This threat classification was to assess the regional conservation status of all reptile species that occur in Otago. Working with an expert panel, ecologists from the Otago Regional Council identified 34 reptile species present in the wild in Otago. These include 32 terrestrial (land) reptile species, comprising 13 gecko species, 18 skink species, and tuatara; there are also two marine reptile species, both sea turtles. The region was identified as a national stronghold (>20% of the national population) for 24 of the 32 (75%) resident species. Each of these species of reptiles are only found in Otago.

[11] Of the native reptile species that are resident in Otago (found in the region year-round), 31 of the 32 (97%) species meet the criteria to be regionally threatened or regionally at

risk. There is also a high percentage (94%) of reptile species in threatened or at-risk categories nationally.

[12] Compared to national assessments, the regional threat ranking was higher for five threatened reptile taxa: cascade geckos, Te Wāhipounamu skink, rockhopper skink, Takitimu gecko, and tuatara. For one species, the Burgan skink, the regional conservation assessment was lower than the national assessment due to the discovery of new populations of this taxon (single taxonomic classification) since the national assessment was published.

[13] Terrestrial reptile species are present in every territorial authority in the Otago region. The most species rich territorial authority is Central Otago with 24 species, followed by Queenstown Lakes District Council with 17 species, Waitaki District Council with 11 species (for the Otago part only), Dunedin City Council with 10 species, and Clutha District Council with 9 species. Terrestrial reptile species have been recorded in all of Otago Regional Council's Freshwater Management Units or rohe (area).

[14] Previous conservation and restoration actions have improved the threat status of reptiles in the Otago region. For example, at Orokonui Ecosanctuary, near Dunedin, where predatory introduced mammals have mostly been removed, the suitability of this mainland site has improved for reptiles to a point where a previously undetectable population of herbfield skinks has been discovered. The Otago region also has the Mokomoko Dryland Sanctuary near Alexandra, currently the country's only mainland fenced sanctuary dedicated to dryland habitats and lizards. In recent years, surveys for reptiles in Otago have resulted in the discovery of new species (e.g., the orange-spotted gecko in 1998 and rockhopper skink, alpine rock skink, and hura te gecko in 2018) and new populations (e.g., orange spotted gecko and cascade gecko).

CONSIDERATIONS

Strategic Framework and Policy Considerations

[15] The biodiversity programme contributes toward the *Healthy water, soil and coast, and Healthy and diverse ecosystems* strategic priorities. The work outlined in this paper contributes to the following elements of ORC's Strategic Direction:

a. Biodiversity Strategy 2018: Our Living Treasure | Tō tatou Koiora Taoka

b. Biodiversity Action Plan Te Mahi hei Tiaki i te Koiora 2019–2024

Financial Considerations

[16] Regional Threat Assessments are budgeted and are a planned activity.

Significance and Engagement

[17] NA

Legislative and Risk Considerations

[18] NA

Climate Change Considerations

[19] NA

Communications Considerations

[20] The reports will be published on ORC website, where it will be available to key stakeholders (e.g., DOC, iwi, consultants) and the public.

NEXT STEPS

[21] Regional threat assessments for other species (taxonomic) groups will continue as part of the biodiversity work programme.

ATTACHMENTS

1. Conservation Status of Reptile Species in Otago [**6.5.1** - 30 pages]

Conservation Status of Reptile Species in Otago

Scott Jarvie, Carey Knox, Jo Monks, James Reardon, Ciaran Campbell

April 2023

Otago Threat Classification Series 1

orc.govt.nz

Otago Regional Council

Regional conservation status of reptile species in Otago

April 2023 – Otago Threat Classification Series 1

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Otago Threat Classification Series is a scientific monograph series presenting publications related to regional threats assessments of groups of taxa in the Otago region. Most will be lists providing regional threat assessments of members of a plant or animal group (e.g., reptiles, birds, indigenous vascular plants), and leverages off national assessments for the New Zealand Threat Classification System within the regional context.

Recommended citation

Jarvie, S., C. Knox, J.M. Monks, J. Reardon, C. Campbell (2023). Regional conservation status of reptile species in Otago. Otago Regional Council, Otago Threat Classification Series, 2023/1

Cover image credits

Hura te ao gecko (*Mokopirirakau galaxias*), Threatened – Regionally Endangered. Photograph by Carey Knox.

Rockhopper skink (*Oligosoma* “rockhopper”), Threatened – Regionally Vulnerable. Photograph by Carey Knox

Acknowledgement

Thanks to Philippa Crisp from Greater Wellington Regional Council and Sabine Melzer from Auckland Council for advice on the regional conservation status process, Pascale Michel from the Department of Conservation | Te Papa Atawhai (DOC) for sharing documentation and for advice on the assessments, Rod Hitchmough and Geoff Patterson for advice on taxonomy, Trent Bell for providing coordinates for a type locality, Rod Hitchmough for advice on the New Zealand Threat Classification System, Alison Cree for discussion on tuatara, Lachie Scarsbrook and Nic Rawlence for discussions on a subfossil site, and Tim Ware for editorial advice. Jeremy Rolfe (DOC) led the development of this systematic approach to assessing the regional conservation status for indigenous species.

Executive Summary

This report provides the first regional conservation status of all known reptile taxa in the Otago region. Following standardised methodology, the regional threat status of all reptile taxa that occur in Otago was assessed. A total of 34 reptile taxa were identified as present in Otago, including 18 skinks, 13 geckos, two marine reptiles (both sea turtles), and tuatara. Fifteen taxa were assessed as Regionally Threatened (Regionally Critical: 3; Regionally Endangered: 4; Regionally Vulnerable: 8), sixteen as Regionally At Risk (Regionally Declining: 16), one as Regionally Not Threatened, and two as Regionally Non-resident Native (Regionally Vagrant). An additional terrestrial gecko taxon was identified as Regionally Extinct.

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Introduction

Threat classifications play an important role in monitoring biodiversity and informing conservation actions. The New Zealand Threat Classification System (NZTCS) is a tool used to assign a threat status to candidate taxa (species, subspecies, varieties, and forma) in Aotearoa New Zealand (Townsend et al. 2008). The classification system was developed to apply equally to terrestrial, freshwater, and marine biota (flora and fauna). The NZTCS scores taxa at the national scale against criteria based on an understanding of population state, size, and trend, while considering population status, impact of threats, recovery potential, and taxonomic certainty. The Department of Conservation | Te Papa Atawhai (DOC) administers the NZTCS in Aotearoa New Zealand, with national assessments used to inform conservation action, target resources, and monitor biodiversity trends and conservation effectiveness.

While DOC is tasked with managing indigenous taxa nationally, regional and district councils have statutory obligations to maintain indigenous biodiversity under the Resource Management Act 1991 (RMA), including to manage the habitats of threatened taxa. The regional threat status of taxa is particularly important in the context of the RMA and in conservation planning. A key requirement of managing the habitats of threatened taxa is to understand regional population sizes, and to monitor trends and conservation effectiveness. Regional threat assessments also provide a stronger foundation for assessing the threat status of taxa nationally.

This report is the first regional conservation status assessment for reptiles in the Otago region. Regional threat assessments have been completed following a standardised methodology by Greater Wellington Regional Council for four taxonomic groups (birds, Crisp 2020a; indigenous freshwater fish, Crisp et al. 2022; indigenous vascular plants, Crisp 2020b; lizards, Crisp 2020c) and Auckland Council for three taxonomic groups (amphibians, Melzer et al. 2022a; reptiles, Melzer et al. 2022b; vascular plants, Simpkins et al. 2023) as of March 2023. The methodology for the regional threat assessments leverages off national threat assessments as determined using the NZTCS (Townsend et al. 2008, Rolfe et al. 2021, Michel 2021), with thresholds for area of occupancy or species numbers adjusted for the land area in the region (Appendix 1). National strongholds and additional regional qualifiers were also considered (Appendix 2).

Methods

The regional threat status of reptiles was assessed by a panel of experts (Jo Monks, James Reardon, and Carey Knox) and Otago Regional Council (ORC) ecologists (Scott Jarvie and Ciaran Campbell) in May 2022. This assessment covers all terrestrial and marine reptiles in the region, following standardised methodology for regional threat assessments as shown in Appendix 1, the list of regional qualifiers in Appendix 2, and the list of national qualifiers in Appendix 3. The national threat assessments and national qualifiers were from Hitchmough et al. (2021). Following Hitchmough et al. (2021), taxa were classified as: 1) ‘taxonomically determinate’, i.e., legitimately and effectively published and generally accepted by relevant experts as distinct; and 2) ‘taxonomically unresolved’, i.e., used loosely to include both undescribed entities which still require formal taxonomic research to confirm their validity and provide them with a formal name and, occasionally, described species whose validity is in question.

Following the standardised methodology, reptile taxa not observed in the region were first removed from consideration based on those recognised in the NZTCS list and recent publications (Hitchmough et al. 2021; Jewell 2022a, b, c; Scarsbrook et al. 2023; see Appendix 4 for information on how these recent publications have changed the names used). The next step was to identify Nationally Threatened and At-Risk taxa that breed or are resident in the region. If more than 20% of the national population is breeding or resident for more than half their life cycle in the region, taxa were assigned National Stronghold status and the NZTCS criteria applied. The regional conservation status must not be a lower threat status than the national status, except if updated information is available. For example, a Nationally Endangered taxon cannot be assessed as Regionally Vulnerable or lower but could be assessed as Regionally Critical. Regional thresholds were set at more than 500 mature individuals present or occupancy of more than 250 ha. If taxa did not meet the threshold, they were assigned a regional threat status by applying the NZTCS criteria. If taxa did meet the threshold and the population trend was ±10% stable or increasing, they were assigned the status Regionally Not Threatened. For Nationally Not Threatened and Non-Resident taxa, the regional population threshold was applied. If the population was not stable to increasing/decreasing by more than 10%, the NZTCS criteria were used to determine the regional threat status. Population trend criteria were applied based on current knowledge, projecting from recent past into the future. Taxa that have become naturalised after deliberate or accidental introduction by humans are classified as Introduced and Naturalised. To be considered naturalised, taxa must have established a self-sustaining population in the wild over at least three generations and must have spread beyond the site of initial introduction.

To inform decisions on distributions and area of occupancy for the regional threat status of reptile taxa, occurrence records were used from the national DOC Herpetofauna database as well as additional records, including from Southern Scales and ORC staff. These occurrence records were taxonomically harmonised with the list of reptile taxa in the NZTCS and recent publications (Hitchmough et al. 2021; Jewell 2022a, b, c; Scarsbrook et al. 2023), then viewed in ArcGIS Pro v2.4.0 and the programming language R v. 4.2.0 (R Core Team 2022), in conjunction with other spatial layers for vegetation cover (Land Cover Database v. 5.0; Manaaki Whenua–Landcare Research 2020) and Land Information New Zealand topographic maps. Information is also provided on whether taxa have been recorded in a territorial authority in the region, or by Freshwater Management Unit (FMU), of which the Clutha Mata-au FMU is further subdivided into five rohe (areas). Taxa that are extinct, regionally extinct, or could occur in the Otago region have also been identified.

Results

A total of 34 reptile taxa were recorded as being present in the Otago region (Table 1; Figure 1). The 32 terrestrial reptile taxa comprise 13 geckos, 18 skinks, and tuatara; while the two marine reptiles are both sea turtles. Of the resident native reptiles, 31 of the 32 (97%) taxa are considered Regionally Threatened or Regionally At Risk. The region was identified as a National Stronghold (>20% national population) for 24 of the 32 (75%) resident taxa (Table 1). The eight regional endemics are Burgan skink (*Oligosoma burganae)*, grand skink (*O. grande*), Kawarau gecko (*Woodworthia* "Cromwell"), orange-spotted gecko (*Mokopirirakau* "Roys Peak"), Otago skink (*O. otagense*), Oteake skink (*O.* aff. *inconspicuum* "North Otago"), schist gecko (*W.* "Central Otago"), and Raggedy Range gecko (*W.* "Raggedy").

Of the 15 Regionally Threatened taxa recorded in the Otago region, three are Regionally Critical (Southland green skink, *O. chloronoton*; Takitimu gecko, *M. cryptozoicus;* tuatara, *Sphenodon punctatus*), four are Regionally Endangered (cascade gecko, *M.* "Cascades"; hura te ao gecko, *M. galaxias*; grand skink, Otago skink), and eight are Regionally Vulnerable (alpine rock skink, *O.* aff. *waimatense* "alpine rock"; Burgan skink; Lakes skink, *O.* aff. *chloronoton* "West Otago"; Oteake skink; Te Wāhipounamu skink, *O. pluvialis* "; Raggedy Range gecko, *W.* "Raggedy"; rockhopper skink, *O.* "rockhopper"; scree skink, *O. waimatense*; Table 1). For the Regionally Critical taxa, the Southland green skink is only known from ≤10 ha in Otago; Takitimu gecko are found in ≤2 subpopulations, both with an estimated ≤200 mature individuals; and for the previously regionally extinct taxon tuatara, there are ≤250 mature individuals in a reintroduced population at Orokonui Ecosanctuary, Te Korowai o Mihiwaka, near Dunedin. Of the Regionally Endangered taxa, Otago and grand skinks are regional endemics; hura te ao geckos have national strongholds in the region; and cascade geckos are known from ≤3 subpopulations, with an estimated ≤200 mature individuals in total. Note that the cascade gecko has only recently been discovered in Otago, with little currently known of their distribution and abundance. For Regionally Vulnerable taxa, seven of the eight have national strongholds in Otago (alpine rock skink; Burgan skink; Lakes skink; Oteake skink; Te Wāhipounamu skink; Raggedy Range gecko; rockhopper skink), with the exception being the scree skink that has a natural southern range limit in the region. Three of the Regionally Vulnerable taxa are regional endemics, namely the Burgan skink, Oteake skink and Raggedy Range gecko. Although the Burgan skink has a national threat listing of Nationally Endangered, recent surveys since the NZTCS assessment of reptile taxa have resulted in the discovery of new populations and, thus, they were considered Regionally Vulnerable.

The Otago region was recorded as having 16 Regionally At Risk taxa, all with the regional conservation status Regionally Declining (Table 1). Of these taxa, 13 were identified as having national strongholds in the region (jewelled gecko, *Naultinus gemmeus*; cryptic skink, *O. inconspicuum*; herbfield skink, *O. murihiku*; Kawarau gecko; kōrero gecko, *W.* "Otago/Southland large"; Nevis skink, *O. toka*; orange-spotted gecko; Otago green skink, *O.* aff. *chloronoton* "eastern Otago"; schist gecko; short-toed gecko, *Woodworthia* "southern mini"; south-western gecko, *W.* "south-western"; southern grass skink, *O.* aff. *polychroma* Clade 5; Tautuku gecko, *M.* "southern forest"). The three regional endemics are Kawarau gecko, orange-spotted gecko, and schist gecko. The three taxa identified as not having national strongholds do have range limits in Otago (Eyres skink, *O. repens*; Southern Alps gecko, *W.* "Southern Alps"; tussock skink, O. *chionochloescens*). The herbfield skink, Te Wāhipounamu skink and tussock skink were described after the NZTCS assessment for reptiles (Jewell 2022a, b, c).

For Regionally Not Threatened taxa in Otago, one taxon was recorded: McCann's skink (*O. maccanni*; Table 1). Two Non-Resident Natives were recorded, both Regionally Vagrant, namely the leatherback turtle (*Dermochelys coriacea*) and olive Ridley turtle (*Lepidochelys olivacea*; Table 1). No reptile taxa were identified as Introduced and Naturalised in the Otago region, nor nationally extinct reptiles. A taxon assessed as being previously found in what is considered present-day Otago with a reasonable degree of confidence is te mokomoko a Tohu (*Hoplodactylus tohu*; Table 1). An additional lizard taxon that may be found in the region is the Barrier skink (*O. judgei*), but there are currently no validated records of the species in Otago (Table 2).

Terrestrial reptile taxa are present in every territorial authority in the Otago region (Table 3). The most speciose territorial authority is Central Otago District Council with 24 taxa, followed by Queenstown Lakes District Council with 17 taxa, Waitaki District Council with 11 taxa (for the Otago part only), Dunedin City Council with 10 taxa, and Clutha District Council with 9 taxa. Terrestrial reptile taxa have been recorded in all of Otago Regional Council's Freshwater Management Units (FMU) or rohe. The most speciose FMU or rohe is the Manuherekia Rohe with 17 taxa, followed by Dunstan Rohe with 16 taxa, Upper Lakes Rohe with 16 taxa, Taieri FMU with 16 taxa, North Otago FMU with 8 taxa, Lower Clutha Rohe with 8 taxa, Dunedin & Coast FMU with 7 taxa, Roxburgh Rohe with 7 taxa, and Catlins FMU with 3 taxa (Table 4).

Table 1: Regional conservation status of Otago reptiles

Name and Authority	Common Name	National Conservation Status (2021)	Regional Conservation Status	Regional Criteria	National Stronghold	Regional Population	Regional Area	Regional Trend	Regional Confidence Population	Regional Confidence Trend	Regional Qualifiers	National Qualifiers
REGIONALLY EXTINCT (1)												
REGIONALLY EXTINCT (1)												
Taxonomically determinate (1)												
Hoplodactylus tohu Scarsbrook et al. 2023 *	te mokomoko a Tohu	Nationally Increasing	Regionally Extinct									CD, RR
REGIONALLY THREATENED (15)												
REGIONALLY CRITICAL (3)												
Taxonomically determinate (3)												
Oligosoma chloronoton (Hardy, 1977)	Southland green skink	Nationally Critical	Regionally Critical	C	No		≤10 ha	>70% decline	Medium	Medium	NR	CD, PD
Mokopirirakau cryptozoicus Jewell & Leschen 2004	Takitimu gecko	Nationally Vulnerable	Regionally Critical	A(2)	No	SUBPOP ≤2, MATIND ≤200		10-30% decline	Low	Low	NR	CI, DP, DPS, DPT, Sp
Sphenodon punctatus (Gray, 1842) †	tuatara	Relict	Regionally Critical	A(1)	No	MATIND <250		±10% stable	High	High	RN, DE	CI, CD, RR
REGIONALLY ENDANGERED (4)												
Taxonomically determinate (3)												
Mokopirirakau galaxias Knox et al., 2021	hura te ao gecko	Nationally Endangered	Regionally Endangered	A(2)	Yes	SUBPOP 3-5, MATIND ≤200		10–30% decline	Medium	Low	NS, NR, TL	CI, DP, DPS, DPT
Oligosoma grande (Gray, 1845)	grand skink	Nationally Endangered	Regionally Endangered	B(1)	Yes	MATIND=250-1000		±10% stable	High	High	RE, NS, TL	CD, CI, PD, RR
Oligosoma otagense (McCann, 1955)	Otago skink	Nationally Endangered	Regionally Endangered	B(1)	Yes	MATIND=250-1000		±10% stable	High	High	RE, NS, TL	CD, RR
Taxonomically unresolved (1)												
Mokopirirakau "Cascades"	cascade gecko	Declining	Regionally Endangered	A(2)	No	SUBPOP ≤3, MATIND ≤200		10–30% decline	Low	Low	CI, DPT	
REGIONALLY VULNERABLE (8)												
Taxonomically determinate (2)												
Oligosoma burganae Chapple et al., 2011	Burgan skink	Nationally Endangered	Regionally Vulnerable §	D(3)	Yes		≤1000 ha	30–50% decline	Medium	Low	RE, NS, TL	CI, DP, DPT, RR, Sp
Oligosoma waimatense (McCann, 1955)	scree skink	Nationally Vulnerable	Regionally Vulnerable	C(3)	No		≤100 ha	30–50% decline	Medium	Low	NR, NS	CI, Sp
Taxonomically unresolved (6)												
Oligosoma aff. *chloronoton* “West Otago”	Lakes skink	Nationally Vulnerable	Regionally Vulnerable	D(3)	Yes		≤1000 ha	30–50% decline	Medium	Low	NS, NR	CI, DP, DPS, DPT, Sp

Regional conservation status of reptile species in Otago

Oligosoma aff. *inconspicuum* “North Otago”	Oteake skink	Nationally Vulnerable	Regionally Vulnerable	C(3)	Yes		≤100 ha	10–30% decline	Medium	Low	RE, NS	CI, DP, DPT, OL
Oligosoma pluvialis Jewell, 2022a ‡	Te Wāhipounamu skink	Declining	Regionally Vulnerable	C(2)	Yes	SUBPOP 3–5, MATIND ≤ 500		10–30% decline	Medium	Low	NS, NR	CI, DP, DPS, DPT, RR
Oligosoma aff. *waimatense* “alpine rock”	alpine rock skink	Nationally Vulnerable	Regionally Vulnerable	C(3)	Yes		≤100 ha	30–50% decline	Medium	Low	NS, NR	CI, DP, DPT, RR
Oligosoma “rockhopper”	rockhopper skink	Declining	Regionally Vulnerable	C(1)	Yes		≤100 ha	10–30% decline	Medium	Low	NS, NR	CI, DP, DPS, DPT, RR
Woodworthia “Raggedy”	Raggedy Range gecko	Nationally Vulnerable	Regionally Vulnerable	C(3)	Yes		≤100 ha	10–30% decline	Medium	Low	RE, NS	CI, DP, DPT, RR
REGIONALLY AT RISK (16)												
REGIONALLY DECLINING (16)												
Taxonomically determinate (4)												
Naultinus gemmeus McCann, 1955	jewelled gecko	Declining	Regionally Declining	B(2)	Yes		≤10000 ha	10–30% decline	Medium	Medium	NS	CI, PD
Oligosoma inconspicuum (Patterson & Daugherty, 1990)	cryptic skink	Declining	Regionally Declining	C(1)	Yes	MATIND> 100000		10–30% decline	High	Medium	NS, NR, TL	CI
Oligosoma repens Chapple et al., 2011	Eyres skink	Declining	Regionally Declining	A(2)	No		≤1000 ha	10–30% decline	Medium	Low	NR, TL	DP, DPR, DPT, RR, Sp
Oligosoma toka Chapple et al., 2011	Nevis skink	Declining	Regionally Declining	C(1)	Yes	MATIND> 100000		10–30% decline	Medium	Low	NS, NR	CI, DP, DPT, RR, TL
Taxonomically unresolved (12)												
Mokopirirakau “Roys Peak” ¶	orange-spotted gecko	Declining	Regionally Declining	A(2)	Yes		≤1000 ha	10–30% decline	Medium	Low	RE §, NS	CI, DP, DPT, RR, Sp
Mokopirirakau “southern forest”	Tautuku gecko	Declining	Regionally Declining	B(2)	Yes		≤10000 ha	10–30% decline	Medium	Low	NS, NR	CI, DP, DPT
Oligosoma aff. *chloronoton* “eastern Otago”	Otago green skink	Declining	Regionally Declining	B(2)	Yes		≤10000 ha	30–50% decline	Medium	Low	NS, NR	CD, DI, DP, DPS, DPT
Oligosoma murihiku Jewell, 2022b **	herbfield skink	Declining	Regionally Declining	A(2)	Yes		≤1000 ha	10–30% decline	High	Medium	NS, NR	CD, DP, DPT, RR
Oligosoma chionochloescens Jewell, 2022c	tussock skink	††	Regionally Declining	B(2)	No		≤10000 ha	10–30% decline	High	Medium	NR	
Oligosoma aff. *polychroma* Clade 5	southern grass skink	Declining	Regionally Declining	C(1)	Yes	MATIND> 100000		10–30% decline	High	Medium	NS, NR	
Woodworthia “Central Otago”	schist gecko	Declining	Regionally Declining	C(2)	Yes		>10000 ha	10–30% decline	Medium	Low	RE, NS	CI, PD

Regional conservation status of reptile species in Otago

Woodworthia "Cromwell"	Kawarau gecko	Declining	Regionally Declining	C(2)	Yes		>10000 ha	10–30% decline	Medium	Low	RE, NS	CI, DP, DPT
Woodworthia "Otago/Southland large"	kōrero gecko	Declining	Regionally Declining	C(1)	Yes	MATIND> 100000		10–30% decline	High	Medium	NS	PD
Woodworthia "Southern Alps"	Southern Alps gecko	Declining	Regionally Declining	C(1)	No	MATIND> 100000		10–30% decline	Medium	Low	NR	
Woodworthia "southern mini"	short-toed gecko	Declining	Regionally Declining	B(2)	Yes		≤10000 ha	10–30% decline	Medium	Low	NS, NR	CI, DP, DPT
Woodworthia "south-western"	south-western large gecko	Declining	Regionally Declining	C(2)	Yes		≥10000 ha	10–30% decline	Medium	Low	NS, NR	CI, DP, DPT, PD
REGIONALLY NOT THREATENED (1)												
Taxonomically determinate (1)												
Oligosoma maccanni (Patterson & Daugherty, 1990)	McCann's skink	Not Threatened	Regionally Not Threatened		Yes	MATIND> 100000		±10% stable	High	Medium	NS, TL	
REGIONALLY NON-RESIDENT NATIVE (2)												
REGIONALLY VAGRANT (2)												
Taxonomically determinate (2)												
Dermochelys coriacea (Vandelli, 1761)	leatherback turtle	Migrant	Regionally Vagrant								TO	
Lepidochelys olivacea (Eschscholtz, 1829)	olive Ridley turtle	Vagrant	Regionally Vagrant §§								DPS, DPT, TO	

* te mokomoko a Tohu (*Hoplodactylus tohu*) has been described since the current national status for reptiles (Hitchmough et al. 2021; Scarsbrook et al. 2023), with same threat status as *Hoplodactylus duvaucelii* "southern" as in the NZTCS (Hitchmough et al. 2021). Note that no known subfossils have been found in Otago, but subfossils have been found south of the Waitaki River, <5 km from the regional boundary. This means the taxon was past the major biogeographical barrier of the Waitaki River (Chapple and Hitchmough 2016) and assessed as being previously found in what is considered present-day Otago with a reasonable degree of confidence. † tuatara (*Sphenodon punctatus*) were regionally extinct in Otago but were reintroduced to Orokonui Ecosanctuary, Te Korowai o Mihiwaka, near Dunedin, in 2012. Since the reintroduction over 10 years ago, high survival rates of founder animals and evidence of reproduction has been recorded (Jarvie et al. 2016, 2016, 2021, accepted; Alison Cree, pers. comm. January, 2023). Thus, the population is tracking towards re-establishment, with tuatara being considered to be in the extant category of Regionally Critical because of the number of mature individuals in Otago <250 individuals despite being in fenced ecosanctuary mostly free of introduced mammalian predators except for the house mouse (*Mus musculus*). Tuatara were assessed with the qualifier Designated (DE). § For Burgan skink (*O. burganae*), the regional conservation status is lower than its current national conservation status due to the discovery of new populations after NZTCS assessment for reptiles (Hitchmough et al. 2021), thus extending the known range (Wildlands 2022); ‡ Te Wāhipounamu skink *(O. pluvialis)* has been described since the current national conservation status for reptiles (Hitchmough et al. 2021; Jewell 2022a), with national qualifiers and trends likely the same as for the pallid (*O.* aff. *inconspicuum* "pallid") in the NZTCS of which it was split (Hitchmough et al. 2021); ¶ orange-spotted gecko (*M.* "Roys Peak") have not been confirmed genetically outside the Otago region but are suspected based on morphology; ** herbfield skink *O. murihiku*) has been described since the current national status for reptiles (Hitchmough et al. 2021; Jewell 2022b), with same status as the herbfield skink (*O.* aff. *inconspicuum* "herbfield") as in the NZTCS (Hitchmough et al. 2021); †† tussock skink (*O. chionochloescens*) was described after the NZTCS assessment for reptiles (Hitchmough et al. 2021; Jewell 2022c); §§ olive Ridley turtle (*L. olivacea*) was confirmed in the Otago region from specimens found at Kaka Point.

Regional conservation status of reptile species in Otago

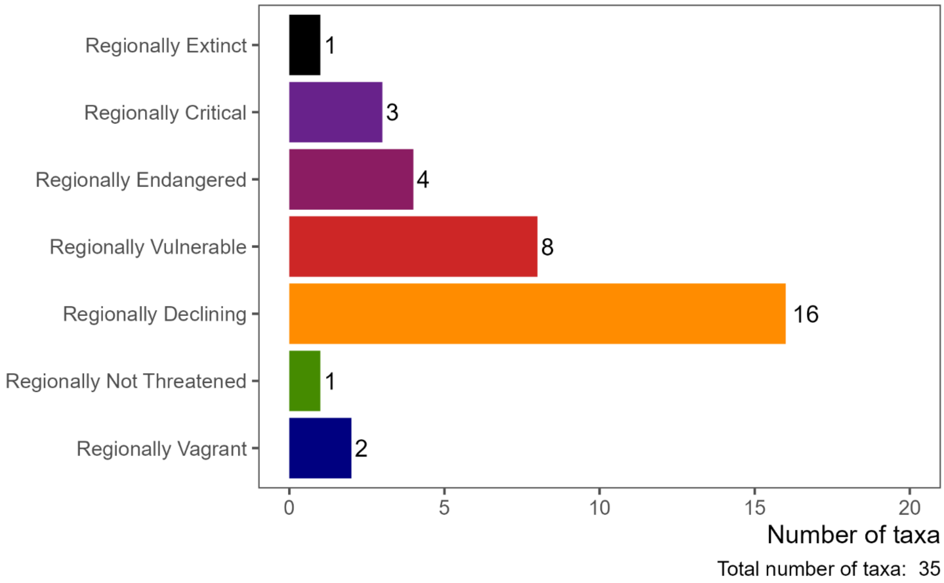

Figure 1: Regional conservation status of reptiles in the Otago region

Table 2: Reptile taxa that could occur in the Otago region

Name and Authority	Common Name	Status	Justification
PUTATIVELY IN REGION (1)			
Taxonomically determinate (1)			
Oligosoma judgei Patterson & Bell, 2009	Barrier skink	Speculative	No confirmed sighting but reports of large skinks have been recorded from high elevation screes in the Otago part of the Eyre Mountains that may belong to this species

Table 3: Presence of terrestrial reptile taxa by territorial authority in the Otago region. ● indicates a taxon has been observed from occurrence records in a territorial authority since 2000; ○ indicates a taxon was observed from occurrence records in a territorial authority before 2000.

Name and Authority	Common Name	Central Otago District Council	Clutha District Council	Dunedin City Council	Queenstown Lakes District Council	Waitaki District Council (Otago part only)
Mokopirirakau "Cascades"	cascade gecko				●	
Mokopirirakau cryptozoicus Jewell & Leschen 2004	Takitimu gecko				●	
Mokopirakau galaxias Knox et al., 2021	hura te ao gecko	●				●
Mokopirirakau "Roys Peak"	orange-spotted gecko	●			●	●
Mokopirirakau "southern forest"	Tautuku gecko		●			
Naultinus gemmeus McCann, 1955	jewelled gecko	●	●	●	●	●
Oligosoma aff. *chloronoton* "eastern Otago"	Otago green skink	●		●	○	●
Oligosoma aff. *chloronoton* "West Otago"	Lakes skink	●			●	●
Oligosoma murihiku Jewell, 2022b	herbfield skink			●		●
Oligosoma aff. *inconspicuum* "North Otago"	Oteake skink	●				
Oligosoma pluvialis Jewell, 2022a	Te Wāhipounamu skink	●			●	
Oligosoma aff. *polychroma* Clade 5	southern grass skink	●			○	
Oligosoma aff. *waimatense* "alpine rock"	alpine rock skink	●				
Oligosoma burganae Chapple et al., 2011	Burgan skink	●		●		
Oligosoma chionochloescens Jewell, 2022c	tussock skink	●	○	●	●	●
Oligosoma chloronoton (Hardy, 1977)	Southland green skink		○			
Oligosoma grande (Gray, 1845)	grand skink	●	○	●	○	○
Oligosoma inconspicuum (Patterson & Daugherty, 1990)	cryptic skink	●	○		●	
Oligosoma maccanni (Patterson & Daugherty, 1990)	McCann's skink	●	○	●	●	●
Oligosoma otagense (McCann, 1955)	Otago skink	●		●	○	●
Oligosoma repens Chapple et al., 2011	Eyres skink				●	
Oligosoma "rockhopper"	rockhopper skink	●				
Oligosoma toka Chapple et al., 2011	Nevis skink	●			●	
Oligosoma waimatense (McCann, 1955)	scree skink	●				
Sphenodon punctatus (Gray, 1842)	tuatara			●		
Woodworthia "Central Otago"	schist gecko	●	●			

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Woodworthia "Cromwell"	Kawarau gecko	●			●	
Woodworthia "Otago/Southland large"	kōrero gecko	●	○	●		●
Woodworthia "south-western"	south-western large gecko	●			●	
Woodworthia "Southern Alps"	Southern Alps gecko	●			●	
Woodworthia "southern mini"	short-toed gecko	○			●	
Woodworthia "Raggedy"	Raggedy Range gecko	●				

Table 4: Presence of terrestrial reptile taxa in freshwater management units (FMU) in the Otago region. The Clutha Mata-au FMU has been further subdivided into five rohe (areas). ● indicates a taxon has been observed from occurrence records in a FMU or Rohe since 2000; ○ indicates a taxon was observed from occurrence records in a FMU or rohe before 2000.

Name and Authority	Common name	Taieri FMU	North Otago FMU	Dunedin & Coast FMU	Catlins FMU	Clutha Mata-au FMU				
						Manuherekia Rohe	Roxburgh Rohe	Upper Lakes Rohe	Dunstan Rohe	Lower Clutha Rohe
Mokopirirakau "Cascades"	cascade gecko							●		
Mokopirirakau cryptozoicus Jewell & Leschen 2004	Takitimu gecko							●		
Mokopirakau galaxias Knox et al., 2021	hura te ao gecko	●				●				
Mokopirirakau "Roys Peak"	orange-spotted gecko					●		●	●	
Mokopirirakau "southern forest"	Tautuku gecko				●					
Naultinus gemmeus McCann, 1955	jewelled gecko	●	●	●	○		○	●		
Oligosoma aff. *chloronoton* "eastern Otago"	Otago green skink	●	○	●		●			○	○
Oligosoma aff. *chloronoton* "West Otago"	Lakes skink					●		○	●	
Oligosoma murihiku Jewell, 2022b	herbfield skink	●	○	●						
Oligosoma aff. *inconspicuum* "North Otago"	Oteake skink	●								
Oligosoma pluvialis Jewell, 2022a	Te Wāhipounamu skink								●	
Oligosoma aff. *polychroma* Clade 5	southern grass skink					○		○	●	
Oligosoma aff. *waimatense* "alpine rock"	alpine rock skink					●				
Oligosoma burganae Chapple et al., 2011	Burgan skink	●					●			
Oligosoma chionochloescens Jewell, 2022c	tussock skink	●	●	●		●	●	●	●	○
Oligosoma chloronoton (Hardy, 1977)	Southland green skink									○
Oligosoma inconspicuum (Patterson & Daugherty, 1990)	cryptic skink							●	●	○
Oligosoma grande (Gray, 1845)	grand skink	●	○			○		○	●	○
Oligosoma maccanni (Patterson & Daugherty, 1990)	McCann's skink	●	●	●		●	●	●	●	○
Oligosoma otagense (McCann, 1955)	Otago skink	●	●			●	○	○	●	
Oligosoma repens Chapple et al., 2011	Eyres skink							●		
Oligosoma "rockhopper"	rockhopper skink	●				●				
Oligosoma toka Chapple et al., 2011	Nevis skink					●			●	

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Oligosoma waimatense (McCann, 1955)	scree skink	●				●				
Sphenodon punctatus (Gray, 1842)	tuatara			●						
Woodworthia "Central Otago"	schist gecko	●				●	●			○
Woodworthia "Cromwell"	Kawarau gecko							○	●	
Woodworthia "Otago/Southland large"	kōrero gecko	●	●	●	○	●	●		●	○
Woodworthia "south-western"	south-western large gecko							●	●	
Woodworthia "Southern Alps"	Southern Alps gecko	●				●		●	●	
Woodworthia "southern mini"	short-toed gecko							●	●	
Woodworthia "Raggedy"	Raggedy Range gecko	●				●				

Discussion

Regional threat assessments have been completed by regional councils in Aotearoa New Zealand, with the resulting regional threat lists being used as a tool to help maintain indigenous biodiversity. For example, regional threat lists have been used to advise resource consent applications, inform conservation actions and target resources, as well as monitor biodiversity trends and conservation effectiveness. This report is the first such regional threat assessment for any taxonomic group in the Otago region. A total of 34 reptile taxa are recorded as present in the Otago region, including 32 terrestrial reptiles and two marine reptiles. Of these reptile taxa, 24 have national strongholds in Otago, with eight of those taxa being regional endemics. An additional terrestrial gecko taxon was identified as Regionally Extinct.

For national assessments of Threatened and At Risk resident reptiles, there is a similarly extremely high number of taxa in these threat categories in Otago as nationally (97% cf. 93%). The regional threat ranking was higher than national assessments for five threatened reptile taxa: cascade gecko, Te Wāhipounamu skink, rockhopper skink, Takitimu gecko, and tuatara. For cascade gecko (Regionally Endangered cf. Declining), Te Wāhipounamu skink (Regionally Vulnerable cf. Declining), rockhopper skink (Regionally Vulnerable cf. Declining), and Takitimu gecko (Nationally Vulnerable cf. Regionally Critical), this was because only a fraction of their national distribution occurs in Otago, with the rate of decline in the region estimated to be the same as nationally. The cascade gecko was also only recently discovered in Otago region, with little currently known about their distribution and abundance, so this listing is precautionary. In comparison, tuatara were regionally extinct but in 2012 were reintroduced to Orokonui Ecosanctuary, with subsequent reinforcements in 2016 and 2017 (Regionally Critical cf. Relict; Cree 2014; Jarvie et al. 2014, 2021, accepted). Since the reintroduction of tuatara to Orokonui Ecosanctuary over 10 years ago, provisional results from monitoring are encouraging for this population with high survival rates and evidence of reproduction (Jarvie et al. 2015, 2016, 2021, accepted; Alison Cree pers. comm. January, 2023). While the population is not yet self-replacing with at least half the breeding adults being products of natural replenishment due to the slow life-history characteristics of tuatara and reintroduction only in 2012, the population is tracking towards re-establishment with the fenced ecosanctuary mostly free of introduced mammalian predators except for the house mouse (Jarvie et al. accepted). The assessment of Regionally Critical for tuatara is similar to the regional threat listing by Greater Wellington Regional Council for tuatara, who have reintroduced populations of tuatara in their region at Zealandia | Te Māra a Tāne, formerly Karori Wildlife Sanctuary, and Matiu/Somes Island. For the Burgan skink, the regional conservation assessment was lower than the national assessment due to the discovery of new populations of this taxon since the conservation status of reptiles was assessed in 2021 (Regionally Vulnerable cf. Nationally Endangered; Hitchmough et al. 2021; Wildlands 2022).

Conservation actions have improved the threat status of reptiles in the Otago region. For example, grand and Otago skinks have recovered sufficiently following intensive predator control at Macraes (Reardon et al. 2012) to downgrade their national threat assessments from Nationally Critical to Nationally Endangered status in the conservation status of reptiles

(Hitchmough et al. 2013). Conservation and restoration efforts to eradicate introduced mammals, and in fencing to prevent mammals from reinvading (Burns et al. 2012), have also increased the suitability of mainland sites for reptiles (Hitchmough et al. 2016; Nelson et al. 2014). For example, at Orokonui Ecosanctuary several years after introduced mammals were eradicated, except for the house mouse (*Mus musculus*) which are mostly maintained at low levels, allowed for a previously undetectable population of herbfield skinks to be discovered. This discovery of herbfield skinks provides further evidence lizard recovery can occur at mainland sites where mammalian pests are excluded or intensively controlled at a landscape scale (Reardon et al. 2012; Hitchmough et al. 2016; Nelson et al. 2014). The Otago region also has the Mokomoko Drylands Sanctuary near Alexandra, Central Otago, currently the country's only mainland fenced sanctuary dedicated to dryland habitats and lizards (https://www.mokomokosanctuary.com/). However, taxon-specific responses to mammalian predator suppression or eradication are also common (Reardon et al. 2012; Hitchmough et al. 2016; Nelson et al. 2014; Norbury et al. 2022), including for some taxa vulnerable not only to larger introduced mammalian predators but also the house mouse (Norbury et al. 2022).

For reptiles in the Otago region, conservation translocations – the intentional movement and release of organisms to restore populations – have been used to establish populations (IUCN/SCC 2013). Types of conservation translocations already used have included reintroduction, the re-establishment of focal taxa within its indigenous range, including for taxa which have gone locally extinct in parts of the region, such as the jewelled gecko (e.g., Knox et al. 2014, 2017), the grand skink (e.g., Whitmore et al. 2011), the Otago green skink, and the Otago skink (e.g., Hare et al. 2012), as well as for a taxon which went extinct in the region: tuatara (Table 1; Jarvie et al. 2014, accepted). Future conservation translocations of candidate taxa discussed in restoration plans for mainland sanctuaries include the grand skink, te mokomoko a Tohu, and Tautuku gecko to Orokonui Ecosanctuary (Otago Natural History Trust 2019) and Otago green skink to Mokomoko Sanctuary, near Alexandra. In future, another type of conservation translocation in managed relocations, the movement of the focal taxa outside its indigenous range to avoid extinctions, could be used (Seddon et al. 2014). This could include for population of reptiles threatened under human-induced climate change by sea-level rise in low-lying coastal areas, such as the herbfield skink at Victory Beach, or under future climates where reptile taxa are not be able to move to a climatically suitable area (Jarvie et al. 2021, 2022). Furthermore, marine reptiles like the olive Ridley turtle identified as present in the region from dead specimen records from the DOC Herpetofauna database, might survive in Otago under climate change.

In recent years, surveys for reptiles in Otago have resulted in the discovery of new taxa (e.g., the rockhopper skink, alpine rock skink, and hura te ao gecko in 2018; Wildland Consultants 2019; Knox et al. 2021; orange-spotted gecko in 1998; Tocher & Marshall 2001; Nielsen et al. 2011) and new populations (e.g., for orange-spotted geckos across 3000 km^2; Knox et al. 2019; cascade gecko; CK pers. obs. 2022). For some subalpine and alpine populations of reptile taxa found in Otago, isolated individuals have been recorded at much lower altitude, suggesting populations were more widespread (Hitchmough et al. 2016). Further development of surveying and monitoring techniques is needed for reptiles as approaches to detect some taxa can be specialised (Hitchmough et al. 2016; Lettink & Monks, 2016). For example, emerging approaches such as drones have been trialled as a tool to survey and monitor lizards, including in Otago (Monks et al. 2022). Ongoing research has also indicated new listing of taxa in Otago between NZTCS assessments from 2015 and 2021, i.e., alpine rock skink, rockhopper skink, and Raggedy Range gecko. The recently described te mokomoko a Tohu was a new split from *H. duvaucelii* (Hitchmough et al. 2016, 2021; Scarsbrook et al. 2023), with this taxon having a subfossil record <5 km from the regional boundary of Otago and south of the major biogeographical boundary of the Waitaki River (Hitchmough & Chapple 2016), thus a large-bodied gecko species was assessed as previously found in or near present-day Otago. The tussock skink, Te Wāhipounamu skink, and herbfield skink were all described after the NZTCS assessment for reptiles (Jewell 2022a, b, c). Although there is dispute on the validity of these taxa, they have been included in this regional threat classification for reptiles as a precautionary measure.

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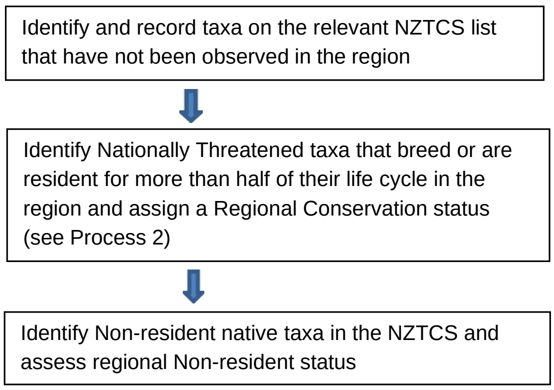
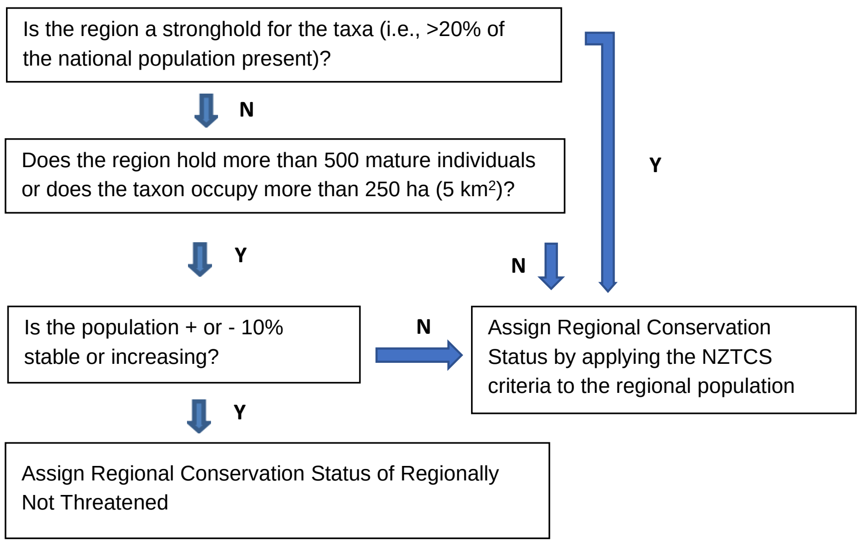
Appendix 1: Process for determining the regional threat status of taxa

Process 1: Determination of regional threat status



Process 2: Determination of strongholds and Regionally Not Threatened species



Appendix 2: List of Regional Qualifiers for Regional Conservation Threat Assessments

Code	Qualifier	Description
FR	Former Resident	Breeding population (existed for more than 50 years) extirpated from region but continues to arrive as a regional vagrant or migrant. FR and RN are mutually exclusive.
HR	Historical Range	The inferred range (extending in any direction) of the taxon in pre-human times meets its natural limit in the region.
IN	Introduced Native	Introduced to the region, though not known to have previously occurred in it.
NS	National Stronghold	More than 20% of the national population breeding or resident for more than half their life cycle in the region.
NR	Natural Range	The known range (extending in any direction) of the taxon meets it natural limit in the region.
RE	Regional Endemic	Known to breed only in the region.
RN	Restored Native	Reintroduced to the region after having previously gone extinct there.
TL	Type Locality	The type locality of the taxon is within the region. Ignore if the taxon is or has ever been regionally extinct

Appendix 3: List of National Qualifiers from the New Zealand Threat Classification System (Townsend et al. 2008; Michel 2021; Rolfe et al. 2021)

Code	Qualifier	Qualifier Type	Description
DPR	Data Poor: Recognition	Assessment Process Qualifier	Confidence in the assessment is low because of difficulties determining the identity of taxon in the field and/or in the laboratory. Taxa that are DPR will often be DPS and DPT. In such cases, the taxon is most likely to be Data Deficient.
DPS	Data Poor: Size	Assessment Process Qualifier	Confidence in the assessment is low because of a lack of data on population size.
DPT	Data Poor: Trend	Assessment Process Qualifier	Confidence in the assessment is low because of a lack of data on population trend.
DE	Designated	Assessment Process Qualifier	A taxon that the Expert Panel has assigned to what they consider to be the most appropriate status without full application of the criteria. For example, a commercial fish that is being fished down to Biomass Maximum Sustainable yield (BMSy) may meet criteria for 'Declining', however, it could be designated as 'Not Threatened' if the Expert Panel believes that this better describes the taxon's risk of extinction.
IE	Island Endemic	Biological Attribute Qualifier	A taxon whose naturally distribution is restricted to one island archipelago (e.g., Auckland Islands) and is not part of the North or South Islands or Steward Island/Rakiura. This qualifier is equivalent to the 'Natural' Population State value in the database.
NS	Natural State	Biological Attribute Qualifier	A taxon that has a stable or increasing population that is presumed to be in a natural condition, i.e., has not experienced historical human-induced decline.
RR	Range Restricted	Biological Attribute Qualifier	A taxon naturally confined to specific substrates, habitats or geographic areas of less than 100 km2 (100,000 ha), this is assessed by taking into account the area of occupied habitat of all sub-populations (and summing the areas of habitat if there is more than one sub-population), e.g., Chatham Island forget-me-not (*Myosotidium hortensia*) and Auckland Island snipe (*Coenocorypha aucklandica aucklandica*). This qualifier can apply to any 'Threatened' or 'At Risk' taxon. It is redundant if a taxon is confined to 'One Location' (OL)
Sp	Sparse	Biological Attribute Qualifier	The taxon naturally occurs within typically small and widely scattered subpopulations. This qualifier can apply to any 'Threatened' or 'At Risk' taxon.
NO	Naturalized Overseas	Population State Qualifier	A New Zealand endemic taxon that has been introduced by human agency to another country (deliberately or accidentally) and has naturalised there, e.g., *Olearia traversiourum* in the Republic of Ireland.
OL	One Location	Population State Qualifier	Found at one location in New Zealand (geographically or ecologically distinct area) of less than 100,000 ha (1000 km2), in which a single event (e.g., a predator irruption) could easily affect all individuals of the taxon, e.g., L'Esperance Rock groundsel (*Senecio esperensis*) and Open Bay leech (*Hirudobdella antipodum*). 'OL' can apply to all 'Threatened', 'At Risk', 'Non-resident Native' – Coloniser and Non-resident Native – Migrant taxa, regardless of whether their restricted distribution in New Zealand is natural or human-induced. Resident native taxa with restricted distributions but where it is unlikely that all sub-populations would be threatened by a single event (e.g., because water channels within an archipelago are larger than known terrestrial predator swimming distances) should be qualified as 'Range Restricted' (RR).
SO	Secure Overseas	Population State Qualifier	The taxon is secure in the parts of its natural range outside New Zealand
SO?	Secure Overseas?	Population State Qualifier	It is uncertain whether a taxon of the same that is secure in the parts of its natural range outside New Zealand is conspecific with the New Zealand taxon.
S?O	Secure? Overseas	Population State Qualifier	It is uncertain whether the taxon is secure in the parts of its natural range outside New Zealand.
TO	Threatened Overseas	Population State Qualifier	The taxon is threatened in the parts of its natural range outside New Zealand.
T?O	Threatened Overseas?	Population State Qualifier	It is uncertain whether a taxon of the same name that is threatened in the parts of its natural range outside New Zealand is conspecific with the New Zealand taxon.
T?O	Threatened? Overseas	Population State Qualifier	It is uncertain whether the taxon is threatened in the parts of its natural range outside New Zealand.
CI	Climate Impact	Pressure Management Qualifier	The taxon is adversely affected by long-term climate trends and/or extreme climatic events. The following questions provide a guide to using the CI Qualifier: Is the taxon adversely affected by long-term changes in the climate, such as an increase in average temperature or sea-level rise? If NO = no Qualifier but needs monitoring and periodic re-evaluation because projected changes to the average climate and sea-level rise may adversely impact the taxon (including via changes to the distribution and prevalence of pests, weeds and predators) in the future. If YES = CI Qualifier Is the taxon adversely affected by extreme climate events, such as a drought, storm or heatwave?

Regional conservation status of reptile species in Otago

			If No = no Qualifier but needs monitoring and periodic re-evaluation because projected changes to the climate are likely to increase the frequency and/or severity of these events in the future. If YES = CI Qualifier Use of the Climate Impact Qualifier would indicate the need for more in-depth research, ongoing monitoring of climate impacts, and potentially a climate change adaptation plan for the taxon
CD	Conservation Dependent	Pressure Management Qualifier	The taxon is likely to move to a worse conservation status if current management ceases. The term 'management' can include indirect actions that benefit taxa, such as island biosecurity. Management can make a taxon CD only if cessation of the management would result in a worse conservation status. The influence of the benefits of management on the total population must be considered before using CD. The benefit of managing a single subpopulation may not be adequate to trigger CD, but may trigger Partial Decline (PD). Taxa qualified CD may also be PD because of the benefits of management.
CR	Conservation Research Needed	Pressure Management Qualifier	Causes of decline and/or solutions for recovery are poorly understood and research is required.
EW	Extinct In The Wild	Pressure Management Qualifier	The taxon is known only in captivity or cultivation or has been reintroduced to the wild but is not self-sustaining. Assessment of a reintroduced population should be considered only when it is self-sustaining. A population is deemed to be self-sustaining when the following two criteria have been fulfilled: it is expanding or has reached a stable state through natural replenishment and at least half the breeding adults are products of the natural replenishment, and it has been at least 10 years since reintroduction
EF	Extreme Fluctuations	Pressure Management Qualifier	The taxon experiences extreme unnatural population fluctuations, or natural fluctuations overlaying human-induced declines, that increase the threat of extinction. When ranking taxa with extreme fluctuations, the lowest estimate of mature individuals should be used for determining population size, as a precautionary measure.
INC	Increasing	Pressure Management Qualifier	There is an ongoing or forecast increase of > 10% in the total population, taken over the next 10 years or three generations, whichever is longer. This qualifier is redundant for taxa ranked as 'Recovering'.
PD	Partial Decline	Pressure Management Qualifier	The taxon is declining over most of its range, but with one or more secure populations (such as on offshore islands). Partial decline taxa (e.g., North Island kākā *Nestor meridionalis septentrionalis* and Pacific gecko *Dactylocnemis pacificus*) are declining towards a small stable population, for which the Relict qualifier may be appropriate.
PF	Population Fragmentation	Pressure Management Qualifier	Gene flow between subpopulations is hampered as a direct or indirect result of human activity. Naturally disjunct populations are not considered to be 'fragmented'.
PE	Possibly/Presumed Extinct	Pressure Management Qualifier	A taxon that has not been observed for more than 50 years but for which there is little or no evidence to support declaring it extinct. This qualifier might apply to several Data Deficient and Nationally Critical taxa.
RF	Recruitment Failure	Pressure Management Qualifier	The age structure of the current population is such that a catastrophic decline is likely in the future. Failure to produce new progeny or failure of progeny to reach maturity can be masked by apparently healthy populations of mature specimens. Population trend qualifiers.
Rel	Relict	Pressure Management Qualifier	The taxon has declined since human arrival to less than 10% of its former range but its population has stabilised. The range of a relictual taxon takes into account the area currently occupied as a ratio of its former extent. Reintroduced and self-sustaining populations within or outside the former known range of a taxon should be considered when determining whether a taxon is relictual. This definition is modified from the definition of the At Risk – Relict category in the NZTCS manual (Townsend et al. 2008). The main difference is that trend is not included in the qualifier definition. This enables the qualifier to be applied to any taxon that has experienced severe range contraction, regardless of whether that contraction continues or has been arrested. This qualifier complements the 'Naturally Uncommon (NU)' qualifier which can be applied to taxa whose abundance has declined but which continue to occupy a substantial part of their natural range.

Appendix 4: Changes affecting reptile taxa found in the Otago region between the publication of Hitchmough et al. (2021) and this report

Name and authority in Hitchmough et al. 2021	Name and authority in this report	Notes	Change in distribution of taxa as relates to Otago
Hoplodactylus duvaucelii "southern" Dumeril & Bibron, 1836	*Hoplodactylus tohu* Scarsbrook et al. 2023		
Oligosoma aff. *polychroma* Clade 5	*Oligosoma chionochloescens* Jewell 2022c	New split from *O.* aff. *polychroma* Clade 5	Contact zone between *O. chionochloescens* and *O.* aff. *polychroma* Clade 5 as proposed by Jewell 2022c is across much of the width of the eastern South Island. See Jewell 2022c for more details.
Oligosoma aff. *inconspicuum* "herbfield"	*Oligosoma murihiku* Jewell 2022b		
Oligosoma. aff. *inconspicuum* "pallid"	*Oligosoma pluvialis* Jewell 2022a	Otago populations previously tag-named *O.* aff. *inconspicuum* "pallid" form part of this more broadly-distributed species, which also includes Fiordland and Westland populations.	

6.6. Marine Significant Ecological Areas Spatial Mapping Project

Prepared for:	Environmental Science and Policy Committee
Report No.	SPS2309
Activity:	Governance Report
Author:	Sam Thomas, Coastal Scientist
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	26 April 2023

PURPOSE

[1] To provide the Committee with information on the mapping project completed by NIWA to map the marine significant ecological areas within Otago's coastal marine area and surrounding adjoining coastal space.

[2] The mapping will be used to inform the review of the Regional Plan: Coast for Otago, and to assist in developing the coastal monitoring programme. The mapping identifies the marine ecological significant areas and key habitats/ecosystems in Otago.

EXECUTIVE SUMMARY

[3] Otago Regional Council (ORC) is responsible for the management of the coastal marine area (CMA) under the Resource Management Act 1991 (RMA) and the New Zealand Coastal Policy Statement (2010) (NZCPS). Regional councils must provide for the preservation of natural character (which includes an ecological element) (section 6a RMA) and protection of indigenous vegetation and fauna (section 6c RMA) along with policy 11 (indigenous biodiversity) of the NZCPS. These policies are implemented through the Regional Plan: Coast for Otago (the Coast Plan). The Coast Plan is overdue to be reviewed, with a review planned to commence in 2024/25.

[4] ORC contracted NIWA to identify marine significant ecological areas (SEAs) within the Otago coastal marine area (CMA) as part of our developing coastal work programme and to implement our statutory functions under the RMA. This programme of work had four core objectives:

- To collate, systematically review and format spatial datasets housed by ORC, NIWA and third parties; and
- To identify SEAs under prescribed management classes that describe similar ecological features and face the same threats to anthropogenic stressors; and
- To classify the coastal marine area using an agreed habitat classification; and
- To undertake a gap analysis for each management class to determine the priorities for future surveys and monitoring programmes.

[5] The project's objectives and currently available data were presented to a stakeholder workshop in December 2021 and the availability of third-party datasets was explored. A

total of 106 datasets comprising 643 spatial layers were collated, reviewed, and deemed to hold usable information across 16 different management classes.

[6] Significant ecological areas (SEAs) were identified using Policy 11 of the NZCPS and Key Ecological Criteria (refer to report for details), with SEAs spilt into management classes, i.e. reef fish, seabirds marine mammals land. The decision support making tool zonation was used to identify the top 30% priority significant ecological areas for management.

[7] Several gaps concerning particular ecological features and geographic areas were identified. Significant gaps exist for intertidal benthic invertebrates, reef fish, marine mammals, and seafloor geomorphic features. Locations on the Catlins coast and North Otago, along with offshore areas, are also generally poorly represented by the available data.

RECOMMENDATION

That the Committee:

1) ***Receives*** *this report.*

2) ***Notes*** *that the marine significant ecological area spatial mapping has been completed.*

3) ***Notes*** *that next steps include a management framework for marine significant ecological areas, and a more detailed monitoring programme for the coastal area.*

BACKGROUND

[8] Otago's coastline is home to a wide range of diverse and unique ecosystems. These ecosystems are biodiversity hotspots with deep sea canyons, bryozoan reefs, Rhodolith beds, gravel/boulder fields and kelp forests providing habitat for Pāua, crayfish, blue cod, sperm whales, albatross, yellow eyed penguins, and sea lions. This diversity of habitats and the nutrient rich currents such as the Southland and Sub Antarctic currents create the conditions that make Otago's marine life richly biodiverse with many iconic species. These unique ecosystems/habitats also provide many ecosystem services and functions including commercial and recreational fishing, having cultural significance, nutrient and oxygen cycling, primary productivity, and carbon storage.

[9] ORC have management responsibilities over the coastal marine area (CMA), which extends from mean high water spring tide mark at the shore out to 12 nautical miles. Within this context, regional councils have obligations under Section 6 of the RMA to manage this area. Of relevance to this report, regional councils must provide for the protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna (Section 6(c) RMA). Regional councils also need to give effect to policies 11a and 11b in the NZCPS – to protect indigenous biological diversity (biodiversity) in the coastal environment. This responsibility is often enacted through the designation of significant ecological areas (SEAs) in the marine realm – where adverse impacts to significant biodiversity features are prevented and/or mitigated.

[10] The identification and designation of SEAs is based on data on coastal biodiversity and habitats and aligning these datasets with criteria that seek to group and manage areas of significant indigenous vegetation and significant habitats of indigenous fauna in the coastal environment. Ecological criteria have been designated nationally by the Department of Conservation (Freeman et al. 2017), and datasets assessed with respect to

their alignment with these criteria have been compiled at regional scales for other regional authorities[1]. The NZCPS also provides its own ecological significance criteria which can further guide regional councils on the assessment of areas for ecological significance.

[11] Datasets for coastal biodiversity and habitats include those held by ORC, as well as a range of other organisations including NIWA, universities and other research institutions were used in this project.

[12] This project included two stakeholder workshops and a desktop data collation and assessment exercise. Drawing upon existing data and additional data supplied following the first workshop, one objective was to compile datasets to inform the identification of significant ecological sites and habitats within the CMA of the Otago region, out to the 12 nautical mile (nm) limit. The project did not include field work to validate ecological information that was supplied. Potential significance was assigned to sites and habitats on the basis of meeting one or more of nine KEA criteria and/or NZCPS criteria, and prioritisation was based on the Zonation decision support tool for classes with sufficient spatial data (see below).

DISCUSSION

[13] This project has pooled a substantial amount of information on the distribution of marine biodiversity within the Otago region. The volume of information reflects the region's richness in biodiversity and is a valuable resource for marine spatial planning. The current identification of SEAs provides the most up to date account of important areas for the various classes of biodiversity – using the best available information. However, it should be noted that substantial gaps exist in our understanding of the distribution of marine biodiversity in Otago, which means certain areas and/or management classes are not well represented. Understanding these gaps is challenged by a lack of information on where surveys/observations have occurred but did not record effort or the distribution of sampling (i.e., absence data). In this way, the majority of information collated in this report can be considered as presence data only - i.e., it contains no information on locations where surveys have occurred but found no observations of ecological features that may inform SEAs. Thus, areas with a consistent absence of SEAs may reflect a paucity of information rather than a true absence of important ecological features.

[14] Based on an extensive literature review of the threats posed from anthropogenic stressors to the ecological features under each management class (McCartain et al. 2021), guidance has been provided on the management of adverse impacts to indigenous biodiversity for each management class. Equally the severity for each stressor has been indicated in relation to each management class for example how severe of a threat is bottom trawling to cockles in an estuary (low).

[15] The report also highlighted numerous data gaps for each management class that was spatially mapped. Part of the reason for undertaking this report was to highlight the knowledge gaps for where future ground truthing or survey work can occur. The report also provides information on where to focus information gathering for example: "*Data gaps on the distribution of intertidal benthic invertebrates were significant in all areas*

[1] Environment Southland, McCartain et al. 2021; Auckland Council, Brough et al. 2021a; Hawke's Bay Regional Council; Lundquist et al. 2020

beyond the immediate surrounds of Dunedin and the Otago Peninsula. In general, there was better information for estuarine intertidal communities than for rocky reef, however such estuarine data was limited to the distribution of cockles."

[16] While this study used the best available information to identify SEAs across the 16 management, some SEAs were inevitably based on information that requires ground-truthing. Such cases occur when the best available information is either 1) older than recommended, or 2) based on modelled or highly interpolated evidence impacts.

[17] The candidate SEAs identified in this project will require ongoing monitoring to determine they continue to meet the relevant ecological significance criteria and to ensure any mitigation of adverse impacts is effective. The additional data acquired during monitoring programmes may also help to refine the identification of SEAs that is likely to be reviewed under future iterations of the Otago coastal plan. Monitoring the highly diverse suite of SEAs that span the full extent of the Otago CMA will be a challenging undertaking and will require input and partnerships from various research providers, mana whenua and government agencies. Staff will continue to develop and refine the monitoring approach to ensure we can take advantage of monitoring techniques that utilise state-of-the-art and emerging technology be used to monitor SEAs in an efficient and cost-effective manner.

[18] This project has brought together a substantial amount of information on marine biodiversity within the Otago region and has made important contributions to the identification of SEAs in this area with very high biodiversity values. With ongoing validation and monitoring, the work presented here will provide significant opportunities for both ORC and other stakeholders to implement meaningful management of adverse impacts to biodiversity in this unique region.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[19] This work will contribute toward the *Healthy water, soil and coast*, and *Healthy and diverse ecosystems* Strategic Directions.

[20] The marine significant ecological areas mapping will provide spatial information to help inform the review of ORC's Regional Plan: Coast. The Policy Team proposes to start the review in 2024/25 and notify the plan in 2025/26.

[21] The marine significant ecological areas mapping will steer the ground truthing and information gathering programme over the next two years (2023 to 2024) through the knowledge gaps highlighted in the report. The spatial mapping information and the ground truthing and information gathering will help form the SOE coastal monitoring programme that will be created to enable ORC to meet its statutory obligations and enable ORC to monitor the effectiveness of its Regional Plan: Coast upon notification in 2025/26.

Financial Considerations

[22] This work is budgeted and planned in the current Long-Term Plan, including budget for ground truthing. It will also be put up for consideration in the next LTP cycle.

Significance and Engagement Considerations

[23] This work does not trigger *He Mahi Rau Rika: Significance and Engagement Policy.*

[24] Engagement will be ongoing between stakeholders and iwi that operate in the coastal space and on a project-by-project basis to undertake ground truthing and subsequent monitoring

[25] Collaboration between key agencies with the aim to develop an MOU/partnerships arrangement between these agencies such as Fisheries NZ, DOC and the Marine Science Department at the University whom ORC may rely on for data.

Legislative and Risk Considerations

[26] The review of the Regional Plan: Coast for Otago will be an important step in ensuring compliance with statutory requirements. The development of the coastal monitoring programme is an important first step towards meetings these requirements.

Climate Change Considerations

[27] Understanding what significant habitats are present in Otago's coastal marine area allows for any appropriate management actions to be enacted to build resilience against climate change.

Communications Considerations

[28] There are no directly relevant communications consideration.

NEXT STEPS

[29] To undertake ground truthing of data poor spatially mapped significant ecological areas that have been highlighted in the NIWA report. An update on ground truthing and coastal programme development will be presented to council in 2024.

[30] Recommendations for cost-effective ground-truthing and monitoring programmes are made that will enable updating of the results presented in this study. Such programmes will allow for a detailed understanding of the distribution of biodiversity within the Otago CMA to guide future management by a range of stakeholders.

ATTACHMENTS

1. NIWA Client report Otago Signficant Ecological Areas FINAL [**6.6.1** - 142 pages]

Identification of significant ecological areas for the Otago coastal marine area

Prepared for Otago Regional Council

June 2022

Climate, Freshwater & Ocean Science

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Contents

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Executive summary

The Otago Regional Council (ORC) contracted NIWA to identify marine significant ecological areas (SEAs) within the Otago coastal marine area (CMA) in order to uphold its role as a territorial authority under the Resource Management Act. This programme of work had four core objectivises

- The collation, systematic review and formatting of spatial datasets housed by ORC, NIWA and third parties
- The identification of SEAs under prescribed management classes that describe similar ecological features and face the same threats to anthropogenic stressors
- Classification of the coastal marine area using an agreed habitat classification
- A gap analyses for each management class to determine the priorities for future surveys and monitoring programmes

The project's objectives and available data were presented to a stakeholder workshop in December 2021 and the availability of third-party datasets was explored. A total of 106 datasets comprising 643 spatial layers were collated, reviewed and deemed to hold usable information across sixteen different management classes. The datasets were formatted in R, using best practise procedures, to ensure consistent spatial domains, extents and data formats. All datasets used for SEA identification using decision support tools were converted to gridded 250 m x 250 m raster datasets.

Two methods of SEA identification were employed dependant on the quantity and extent of information available for each management class. For classes with a significant volume of overlapping data on the distribution of ecological features, the decision support tool Zonation was used to systematically identify SEAs with the top 30% of priority areas being used to guide the establishment of SEA boundaries. For classes with no overlapping datasets and/or when features occurred in confined and discrete locations, a manual SEA designation process was used based on the distribution of established ecological features. The number of SEAs per management class varied between 1 and 42 and were distributed throughout the CMA. Areas around Otago Peninsula and Dunedin had a high number of SEAs which reflects both the importance of this area and the uneven distribution in available spatial data. While the best available information was used for SEA identification, there are instances where SEAs require ground-truthing and/or extent definition when the best available information had some associated uncertainty. Such instances have been flagged in a geodatabase of SEAs that will be made available to ORC along with this report.

A number of gaps concerning particular ecological features and geographic areas were identified. Significant gaps exist for intertidal benthic invertebrates, reef fish, marine mammals, and seafloor geomorphic features. Locations on the Catlins coast and North Otago, along with offshore areas, are also generally poorly represented by the available data. Recommendations for cost-effective ground-truthing and monitoring programmes are made that will enable updating of the results presented in this study. Such programmes will allow for a detailed understanding of the distribution of biodiversity within the Otago CMA to guide future management by a range of stakeholders.

1 Introduction

1.1 Background and policy framework

As a territorial authority, Otago Regional Council (ORC) have management responsibilities over the coastal marine area (CMA), which extends from mean high water spring tide mark at the shore out to 12 nm (Figure 1-1). Within this context, regional councils have obligations under Section 6 of the Resource Management Act 1991 (RMA). Of particular relevance to this report, regional councils must provide for the protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna (Section 6(c)). Regional councils also need to give effect to policies of the New Zealand Coastal Policy Statement 2010 (NZCPS), in particular, Policy 11a and 11b – to protect indigenous biological diversity (biodiversity) in the coastal environment. This responsibility is often enacted through the designation of significant ecological areas (SEAs) in the marine realm – where adverse impacts to significant biodiversity features are prevented and/or mitigated.

The identification and designation of SEAs requires acquisition and appraisal of the underpinning data on coastal biodiversity and habitats, and aligning these datasets with criteria to designate areas of significant indigenous vegetation and significant habitats of indigenous fauna in the coastal environment. Ecological criteria have been designated nationally by the Department of Conservation (Freeman et al. 2017), and datasets assessed with respect to their alignment with these criteria have been compiled at regional scales for other regional authorities (e.g., Environment Southland, McCartain et al. 2021; Auckland Council, Brough et al. 2021a; Hawke's Bay Regional Council; Lundquist et al. 2020). The NZCPS also provides its own ecological significance criteria (Figure 2-2), which can further guide regional councils on the assessment of areas for ecological significance. A stocktake involving the collection and assessment of data on marine fauna and flora within the Otago region will aid in the designation of SEAs, and identify gaps that can be targeted by new sampling and monitoring programmes.

Datasets for coastal biodiversity and habitats include those datasets developed or collated by Otago Regional Council, and by a diversity of other organisations including NIWA, universities and other research institutions. Nationally, the Marine Science Advisory Group (MSAG), a central government advisory group that includes representatives from the Department of Conservation (DOC), the Ministry for Primary Industries (MPI) and the Ministry for the Environment (MfE), is also addressing significant gaps in data on marine ecosystems and biodiversity. The MSAG recently funded the compilation of datasets that address nine key ecological area (KEA) criteria, based on criteria identified for ecologically and biologically significant areas (EBSAs) under the Convention on Biological Diversity (Clark et al. 2014; Freeman et al. 2017). National KEA layers can be assessed for their role in supplementing gaps in knowledge of marine ecosystems and biodiversity in the Otago region, and include datasets addressing nine key ecological area criteria (Stephenson et al. 2018; Lundquist et al. 2020a). Additionally, the KEA and associated projects led to the development of over 600 predictive layers based on species distribution models (SDMs) representing predicted habitat suitability of cetaceans, demersal fish, rocky reef fish, benthic invertebrates, and macroalgae (Lundquist et al. 2020a) and a new seafloor community classification for Aotearoa New Zealand (Stephenson et al. 2022)

1.2 Scope and aims

This project included two stakeholder workshops and a desktop data collation and assessment exercise. Drawing upon existing data and additional data supplied following the first workshop, one objective was to compile datasets to inform the identification of significant ecological sites and habitats within the CMA of the Otago region, out to the 12 nautical mile (nm) limit. The project did not include field work to validate ecological information that was supplied. Potential significance was assigned to sites and habitats on the basis of meeting one or more of nine KEA criteria and/or NZCPS criteria, and prioritisation was based on the Zonation decision support tool for classes with sufficient spatial data (see below).

The specific aims of the project included:

1. Introduce the project and the process of identifying SEAs and decision support tools at an Otago regional stakeholder workshop, and seek third party datasets that can fill gaps in the identification of SEAs.
2. Summarise and evaluate the quality of the various data sets that could be used in the assessment of SEAs, drawing on ORC, NIWA and external databases, including data that are made available to NIWA following the first workshop. Reformat as required, and allocate datasets to management classes that represent similarly in responses to threats in the CMA.
3. Utilise the Zonation decision support tool to identify SEAs for the Otago CMA for each management class.
4. Identify significant gaps in data availability that are barriers to accurate spatial planning within the Otago CMA.
5. Present at a final Otago regional stakeholder workshop to showcase and acquire stakeholder input on the final results of the project.
6. Submit report and associated geospatial datasets to support SEA identification.

Figure 1-1: The Otago CMA. The Otago coastal marine areas with notation of the locations featuring in this report.

2 Methods

This project used a streamlined process (Figure 2-1) to deliver the identification of SEAs with input from a broad stakeholder group consisting of staff from ORC and other government agencies (Ministry for Primary Industries, Department of Conservation), Ngāi Tahu papatipu runaka, scientists from the University of Otago, and local ecological experts. The project was initiated with a stakeholder workshop in December 2021 where the background, aims and proposed methods of the project were introduced to stakeholders, and a range of potential datasets for informing SEAs were identified and discussed (see Appendix A).

Following the initial workshop, a list of identified datasets was collated from within NIWA, ORC and from third-parties, and datasets were critically reviewed and weighted according to reliability (see next section). Datasets were assessed according to two ecological significance criteria; the Key Ecological Areas significance criteria and criteria specified by policy 11 under the National Coastal Policy Statement (Figure 2-2; Table 2-1). Each dataset that met significance criteria was then attributed to defined management classes (see Section 2.2). All datasets that held relevant information on the identification of SEAs were then formatted and reprojected as needed to consistent projection and grid. SEAs were identified for each management class using either 1) systematic identification of SEAs using spatial decision support tools, or 2) manual SEA identification for management classes informed by discrete, limited, or non-overlapping datasets. Threats to the biodiversity values within each SEA were reviewed, ranked and tabulated. A final stakeholder workshop was held in May 2022 (Appendix A) which showcased the datasets that informed the identification of SEAs, and illustrated the SEAs for each management class. Significant gaps in knowledge of the distribution of significant ecological features were discussed in order to guide future data collection.

Figure 2-1: Streamlined process. The process and methods used to identify SEAs in this project.

Policy 11 of the NZ Coastal Policy Statement (2010) – Ecological significance criteria

To **protect** indigenous biological diversity in the coastal environment:

(a) **avoid adverse effects of activities** on:

i. indigenous taxa that are listed as threatened or at risk in the New Zealand Threat Classification System lists;
ii. taxa that are listed by the International Union for Conservation of Nature and Natural Resources as threatened;
iii. indigenous ecosystems and vegetation types that are threatened in the coastal environment, or are naturally rare;
iv. habitats of indigenous species where the species are at the limit of their natural range, or are naturally rare;
v. areas containing nationally significant examples of indigenous community types; and
vi. areas set aside for full or partial protection of indigenous biological diversity under other legislation.

(b) **avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities** on:

i. areas of predominantly indigenous vegetation in the coastal environment;
ii. habitats in the coastal environment that are important during the vulnerable life stages of indigenous species;
iii. indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification, including estuaries, lagoons, coastal wetlands, dunelands, intertidal zones, rocky reef systems, eelgrass and saltmarsh;
iv. habitats of indigenous species in the coastal environment that are important for recreational, commercial, traditional or cultural purposes;
v. habitats, including areas and routes, important to migratory species; and
vi. ecological corridors, and areas important for linking or maintaining biological values identified under this policy.

Figure 2-2: NZCPS significance criteria. The National Policy Statement ecological criteria used to assess 'significance' of ecological features in this project.

Table 2-1: KEA criteria. The Key Ecological Areas ecological significance criteria used to assess 'significance' of ecological features in this project.

	Criterion	Definition	Rationale	New Zealand Examples
1	Vulnerability, fragility, sensitivity, or slow recovery.	Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.	In the absence of protection, associated biodiversity may not be able to persist.	Biogenic habitats, including bryozoan beds, sponge communities and coldwater corals. Low fecundity and, or high longevity (fish) species such as bramble sharks, hapuku, king tarakihi, orange roughy.

	Criterion	Definition	Rationale	New Zealand Examples
2	Uniqueness/rarity/endemism.	Area contains either (i) unique ("the only one of its kind", rare (occurs only in a few locations) or endemic species, populations or communities; and/or (ii) unique, rare or distinct, habitats or ecosystems; and/or (iii) unique or unusual geomorphological or oceanography features.	These areas contain biodiversity that is irreplaceable; non-representation in protected areas may result in loss or reduction in biodiversity or features. These areas contribute towards larger-scale biodiversity.	Hydrothermal vents; seeps; areas containing co-occurring geographically restricted species; biogenic habitats.
3	Special importance for life history stages.	Areas that are required for a population to survive and thrive.	Species' particular requirements make some areas more suitable for carrying out life history stages.	Fish spawning or nursery grounds; pinniped breeding colonies; migratory corridors; sites where animals aggregate for feeding.
4	Importance for threatened / declining species and habitats.	Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species.	Protection may enable recovery or persistence of these threatened / declining species or habitats.	Estuaries with populations of threatened shorebirds; foraging areas for marine mammals and seabirds.
5	Biological productivity.	Area containing species, populations or communities with comparatively higher natural biological productivity.	These areas can support enhanced growth and reproduction, and support wider ecosystems.	Hydrothermal vents; frontal zones; areas of upwelling.
6	Biological diversity.	Area contains comparatively higher diversity of ecosystems, habitats, communities or species, or has higher genetic diversity.	These areas are important for evolutionary processes, for species' and ecosystem resilience and contribute towards large-scale biodiversity.	Structurally complex communities such as deep-water sponge and coral communities; seamounts. Areas with high diversity of fish and invertebrate species.

	Criterion	Definition	Rationale	New Zealand Examples
7	Naturalness.	Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.	Provides enhanced ability to protect biodiversity that is in better condition; reduces need to rely on recovery from degraded state (recovery may occur on a different trajectory); these areas may include species and/or habitats that do not occur or are not represented well in more degraded areas; important role as reference sites.	Remote areas; marine areas adjacent to protected terrestrial areas; areas not impacted by bottom trawling or invasive species.
8	Ecological function.	Area containing species or habitats that have comparatively higher contributions to supporting how ecosystems function.	Some species, habitats or physical processes play particularly important roles in supporting how ecosystems function – their protection provides coincidental protection for a range of other species and wider ecosystem health.	Soft sediment habitats containing high densities of bioturbators; areas of high functional trait diversity; areas with functionally important mesopelagic communities (including myctophids).

	Criterion	Definition	Rationale	New Zealand Examples
9	Ecosystem services.	Area containing diversity of ecosystem services; and/or areas of particular importance for ecosystem services.	Provides for ability to protect species and habitats that provide particularly important services to humans. Provides ability to better contribute to CBD Aichi Target 11.	Areas containing dense populations of filter-feeding invertebrates; areas important for seafood provisioning. Areas important for supporting or regulating ecosystem services (e.g., areas of nutrient regeneration, biogenic habitat provision, carbon sequestration, sediment retention, gas balance, bioremediation of contaminants, storm protection) that underpin the delivery of provisioning or cultural ecosystem services.

2.1 Dataset review

Following methods developed under projects recently undertaken by NIWA for other regional authorities (e.g., Environment Southland, McCartain et al. 2021; Auckland Council, Brough et al. 2021); Hawke's Bay Regional Council, Lundquist, C et al. 2020b), we applied a rigorous approach to review and format spatial datasets that contain some information on areas of ecological significance. All datasets contained information on 'ecological features', i.e., discrete occurrences of species/habitats/ecosystem processes that represent components of Otago's marine ecosystem. Datasets were pooled from a variety of sources: marine ecological datasets possessed by ORC; NIWA-housed datasets; datasets from the Key Ecological Areas research programme administered by NIWA under contracts to the Department of Conservation; and datasets held by third party research/management organisations. Third party datasets were identified at the first workshop held with broad range of stakeholders with interests and knowledge in the Otago CMA, and these datasets were collated and reviewed as part of this project.

All available datasets were reviewed according to four factors: 1) the temporal extent (i.e., age); 2) the spatial extent of the data; 3) methods used to collect the data; and 4) the traceability of the dataset. For 1), we were guided by temporal cut-offs for 'best-available-information' established by experts in marine habitats during a thorough review of marine spatial datasets in the Auckland region (Brough et al. 2021b). Datasets beyond these cut-offs were down-weighted in terms of their contribution towards SEA identification in recognition that older information is preferable to no information. For 2), datasets that contain information for a substantial proportion of the Otago CMA were preferred to those that inform a small number of discrete locations. Only datasets that have information sampled using appropriate methodologies were considered for inclusion within this project and datasets were required to be traceable to particular and reputable field surveys, expert opinion or otherwise reliable sources (e.g., data from commercial fishing operations). Datasets were excluded from further analyses if they contained very old information, represented only a very small area within the CMA, were collected using inappropriate methods, or if their provenance was unclear (i.e., methods or data collector were not traceable).

In order for dataset reliability to be included within the identification of SEAs, a weighting procedure was established based on McCartain et al. (2021) (Table 2-2). Reliability was determined based on a combination of the aforementioned factors and the type of information represented (Table 2-2). For example, datasets that pooled empirical observations on the distribution of ecological features from robust field programs receives the highest weighting, while products derived from those observations (i.e., model predictions or interpolated surfaces) would receive a slightly lower weighting (Table 2-2). Such data quality scores were used as weights when using spatial decision support tools to identify SEAs (see section2 4.1) and were used to inform whether SEAs require ground-truthing or extent definition for both SEA identification methods.

Table 2-2: Data quality score. The data quality scores used to weight a dataset's contribution to the identification of SEAs based on its reliability.

Data quality score	Description	Examples
5	Empirical evidence from observations/surveys	Presence locations (point records), habitat extent with thorough ground-truthing (polygons), multi-beam bathymetry (raster dataset)
4	Modelled or interpolated evidence confirmed by local data validation or expert opinion	Habitat extent based on interpolation (polygons), modelled biogenic habitat provisions layer (raster)
3	Modelled or highly interpolated datasets from national scale models, limited or no local data validation	National scale species distribution model with limited local validation (raster).
2	Anecdotal evidence with no empirical evidence	Finfish spawning habitat (polygon), habitat extent derived from industry opinion
1	No available evidence	National scale biogenic habitat records with no observations in the Auckland Region.

2.2 Management classes

The available spatial datasets were aggregated into defined ‘management classes’; groupings of ecological features that share similar taxonomic and/or biophysical characteristics and are subject to the same threats (Table 2-3). SEAs were identified under each management class, allowing ORC to target the prevention of adverse effects on biodiversity to the same ‘types’ of habitat/species assemblage, that share the same threats. Previous SEA mapping with territorial authorities has found this approach to be more amenable to RMA policy interventions than designating SEAs that are important for all classes of indigenous biodiversity (McCartain et al. 2021).

In this project, we utilised the list of management classes established for SEA identification in the neighbouring Southland region (McCartain et al. 2021). This initial list was refined with input from stakeholders during the project's first workshop with the 'Fish' management class being split in two; 'Fish – demersal/pelagic' and 'Fish – reef associated'. All other relevant management classes were based on management classes identified in the Southland analysis.

Table 2-3: Management classes. List of the sixteen management classes used to pool ecological features and under which to identify SEAs. The relevant section of the national coastal policy statement criteria represented by each class is provided.

Management Class	Definition/examples	Section of NZCPS Policy 11	SEA method
Benthic invertebrates-intertidal	Important locations for intertidal benthic invertebrates (e.g., cockle beds)	Section (a) and (b)	Zonation
Benthic invertebrates-subtidal	Important locations for sub-tidal benthic invertebrates – not necessarily biogenic habitat formers (e.g., hotspots for taxa with key ecosystem functions).	Section (b)	Zonation
Biogenic habitats - invertebrates (Bivalves, bryozoans, sponges, corals, tube building worms)	Important locations for biogenic habitats formed by benthic invertebrates (e.g., oyster reef, bryozoan thicket).	Section (a) and (b)	Zonation
Coastal vegetation	Important locations for coastal vegetation (e.g., salt marsh, pīngao)	Section (a) and (b)	Zonation
Estuaries/coastal lagoons/wetlands	Important estuaries, coastal lagoons and wetlands (e.g., Awarua wetland).	Section (b)	Manual
Fish (demersal, pelagic)	Important locations for fish including demersal, pelagic (e.g., important spawning habitat)	Section (b)	Zonation
Fish (reef associated)	Important locations for fish including demersal, pelagic (e.g., locations with high abundance of butterfish)	Section (b)	Zonation
Kelp forest	Important locations for 3-dimensional biogenic habitat formed by kelp stands (e.g., *Macrocystis pyrifera*)	Section (b)	Zonation
Marine flora	Important locations for aquatic plants including seagrass and all algae taxa (except biogenic kelp forest).	Section (a) and (b)	Zonation
Marine Mammals terrestrial (breeding/haul out)	Locations important for marine mammals on land (e.g., fur seal/sea lion breeding colonies)	Section (a) and (b)	Manual
Marine Mammals ocean	Locations important for marine mammals at sea (e.g., foraging locations)	Section (a) and (b)	Zonation

Management Class	Definition/examples	Section of NZCPS Policy 11	SEA method
Naturally uncommon ecosystems	Occurrence of naturally rare coastal, terrestrial, habitats (e.g., seabird burrowed soils, rock stacks).	Section (a) and (b)	Manual
Pelagic productivity	Potentially important locations for high primary productivity from phytoplankton activity (e.g., areas of high ChlA concentration, Southland Current convergence zone)		Manual
Sea/shorebirds - marine (foraging locations)	Locations important for shore/seabirds at sea that represent foraging areas (e.g., sightings hotspots)	Section (a) and (b)	Zonation
Sea/shorebirds - terrestrial (roosting and nesting locations)	Locations important for shore/seabirds on land that represent roosting/nesting areas (e.g., penguin colonies)	Section (a) and (b)	Zonation
Seafloor geomorphological features	Locations with notable geomorphic features on the seafloor (e.g., submarine canyons, extensive reef platforms)	Section (b)	Manual

2.3 Dataset formatting

Spatial datasets are typically represented by a broad range of formats – from non-digitised datasheets (e.g., excel files), to feature class geographic information system (GIS) datasets (e.g., point, polygons, lines) and gridded cell-based data (e.g., raster datasets). To systematically identify SEAs, it is necessary to format datasets so that spatial information is represented in the same way for each management class. The use of spatial decision support tools for SEA identification requires all input data on biodiversity to be represented as gridded raster datasets (Moilanen et al. 2009). Thus, features class data were converted to rasters using the following methods:

Point datasets

Point data are used to represent the spatial occurrence of species, habitats or ecological processes but typically possess no information on a feature's extent (i.e., home range, habitat extent). Point datasets were rasterised in two ways: 1) Datasets were rasterised such that each grid cell within a defined buffer around a point were coded as present (1), with remaining cells coded as absent (0). Buffer size varied between 250-1000 m depending on the taxa/habitat and was informed by expert opinion on the likely extent of a species/habitat occurrence. This approach was used for datasets where each point represents a unique spatial occurrence that bears no spatial relationship with other points in the datasets (Figure 2-3). Datasets that pooled observations of the same or similar species/habitats, collected using similar sampling methods during systematic surveys, were rasterised using kernel density estimation (KDe) (Worton 1989). KDe generates a raster dataset that represents the density of the underlying point data based on a fixed interpolation function which is defined by the smoothing/bandwidth parameter (a fixed distance). Here, we used Silverman's rule of thumb (Silverman 2018) to generate bandwidth parameters for each point dataset (Figure 2-3).

For both methods, point datasets were rasterised at 250 m x 250 m cell resolution, for the full extent of the Otago CMA.

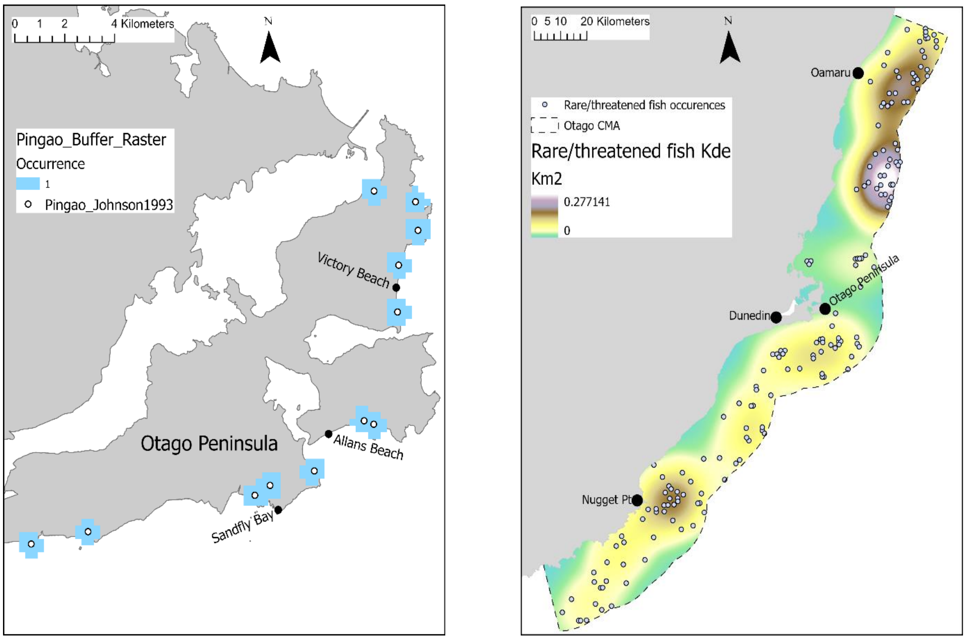

Figure 2-3: Formatting point data. Examples of formatting point data as raster datasets using two methods. Converting buffered areas around points to occurrence (left), and using KDe to construct a density surface (right).

Polygon datasets

Polygon datasets are often used to portray the extent of species/habitats with geographic boundaries. Polygon features may also contain useful ancillary information to guide the use of data, e.g., habitat quality, temporal extent or limitations. Polygons were rasterised to denote the extent of the ecological feature they represent (coded by 1). All areas outside of polygons were set to 0.

Raster datasets

It was necessary to format several existing raster datasets to ensure consistent cell alignment, extent and resolution. A study-area template was generated for the full extent of the Otago CMA (for marine based management classes), and another for the full Otago region (for terrestrial based management classes, e.g., bird colonies). The extent of the template was defined based on the geographic boundaries of the Otago region, and a 250 m x 250 m grid was configured using an Albers Equal Area spatial projection recently developed for the NZ region (Wood et al. 2020).

All existing raster datasets were matched to the relevant template, with grid-cell values being resampled with bilinear interpolation when changes in resolution were required. All processing was undertaken in R (R Core Team 2022) using the package *raster* (Hijmans 2019).

2.4 Significant area designation

Depending on the type of information available for a management class, one of two methods were used to identify SEAs. When a class was informed by a substantial number of overlapping datasets the decision support tool Zonation (Moilanen et al. 2009) was used to identify SEAs. In contrast, when the available information was more limited, non-overlapping and suggestive of discrete, isolated areas of importance, a manual method of identification was used. See Table 2-3 for the method used for each management class.

2.4.1 Zonation

The decision support tool Zonation (Moilanen et al. 2009) provides spatial prioritisation analyses that systematically identify spatial solutions for meeting defined management objectives (Lundquist et al. 2021). Objectives are characterised by a suite of 'scenarios' that include various options associated with the typical decision points around marine spatial planning. These include the analysis area, data gaps, uncertainty, habitat condition, cost, spatial resolution, cell aggregation, connectivity and weightings assigned to any of the key biodiversity inputs (Lundquist et al. 2021).

In this project, our objectives were to identify the locations that support the highest biodiversity value for each management class (Table 2-3), while considering differences in dataset quality. Zonation spatial prioritisations were developed for each management class using the core area cell removal rule, a warp factor of 1000, and no offsetting for habitat condition, uncertainty or cost. The input biodiversity layers were weighted according to their respective data quality score (Table 2-2), with additional weighting being given to species/habitats of particular significance (e.g., endangered species that meet Policy 11 section a) following discussions with ORC. The resultant spatial prioritisations (e.g., Figure 2-4) were used to guide the construction of SEAs based on either 1) the top 30% the prioritisation area or 2) the top 100% of the prioritisation area. The latter was used for relatively restricted coastal habitats (e.g., seagrass, saltmarsh) where, given the relative rarity of the habitats, it was agreed that the full extent of each habitat should be included within a SEA. The use of Zonation for prioritisation of these rarer habitats provides ORC with the future opportunity to distinguish between SEAs based on habitat quality or size in the future.

Polygons were constructed to represent the boundaries of individual SEAs that took into consideration the top 30% of priority areas from the Zonation analysis as well as minimising boundary complexity - an important consideration for monitoring and enforcement (Brough et al. 2021a). A polygon feature class layer of the total SEAs for each management class is provided.

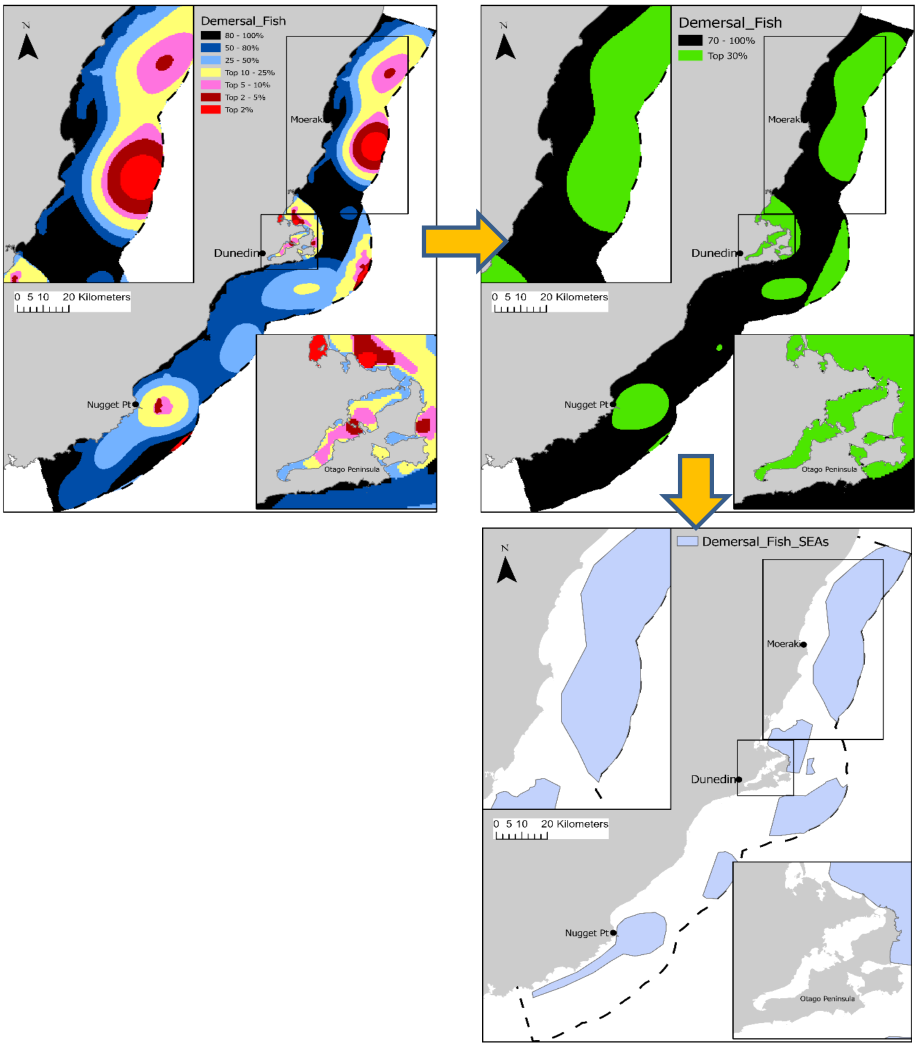

Figure 2-4: Zonation SEA delineation. Example of SEA delineation using Zonation where the output of a spatial prioritisation (top left) is converted to represent the top 30% priority areas (top right), with the final SEA boundaries being constructed as polygons (bottom). Note in this example using the demersal fish class, commercially sensitive data on catch distribution is masked out.

2.4.2 Manual delineation

Manual delineation was undertaken in ArcGIS Pro (ESRI), by constructing/copying polygon features using existing datasets. Construction of SEA polygons was undertaken when the underlying spatial dataset consisted of point or raster datasets and polygons were copied when the spatial dataset consisted of polygon features (e.g., layers for pinniped colony extents, naturally uncommon ecosystems, estuaries). SEA polygon construction aimed to use the smallest area to capture the spatial bounds of the ecological feature represented by point/polygon data. However, due to the inherent subjectivity associated with this process it is recommended such SEAs are the focus of extent definition (see Section 6.2).

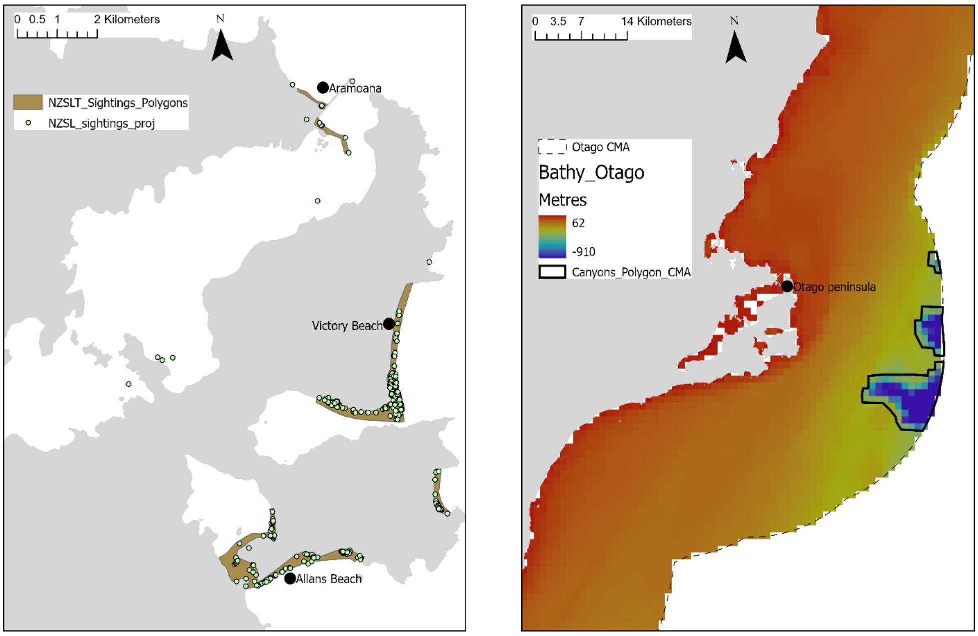

Figure 2-5: Example of manual SEA delineation. Examples of manual delineation of SEAs using point dataset (left) and raster datasets (right), where non-overlapping ecological features are defined manually for NZ sea lion haul outs and submarine canyons respectively.

3 Results

In the following section we provide information on the available datasets, their appropriateness for identifying SEAs, and the ecological significance criteria they inform. We also provide the results of the identification of significant areas for each management class. A geodatabase of feature class polygon GIS layers (ESRI format) denoting the SEAs for each class has been prepared and is made available with this report. Each SEA layer contains the attributes described in Table 3-1, and the full table for each management class is provided in Appendix B. The outputs of the zonation prioritisation analysis for those management classes for which this method was employed are provided in Appendix C.

Table 3-1: SEA attributes. The information provided in the attributes table for the SEAs under each management class.

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Name reflecting the geographic location and management class of the SEA	Unique SEA code	Summary of the ecological features found within the SEA	List of the spatial datasets used to provide evidence on the occurrence of important ecological features	List of the KEA significance criteria met by features within the SEA	List of the National coastal policy statement criteria met by features within the SEA	Whether the SEA requires extent definition (yes/no)	Whether the SEA requires ground-truthing (yes/no)

3.1 Benthic Invertebrates – intertidal

Datasets

Following the review process, five datasets had useful information on the distribution of intertidal benthic invertebrates that could be used for identifying SEAs. Three of these datasets originated from ORC studies on mapping the distribution of cockles (e.g., clams; *Austrovenus stutchburyi)* within Otago estuarine environments, including two estuarine habitat mapping studies in Blueskin Bay and the Catlins River Estuary. A point dataset on the locations of green-lipped mussel (*Perna canaliculus*) was available from NIWA and spatial data reporting the distribution (and value) of commercial harvesting for clams was provided by MPI.

Table 3-2: Datasets for the intertidal benthic invertebrates management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Catlins2016_Substrate_Biogenic	Cockles layer from 2016 intertidal broad scale habitat mapping of Catlins Estuary undertaken by Wriggle Coastal Management for Otago Regional Council	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 8, 9	11 b (ii), b (iii), b (iv), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Cockles_ORCEstuary	Cockle layer, mapped as part of a project identifying significant habitats of indigenous fauna across Otago Region, for the Otago Regional Council	Polygon	ORC Marine Shapefiles	5	1, 8, 9	11 b (ii), b (iii), b (iv), b (vi)
Blueskin2020_21 _Substrate	Cockle layer from 2020-2021 intertidal broad scale habitat mapping of Blueskin Bay undertaken by Salt Ecology for Otago Regional Council	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 8, 9	11 b (ii), b (iii), b (iv), b (vi)
Perna_Buffer_Presence	Dataset on the occurrence of green shell mussels	Polygon	Moana project/NIWA	3	1, 8, 9	11 b (iii), b (iv), b (vi)
MPI spatial catch data - clams	MPI catch reporting on Cockles	Raster	MPI	5	1, 8, 9	11 b (ii), b (iii), b (iv), b (vi)

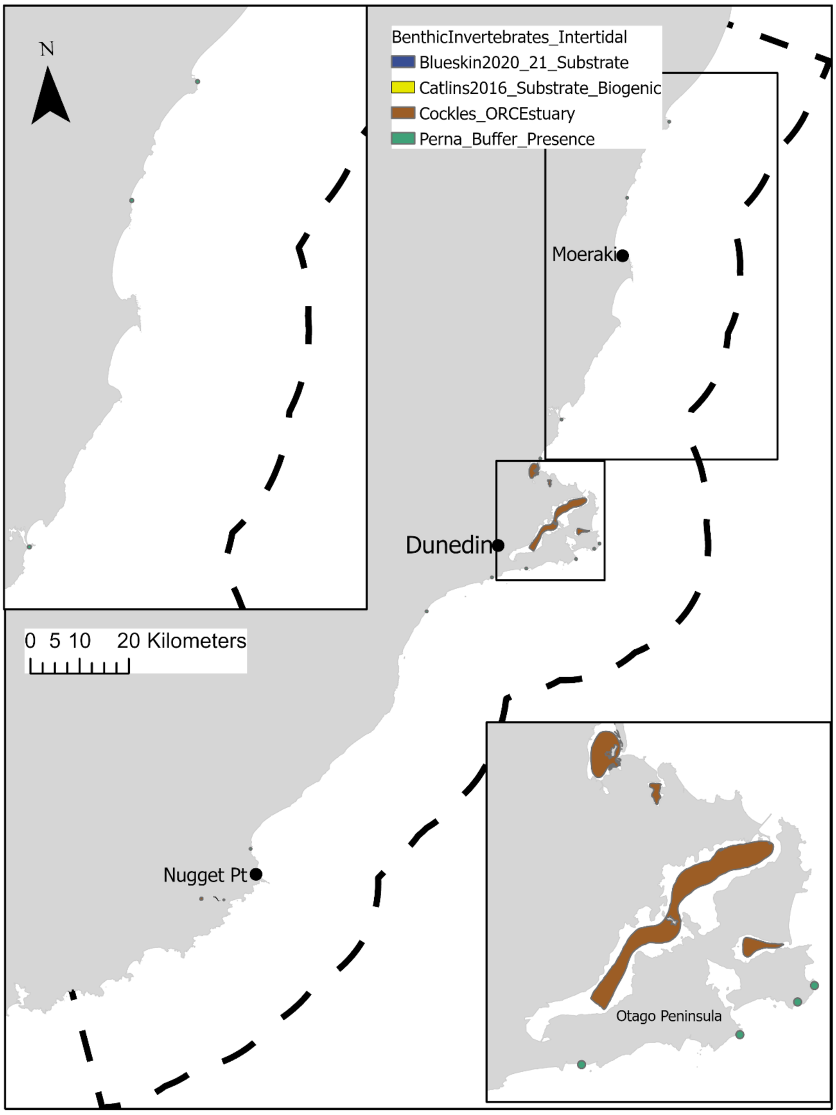

Figure 3-1: Example data for the intertidal benthic invertebrate management class. Data layers for the intertidal benthic invertebrate management class include polygons of cockle distribution in mapped estuaries and approximate distribution within confined spatial waterways (e.g., Otago Harbour). The presence locations for green-lipped mussel are also shown.

Significant areas

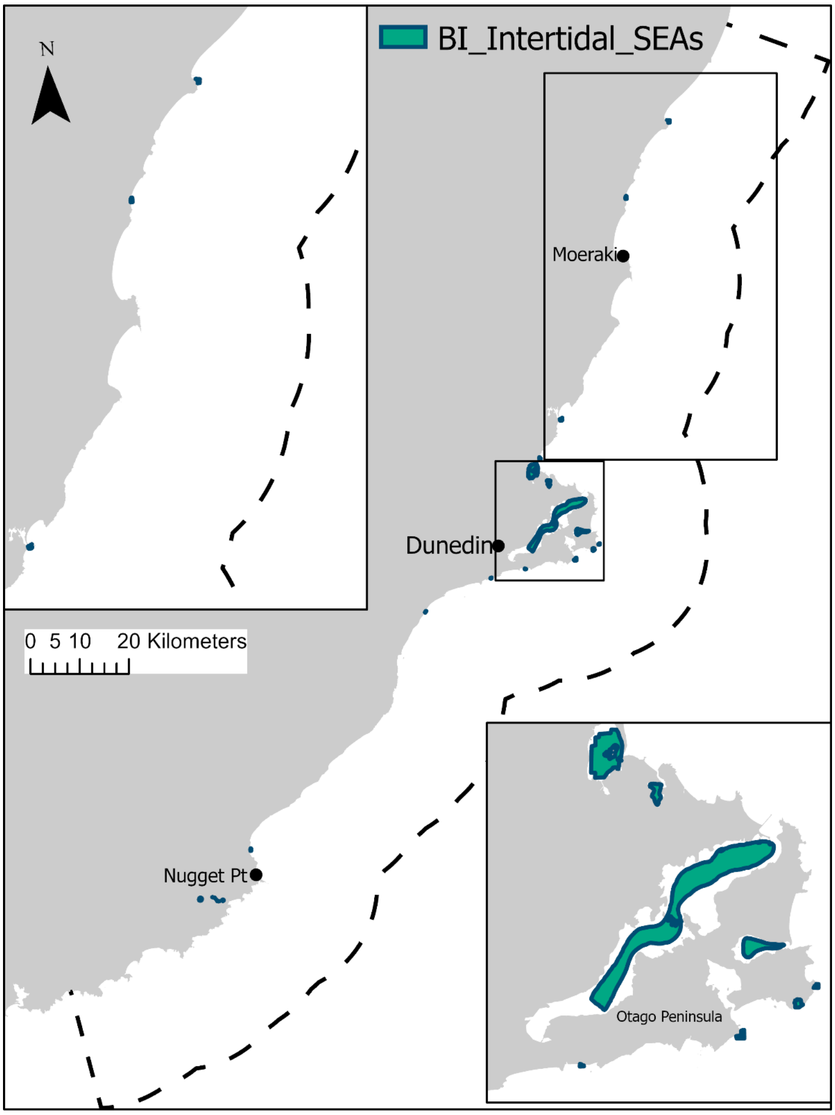

Figure 3-2: SEAs for the intertidal benthic invertebrate management class.

Analysis of spatial data on important ecological features for intertidal benthic invertebrates led to the identification of 16 SEAs throughout the Otago region. SEAs were located mainly in the Otago Harbour and around Otago Peninsula, Blueskin Bay and the Catlins River, with smaller SEAs near Kaka Point, Taieri Mouth, Kakaho and Oamaru. SEAs for this class consisted of areas of particular importance and/or occurrence for clam/cockle and green-lipped mussels.

3.2 Benthic Invertebrates – subtidal

Datasets

For the subtidal benthic invertebrates, six datasets had useful information for identifying SEAs. The national scale species distribution models (SDMs) contained layers for 109 subtidal benthic invertebrate genera which have been expert appraised (Stephenson & Brough et al., submitted). One dataset consists of kernel density layers for benthic invertebrate species within three functional groups (bioturbators, substrate de-stabilisers, substrate stabilisers) (Lundquist et al. 2020a) and the remaining four datasets are point records for endemic, rare, threatened and unique benthic invertebrates (Stephenson et al. 2018).

Table 3-3: Datasets used for the subtidal benthic invertebrates management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Benthic invertebrate SDMs (109)	Habitat suitability model layers for 109 benthic invertebrate species	Raster	KEA Database	3	1, 2, 4, 6,	11 a (i), a (v), b (ii), b (iii), b (vi)
Benthic_invertebrate_ functional_groups	Kernel density layers for benthic invertebrate species in the functional groups Bioturbators, SubstrateDeStabilizers, SubstrateStabilizers	Raster	KEA Database	3	1, 8,	11 b (iii), b (vi)
Invertebrates_Endemic_OBIS_EEZ	Point records of endemic benthic invertebrates	Point	KEA Database	3	2, 6,	11 b (iii)
Invertebrates_rare_EEZ	Point records of rare benthic invertebrates	Point	KEA Database	3	2, 6	11 a (iii)
Invertebrates_Threatened_EEZ	Point records of threatened benthic invertebrates	Point	KEA Database	3	2, 4, 6	11 a (i)
Invertebrates_Unique_EEZ	Point records of unique benthic invertebrates	Point	KEA Database	3	2, 6	11 a (iii)

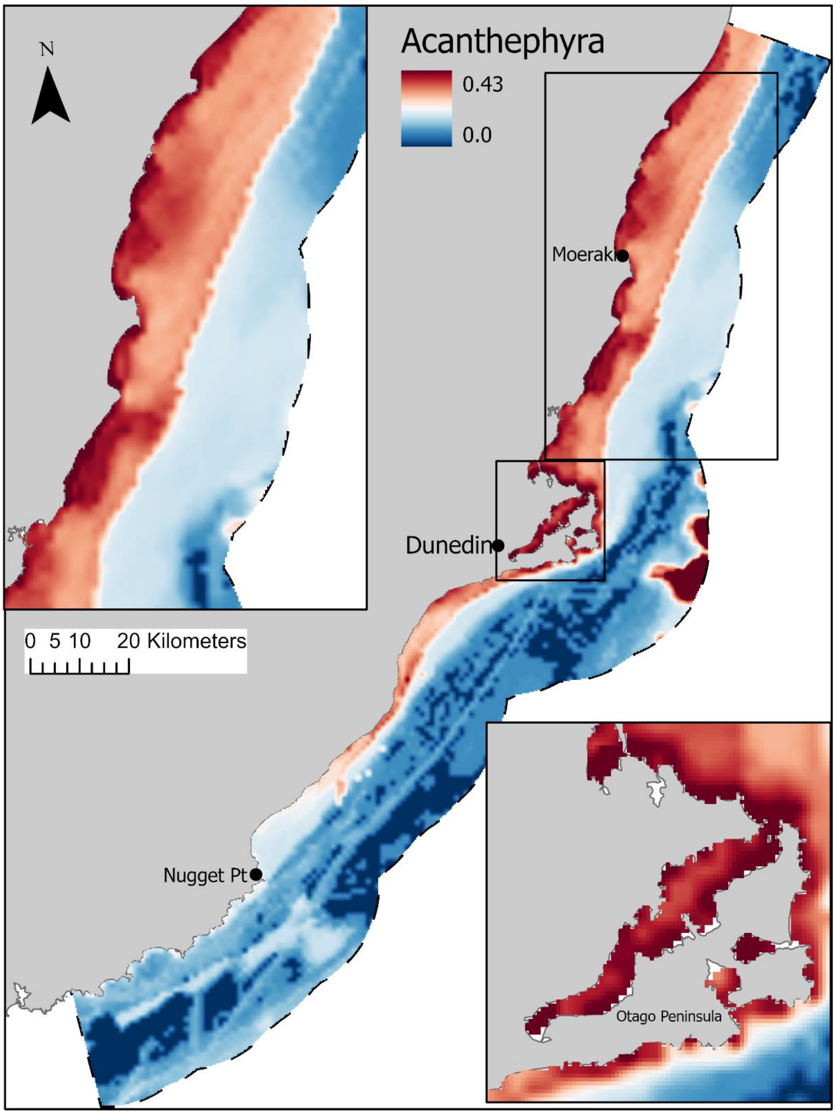

Figure 3-3: SDM for *Acanthephyra*. Species distribution model of the shrimp *Acanthephyra*, an example dataset of the subtidal benthic invertebrate management class.

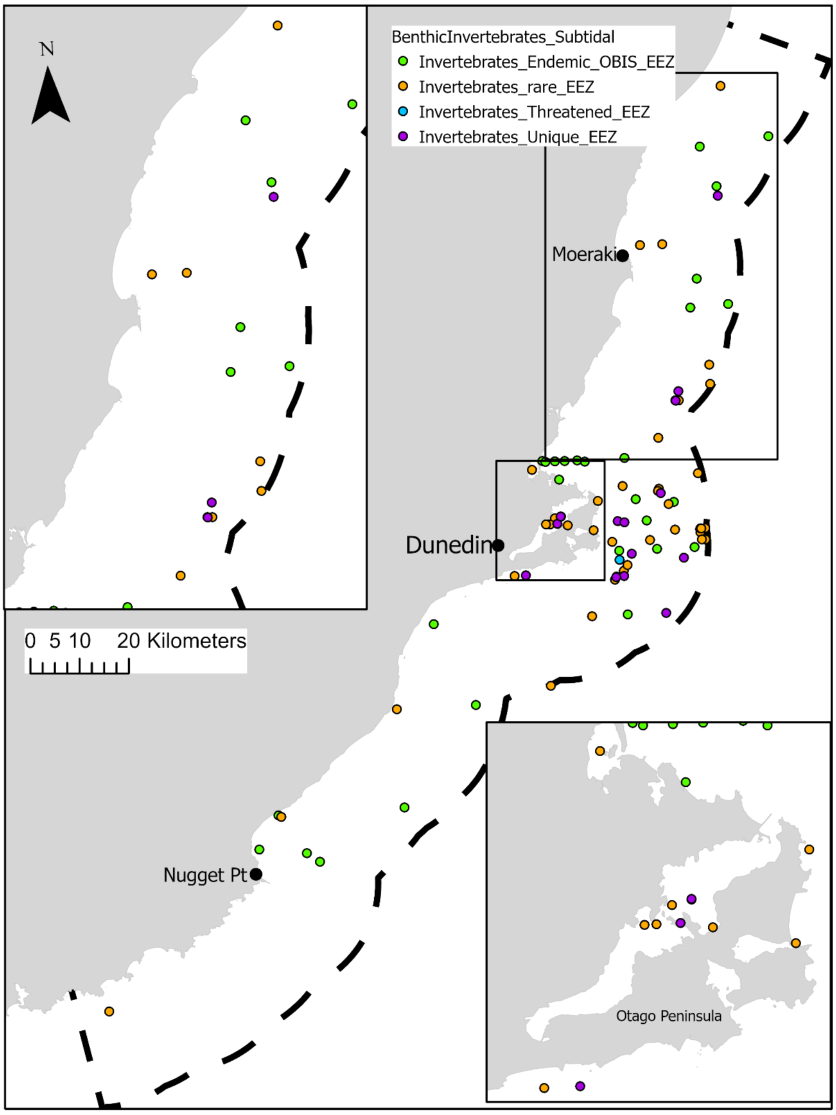

Figure 3-4: Subtidal invertebrate point data. Example point layers for the subtidal benthic invertebrate management class.

Significant areas

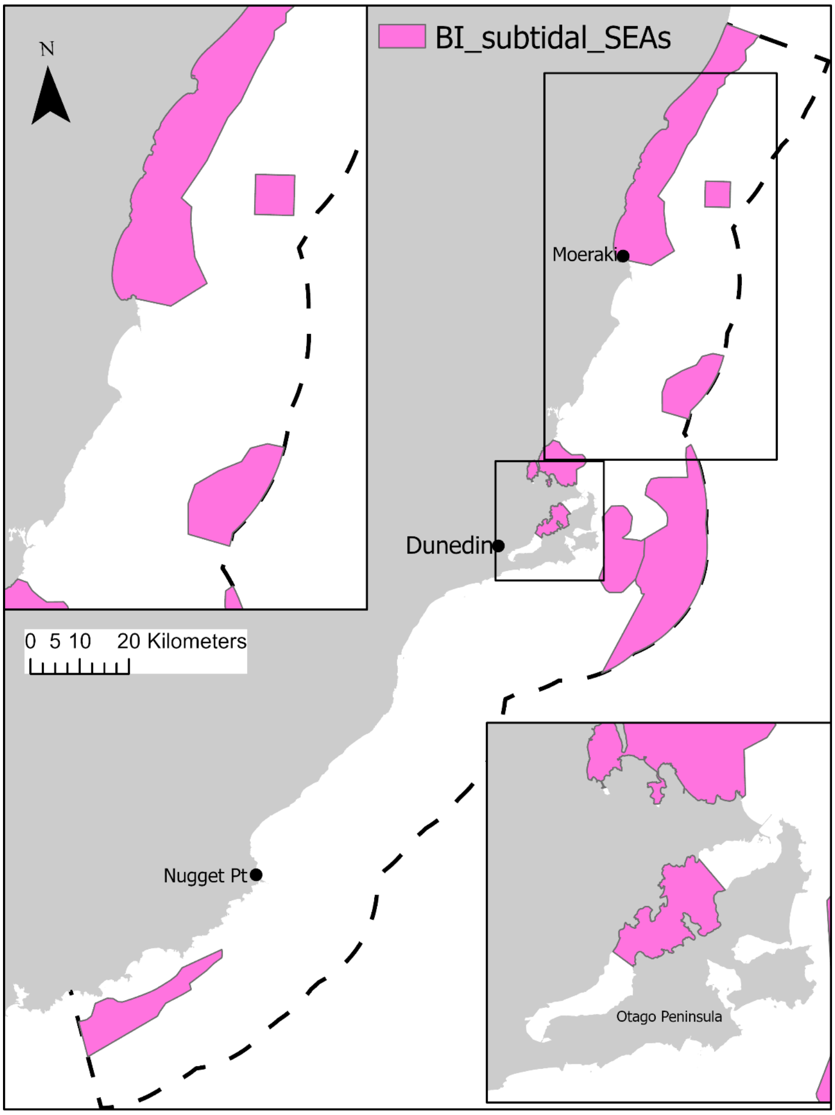

Figure 3-5: SEAs for the subtidal benthic invertebrate management class.

Analysis of spatial data on important ecological features for subtidal benthic invertebrates led to the identification of eight SEAs throughout the Otago region. SEAs were located in Otago Harbour, Blueskin Bay, the south Catlins and North Otago Coast, as well as some offshore locations near the Peninsula and around the head of the Karitane Canyon. SEAs for this class consisted of areas highly suitable habitat for numerous benthic invertebrate species and occurrence of rare, threatened or unique species.

3.3 Biogenic Habitats – invertebrates

Datasets

There were 15 datasets with useful information on the distribution of biogenic habitats that could be used for identifying SEAs. The national scale SDMs contained 64 expert appraised layers for benthic invertebrate biogenic habitat forming genera (Stephenson & Brough et al., submitted). A dataset for protected coral species contained 12 habitat suitability model layers (Anderson et al. 2020). Two additional layers for the downward-structure-formers and upward-structure-formers benthic invertebrate functional groups were included. The DOC SeaSketch database provided two polygon layers for biogenic reef and biogenic bryozoan distributions. The remaining datasets are all point records, and for key reef building bryozoans there are other datasets reviewed in Lundquist et al. (2020). For key bed-forming bivalves there are datasets from OBIS, NIWA Inverts and Te Papa. For sponge garden species there are datasets from OBIS and NIWA-specify. There is one point record for rhodoliths in the Otago region (Lundquist et al. 2020).

Table 3-4: Datasets used for the biogenic habitats management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Biogenic habitat formers 64 SDMs	National scale habitat suitability model layers for 64 benthic invertebrate biogenic habitat forming genera.	Raster	KEA Database	3	1, 3, 4, 6, 8	11 a (iii), b (ii), b (iii), b (vi)
Protected Coral models (12)	Habitat suitability model layers for protected coral species	Raster	KEA Database	3	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)
Benthic_invertebrate_ functional_groups (DownwardStructure, UpwardStructFormers)	Habitat suitability model layers for benthic invertebrate species in the functional groups DownwardStructure, UpwardStructFormers	Raster	KEA Database	3	1, 8,	11 b (ii), b (iii), b (vi)
Bryozoans_AMSmith_ mergedtsp	A bryozoan species-level dataset for sampling collections (e.g. dredging) all around southern New Zealand over the last decade (2010-2018) provided by Abigail Smith.	Point	KEA Database	3	1, 3, 4, 6, 8	11 b (ii), b (iii), b (vi)
MPA_Habitat_Biogenic	Biogenic layer of MPA Policy habitats of the Otago Regional Council Territorial Sea	Polygon	ORC Marine Shap efiles	2	1, 3, 5, 6, 8	11 b (ii), b (iii), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
NIWA_rhodoliths18	Distribution of Rhodoliths around New Zealand, based on presence-only data of identified specimens collected by NIWA	Point	KEA Database	5	1, 2, 6,	11 b (ii), b (iii), b (vi)
Obis_clip_keybiv2	Known distribution of key bed forming bivalves from OBIS-NZ dataset.	Point	KEA Database	3	1, 8	11 b (ii), b (iii), b (vi)
Obis_clip_keybryo	Presence-only locations of key reef-building bryozoan species in New Zealand	Point	KEA Database	3	1, 3, 4, 6, 8	11 b (ii), b (iii), b (vi)
Obis_clip_keyspg	Known distribution of key 'sponge garden' species in New Zealand. Presence of all species from OBIS-NZ dataset.	Point	KEA Database	3	1, 6, 8	11 b (ii), b (iii), b (vi)
Reefs_biogenic	Important biogenic and rocky reefs identified as part of the mapping of significant habitats of indigenous fauna in the marine environment of Otago Region.	Polygon	Doc SeaSketch database	3	1, 3, 5, 6, 8	11 b (ii), b (iii), b (vi)
Specify_clip_keybiv	Known distribution of key bed forming bivalves from NIWA-Specify dataset, NIWA's Invertebrate Collection	Point	KEA Database	3	1, 8	11 b (ii), b (iii), b (vi)
Specify_clip_keyspg	Known distribution of key 'sponge garden' species in New Zealand. Presence of all species from NIWA Invert dataset.	Point	KEA Database	3	1, 6, 8	11 b (ii), b (iii), b (vi)
Tepapa_clip_keybiv	Known distribution of key bed forming bivalves from Te Papa dataset.	Point	KEA Database	3	1, 8	11 b (ii), b (iii), b (vi)
Wood_Biogenic_ habitats_review	Presence-only locations of key reef-building bryozoan species in New Zealand	Point	KEA Database	3	1, 3, 5, 6, 8	11 b (ii), b (iii), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Biogenic_bryozoan	Estimated distribution of bryozoans off Otago Peninsula	Polygon	Doc SeaSketch database	4	1, 2, 4, 6, 8	11 b (ii), b (iii), b (vi)

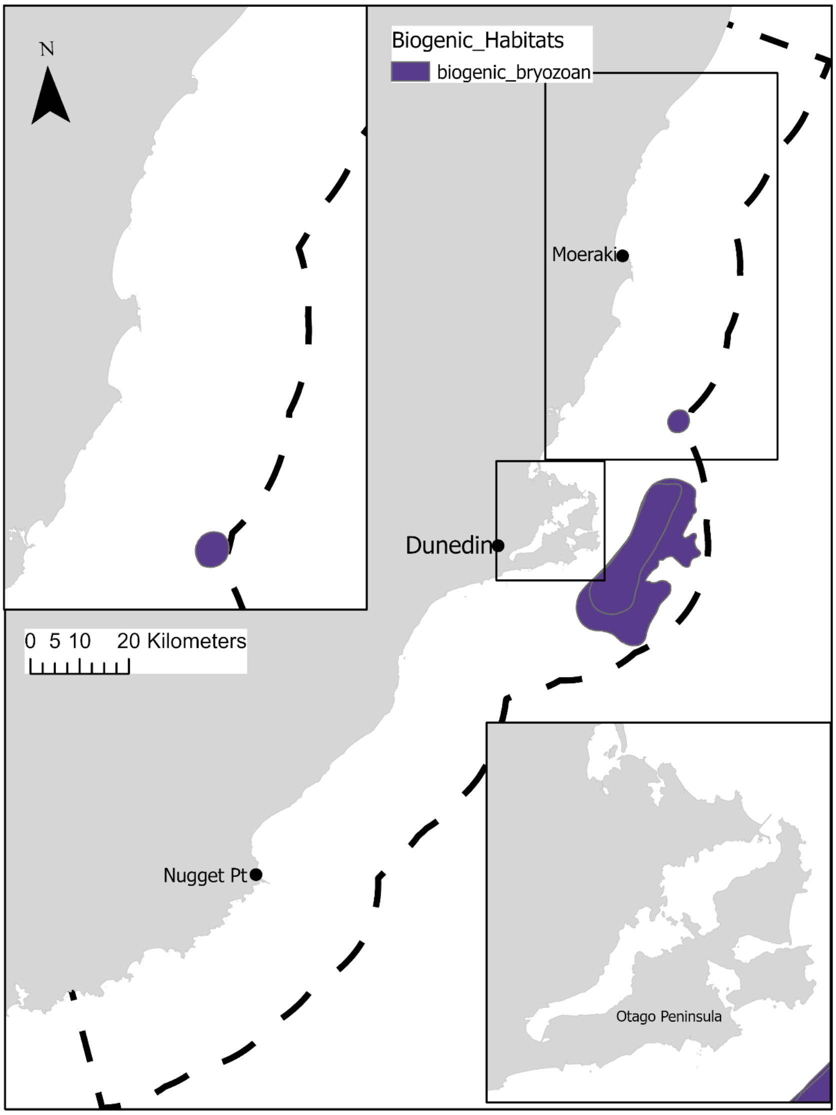

Figure 3-6: Otago shelf bryozoans. Estimated distribution of bryozoans off the Otago Peninsula from the DOC SeaSketch database, an example dataset for the biogenic habitats management class.

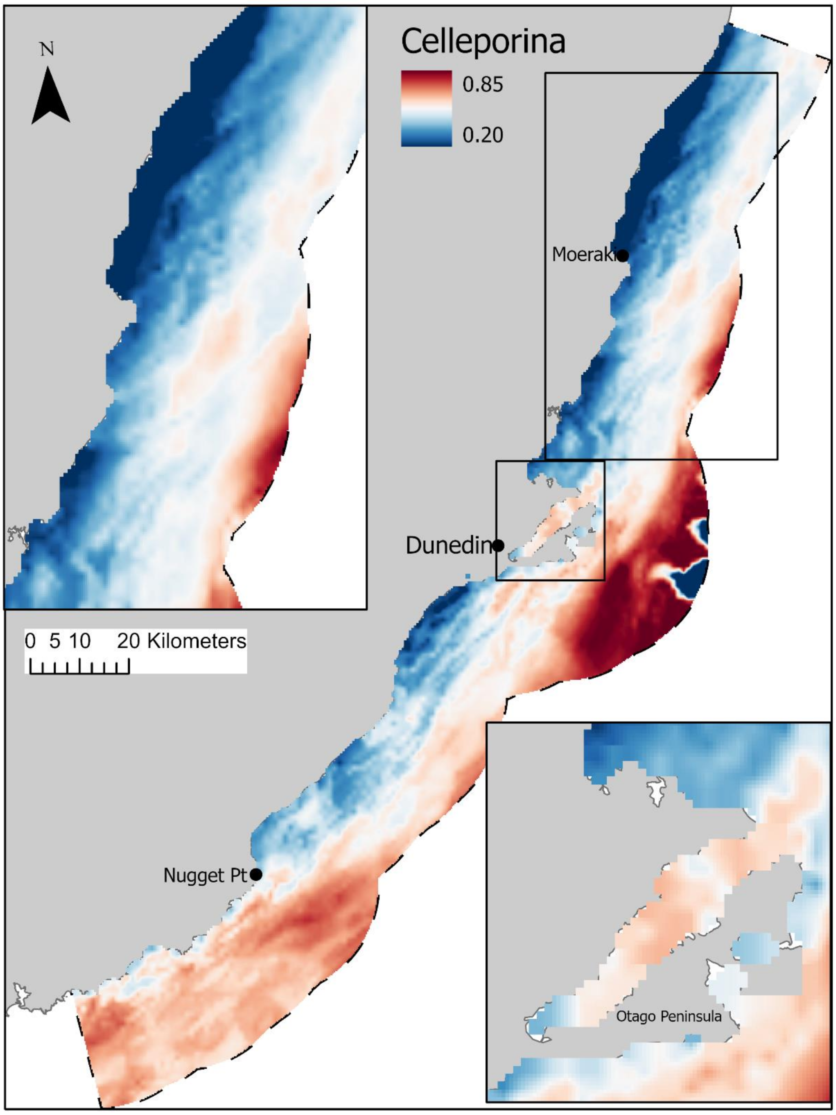

Figure 3-7: SDM of *Celleporina*. Species distribution model of the bryozoan *Celleporina*, an example dataset for the biogenic habitat management class.

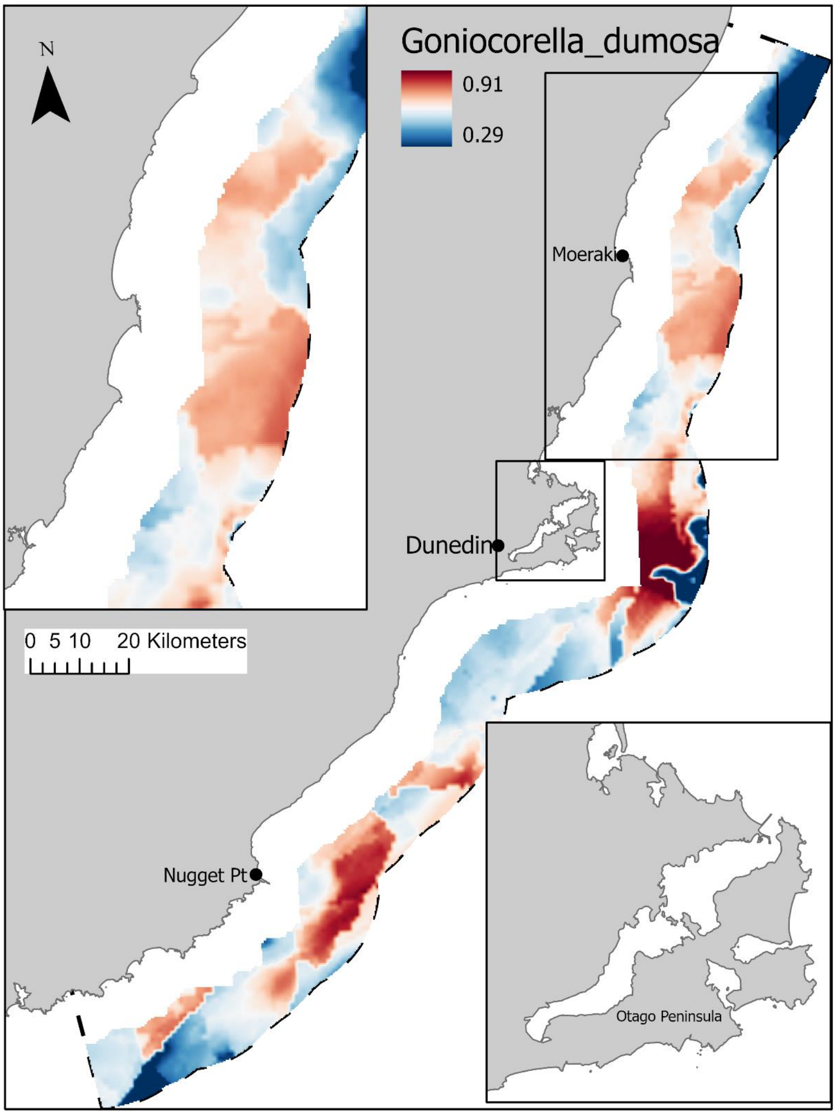

Figure 3-8: SDM of *Goniocorella dumosa*. Species distribution model of protected coral *Goniocorella dumosa*, an example dataset for the biogenic habitat management class.

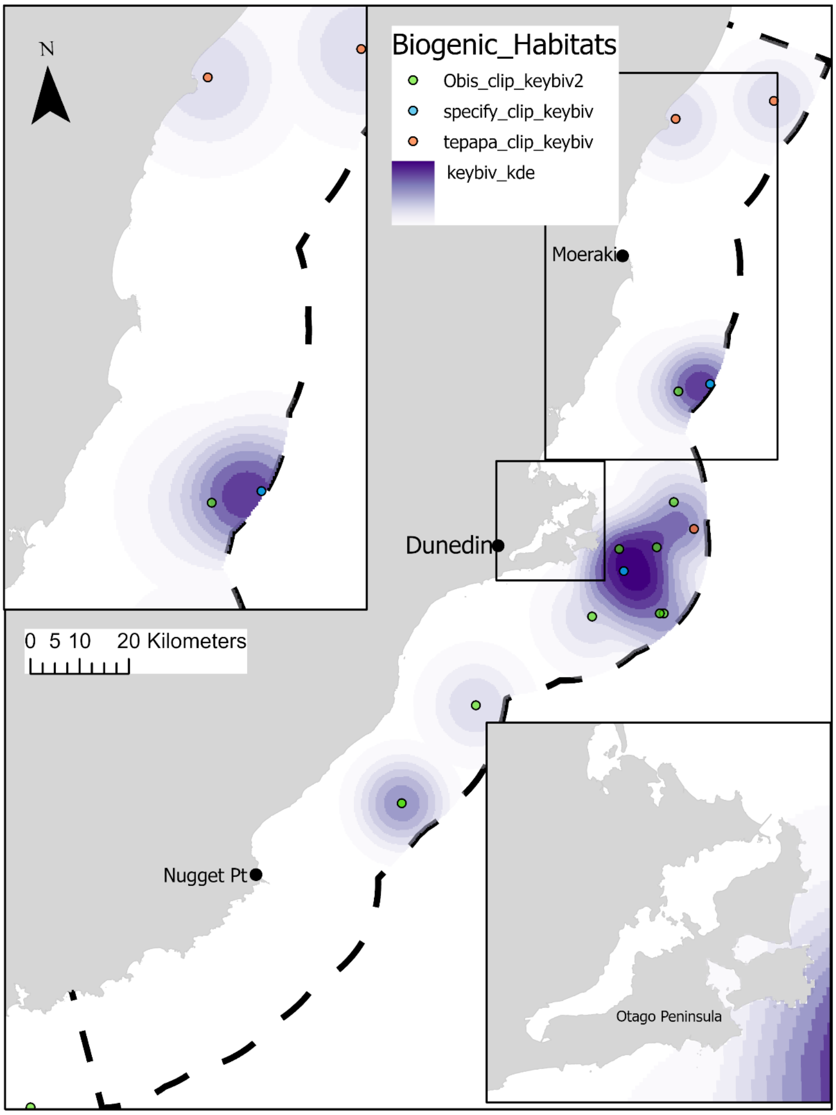

Figure 3-9: Biogenic point data. Example point layers of key bivalve species and the generated kernel density for the biogenic habitat management class.

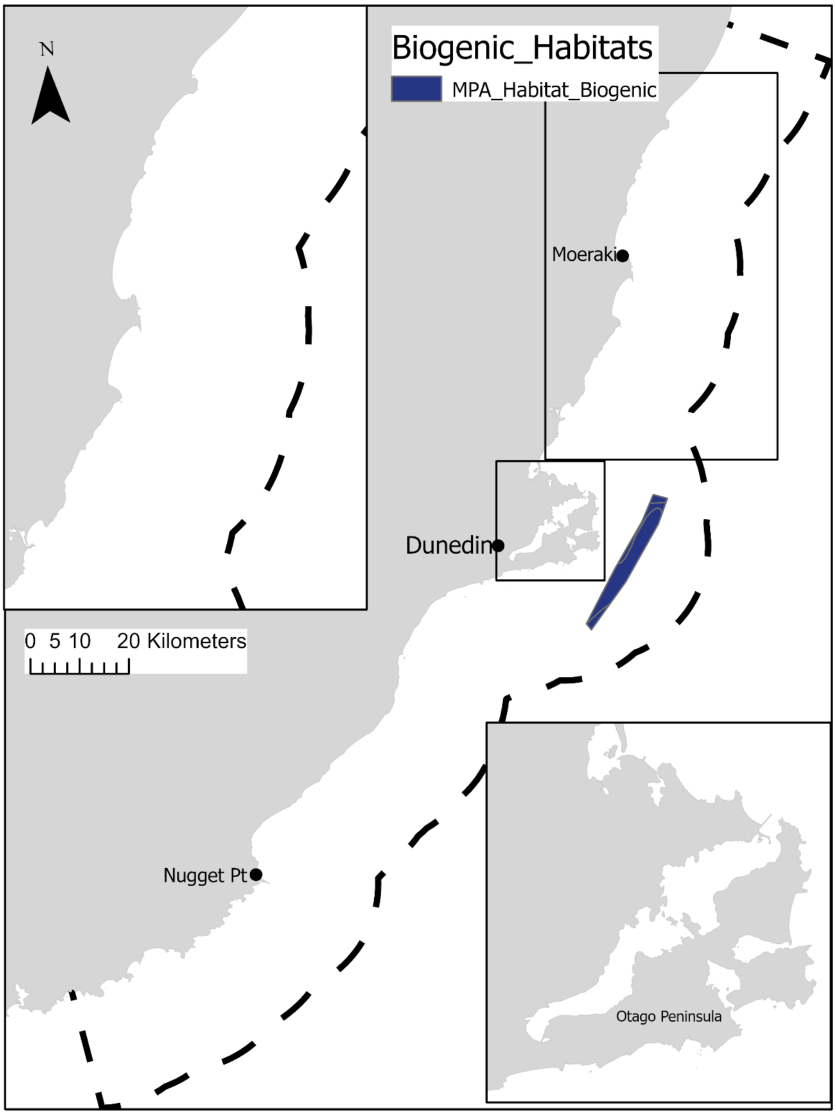

Figure 3-10: MPA policy - biogenic. Example biogenic layer from the MPA Policy habitats of the Otago Regional Council Territorial Sea.

Significant areas

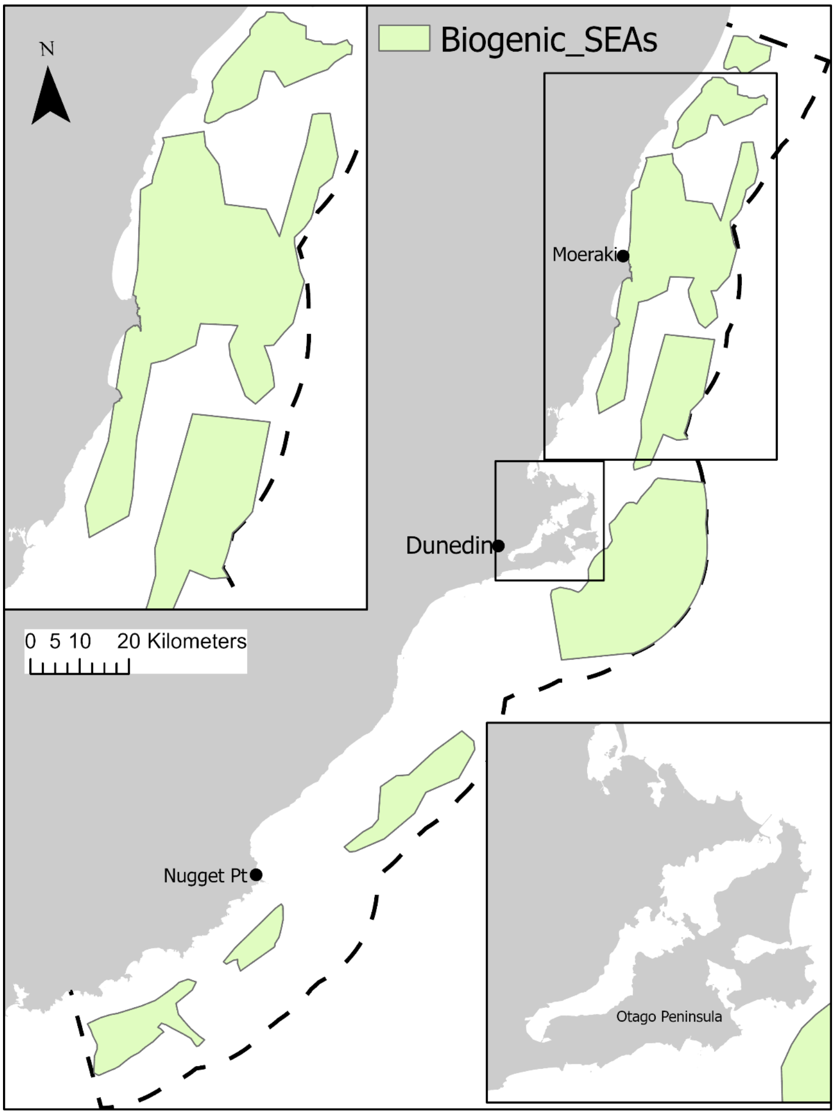

Figure 3-11: SEAs for the biogenic habitats management class.

Analysis of spatial data on important ecological features for biogenic habitat forming invertebrate species led to the identification of 8 SEAs throughout the Otago region. SEAs were located mostly off the North Otago coast, one off Otago Peninsula and three smaller SEAs off the South Otago/Catlins coast. SEAs for this class consisted of areas of particular importance and/or occurrence for numerous biogenic habitat-forming species, including bryozoans, bivalves and sponges as well as protected coral species.

3.4 Coastal vegetation

Datasets

There were ten datasets with useful information on the distribution of coastal vegetation for identifying SEAs. Nine of these originated from ORC studies on mapping the locations of saltmarsh (8) and estuarine shrub (1) within estuarine environments. The remaining two datasets report point records of Pingao *(Ficinia spiralis)* on the Otago peninsula from (Johnson 1993) and from INaturalist observations throughout Otago.

Table 3-5: Datasets used for the coastal vegetation management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Blueskin2020_21_ SaltMarsh	Mapped distribution of saltmarsh within Blueskin estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Catlins2016_SaltMarsh	Mapped distribution of saltmarsh within Catlins estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Estuarine_Shrub	Mapped distribution of Estuarine shrubs with ORC monitored estuaries	Polygon	ORC Otago GIS map packages, Salt Ecology	1		
Kaikorai2018_SaltMarsh	Mapped distribution of saltmarsh within Kaikourai estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Kakanui2021_SaltMarsh	Mapped distribution of saltmarsh within Kakanui estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
MPA_Habitat_SaltMarsh	Distribution of saltmarsh from MPA habitat classification	Polygon	ORC Marine Shapefiles	3	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Shag2016_SaltMarsh	Mapped distribution of saltmarsh within Shag estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Tokomairiro2018_ SaltMarsh	Mapped distribution of saltmarsh within Tokomairiro estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Waikouaiti2017_ SaltMarsh	Mapped distribution of saltmarsh within Waikouaiti estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)
Otago Peninsula Pingao	Observed locations of Pingao on Otago Peninsula from Johnson 1993	Point	NIWA digitised from Johnson 1993	5	1, 2, 4, 8	11 a (i), a (iii), b(i), b (ii), b (iii), b (v), b (vi)
iNaturalist Pingao	Database of citizen science, opportunistic pingao observations from iNaturalist	Point	iNaturalist	3	1, 2, 4, 8	11 a (i), a (iii), b(i), b (ii), b (iii), b (v), b (vi)

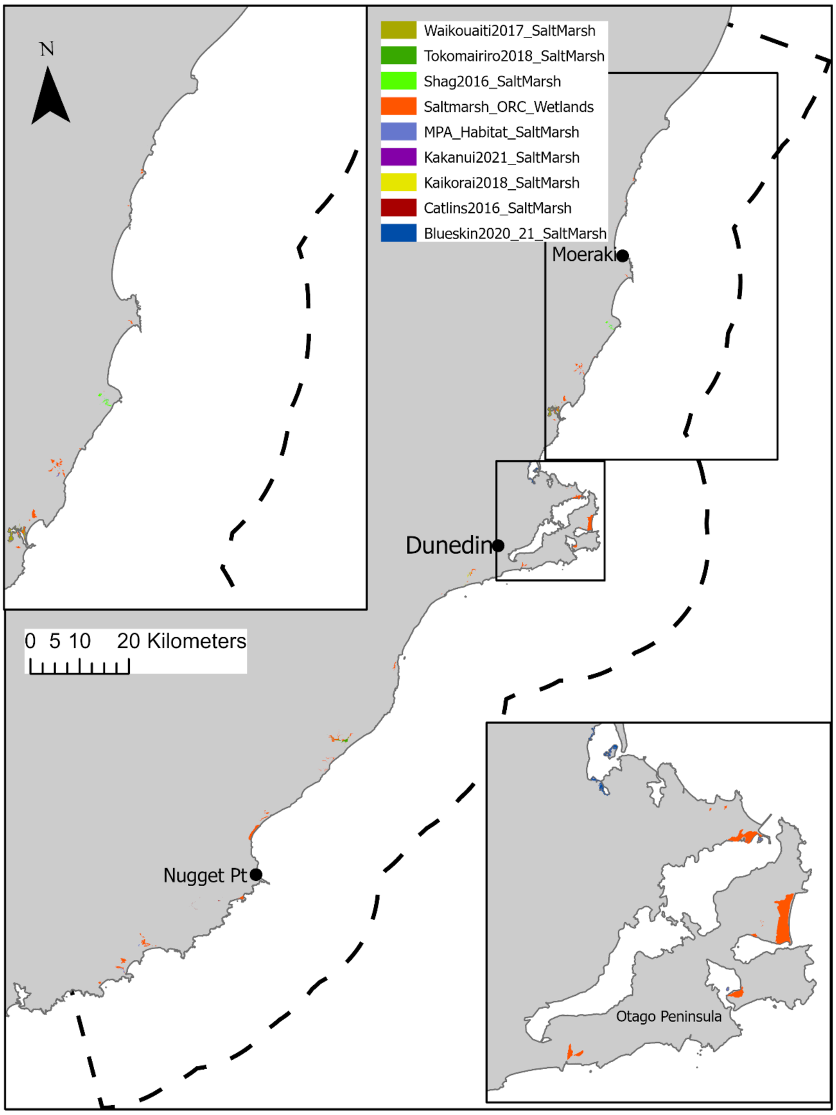

Figure 3-12: Locations of saltmarsh. Locations of saltmarsh mapped by Otago regional council, example datasets for the coastal vegetation management class.

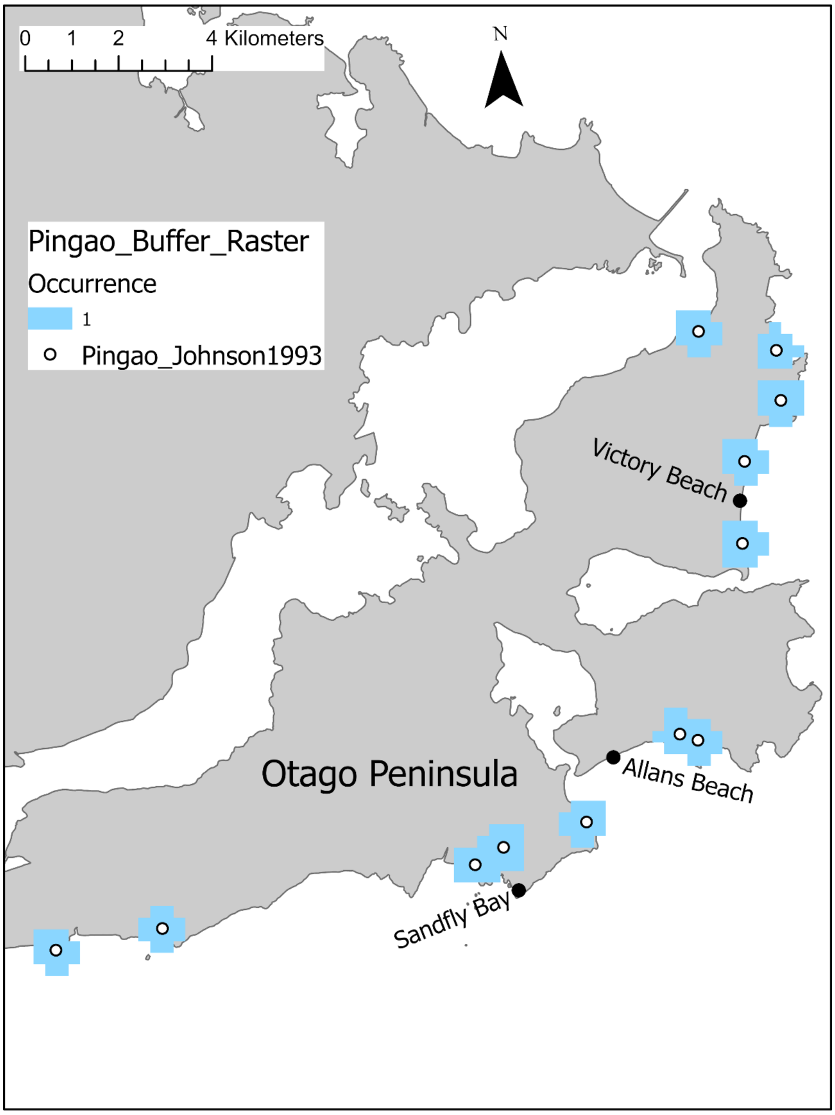

Figure 3-13: The occurrence of pingao (aka pikao) on the Otago peninsula. Point records for the occurrence of pikao on the Otago peninsula, an example dataset for the coastal vegetation management class.

Significant areas

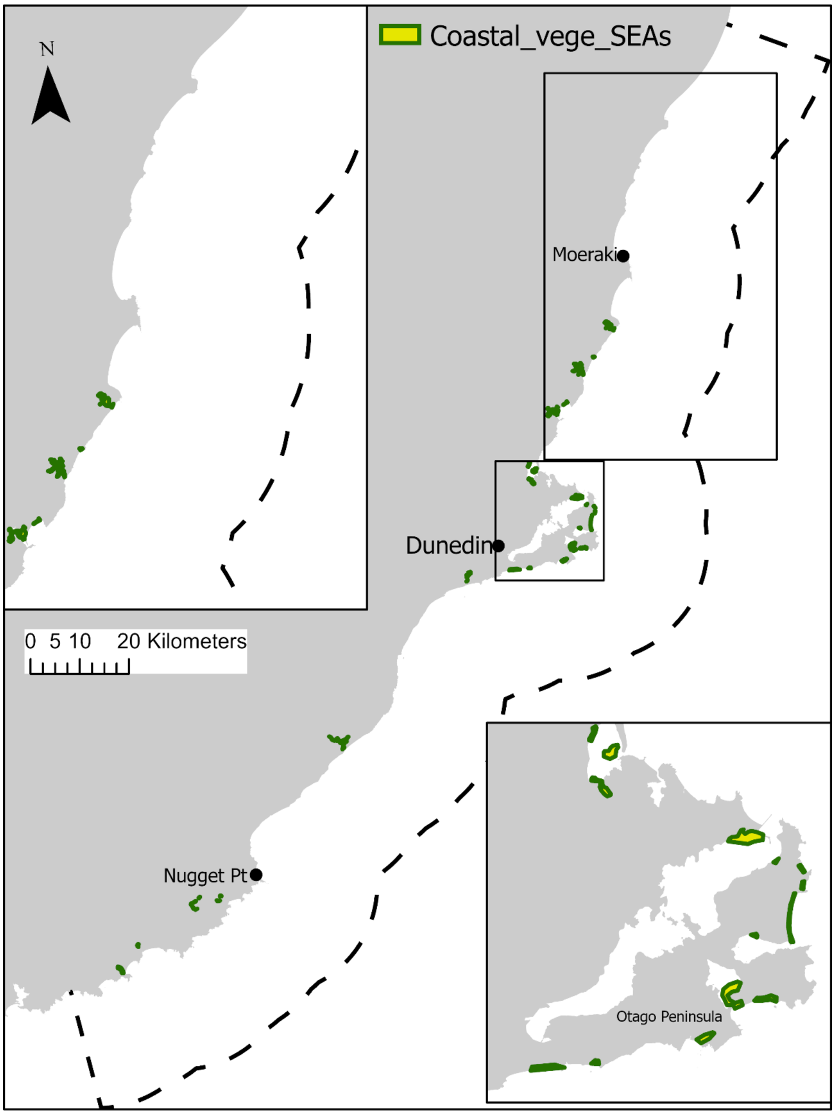

Figure 3-14: SEAs for the coastal vegetation management class. Locations of SEAs for the coastal vegetation management class. The outline of each feature has been enlarged to aid in the viewing of smaller features.

Analysis of spatial data on important ecological features for coastal vegetation led to the identification of 22 SEAs throughout the Otago region. SEAs were located mainly on the Otago Peninsula, at Blueskin Bay, Waikouaiti and the Catlins coasts, with some isolated SEAs at the Shag River, Pleasant River Estuary, Bobby's Head and Tokomairiro mouth. SEAs for this class consisted of areas of occurrence for saltmarsh and pingao.

3.5 Estuaries/Coastal Lagoons and Wetlands

Datasets

There were ten datasets that had useful information on the locations of estuaries, coastal lagoons and wetlands for identifying SEAs. Seven of these originated from ORC studies carried out by Salt Ecology to map the extent of estuaries in Otago. A further ORC dataset provides information on wetland extent, clipped to within 1km of the coastline to determine 'coastal' wetlands. National scale datasets from LINZ provided some information on coastal lagoons.

Table 3-6: Datasets used for the estuaries/coastal lagoons and wetlands management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Blueskin2020_21_Estuary	The mapped extent of Blueskin Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Catlins2016_Estuary	The mapped extent of Catlins Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Kaikorai2018_Estuary	The mapped extent of Kaikorai Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Kakanui2021_Estuary	The mapped extent of Kakanui Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
ORC2_Wetlands_1km	The mapped extent of wetland in the Otago regions - subset coastal wetlands	Polygon	ORC Marine Shapefiles	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Shag2016_Estuary	The mapped extent of Shag Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Tokomairiro2018_Estuary	The mapped extent of Tokomairiro Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Waikouaiti2017_Estuary	The mapped extent of Waikouaiti Estuary - intertidal and subtidal	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Nz-lake-polygons-topo_LINZ	LINZ dataset on the distribution and extent of 'lakes', which include some coastal lagoons	Polygon dataset	LINZ	3	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)
Nz-lagoon-polygons-topo_LINZ	LINZ dataset on the distribution and extent of 'lagoons', which include some coastal lagoons	Polygon dataset	LINZ	3	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)

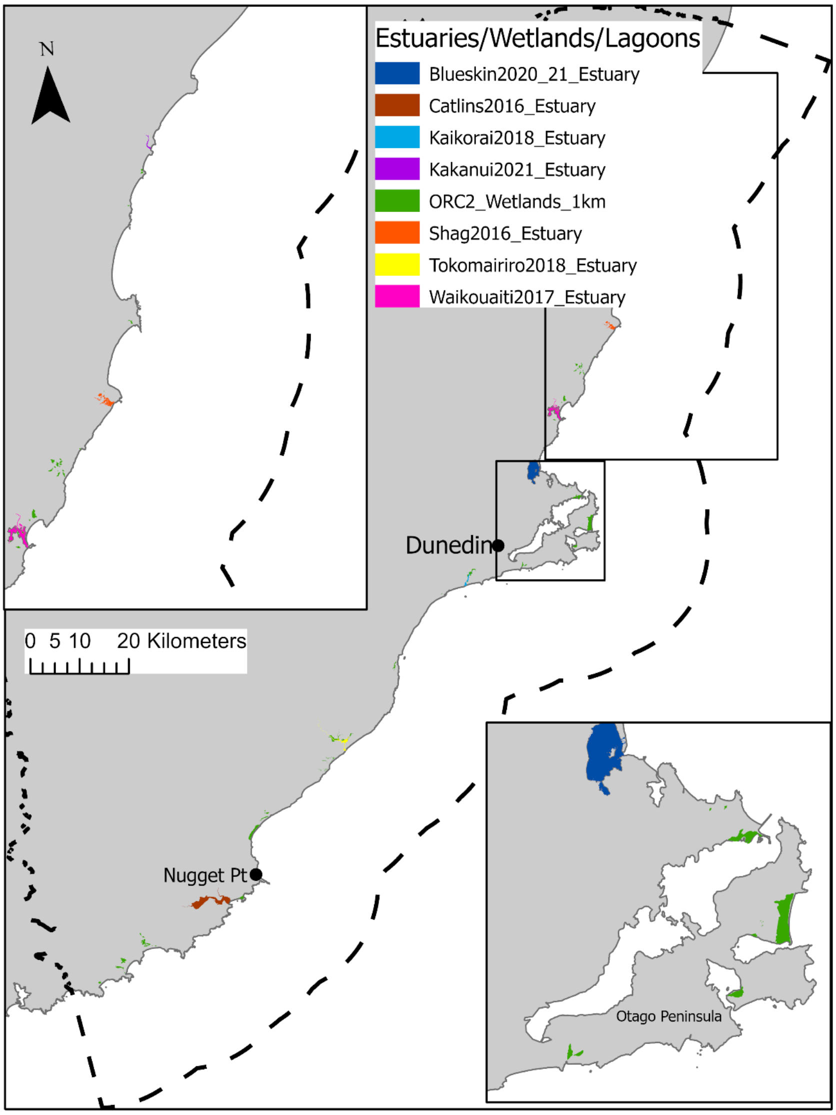

Figure 3-15: Locations of mapped estuaries. Locations of estuaries mapped by the Otago regional council, example datasets for the estuaries/wetlands/lagoons management class.

Significant areas

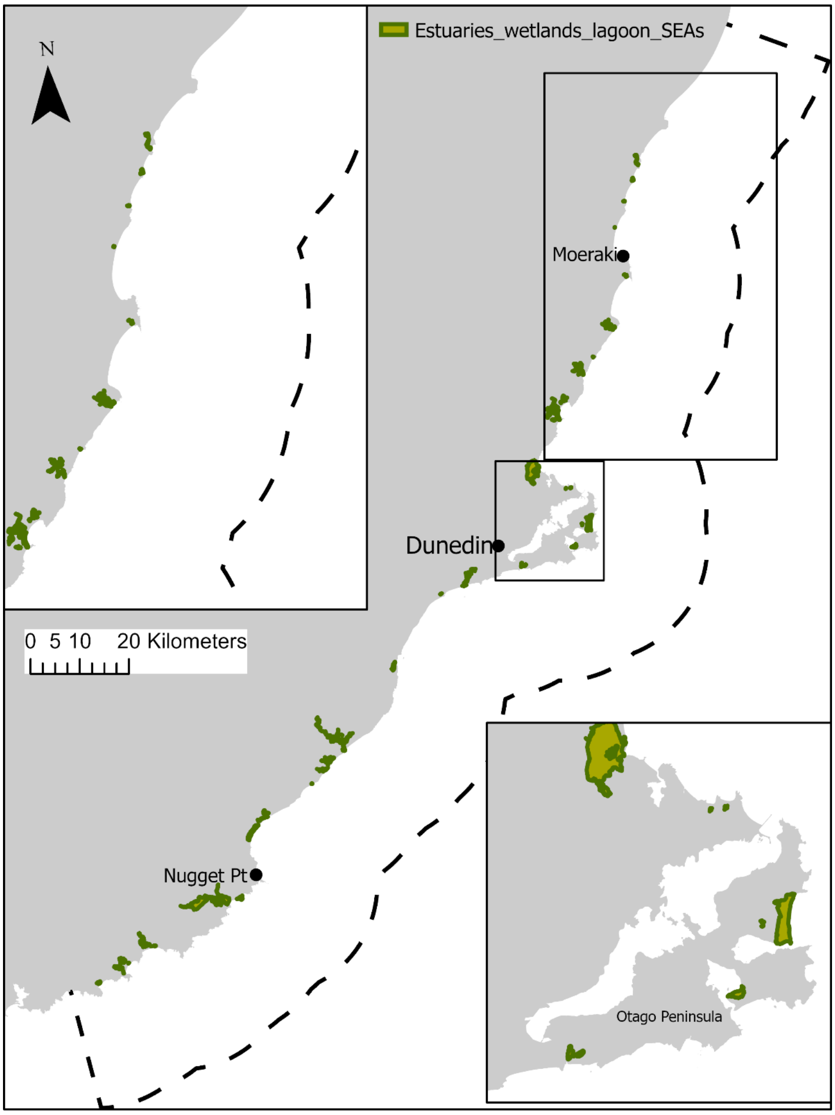

Figure 3-16: SEAs for the estuaries/coastal lagoons and wetlands management class. Locations of SEAs for the estuaries/coastal lagoons and wetlands management class. The outline of each feature has been enlarged to aid in the viewing of smaller features.

Spatial data on important ecological features for estuaries/coastal lagoons and wetlands led to the identification of 41 SEAs throughout the Otago region. SEAs were located at all known locations of coastal estuaries, lagoons and wetlands.

3.6 Demersal Fish

Datasets

Four datasets contained useful information on the distribution of demersal fish for identifying SEAs. The national scale SDM dataset contained 214 expert-appraised species layers (Stephenson & Brough et al., submitted). Another dataset maps expert derived spawning locations for 21 commercially important species. Spatial data reporting the distribution (and value) of commercial harvesting for 10 demersal fish species was provided by MPI was also available (though is not shown due to commercial sensitivities). A final dataset contained four layers of point records for rare, threatened, unique and endemic fish species (Stephenson et al. 2018).

Table 3-7: Datasets used for the demersal fish management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
214 Demersal Fish SDMs	National scale SDMs for demersal fish. Expert appraised	Raster	KEA Database	3	6, 9	11 a (iii), b (ii), b (iv), b (v)
21 Finfish Spawning areas	Expert derived spawning locations for commercially important species	Polygon	KEA Database	2	3, 6	11 b (ii), b (iv), b (v)
NZ_fish_point_records_rarity (4 layers)	Occurrence of rare, threatened, unique fish species	Point	KEA Database	3	1, 2, 4, 6	11 a (iii), b (ii), b (iv), b (v)
MPI spatial catch data - 10 species	Spatial fishing returns (catchKg) for key Otago species	Raster	MPI	5	5, 6, 9	11 b (iv)

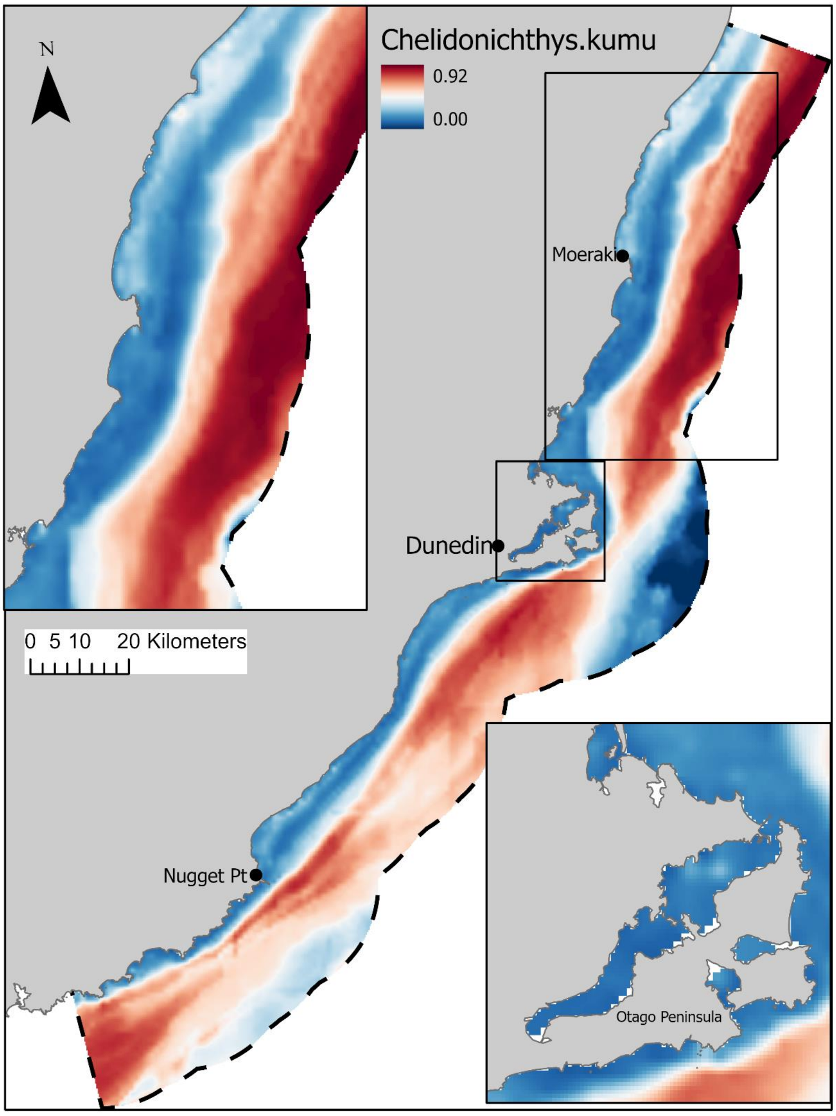

Figure 3-17: Example dataset from the demersal fish management class. Species distribution model of gurnard (*Chelidonichthys kumu*) with red indicating areas of high habitat suitability.

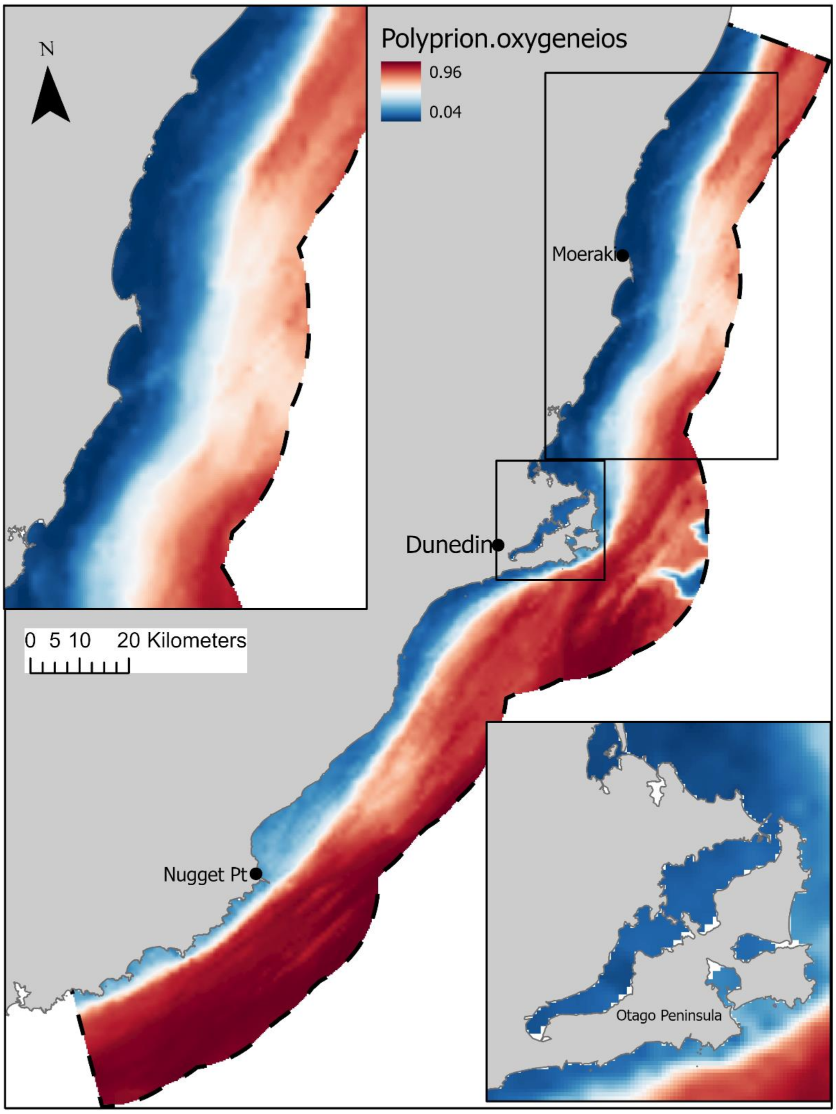

Figure 3-18: Example dataset from the demersal fish management class. Species distribution model of hāpuku (*Polyprion oxygeneios*) with red indicating areas of high habitat suitability.

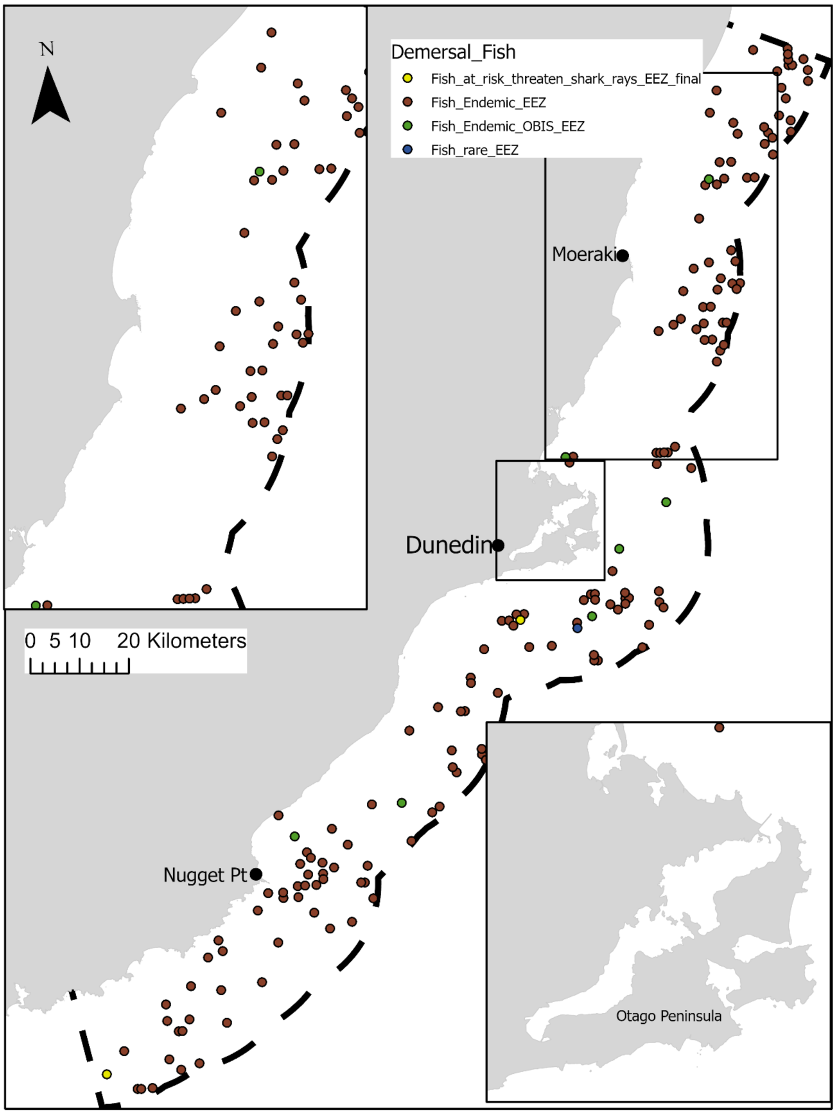

Figure 3-19: Occurrence of rare, threatened and endemic fish. Point records of all rare (blue), threatened (yellow) and endemic (green and brown – OBIS) fish, example datasets for the demersal fish management class.

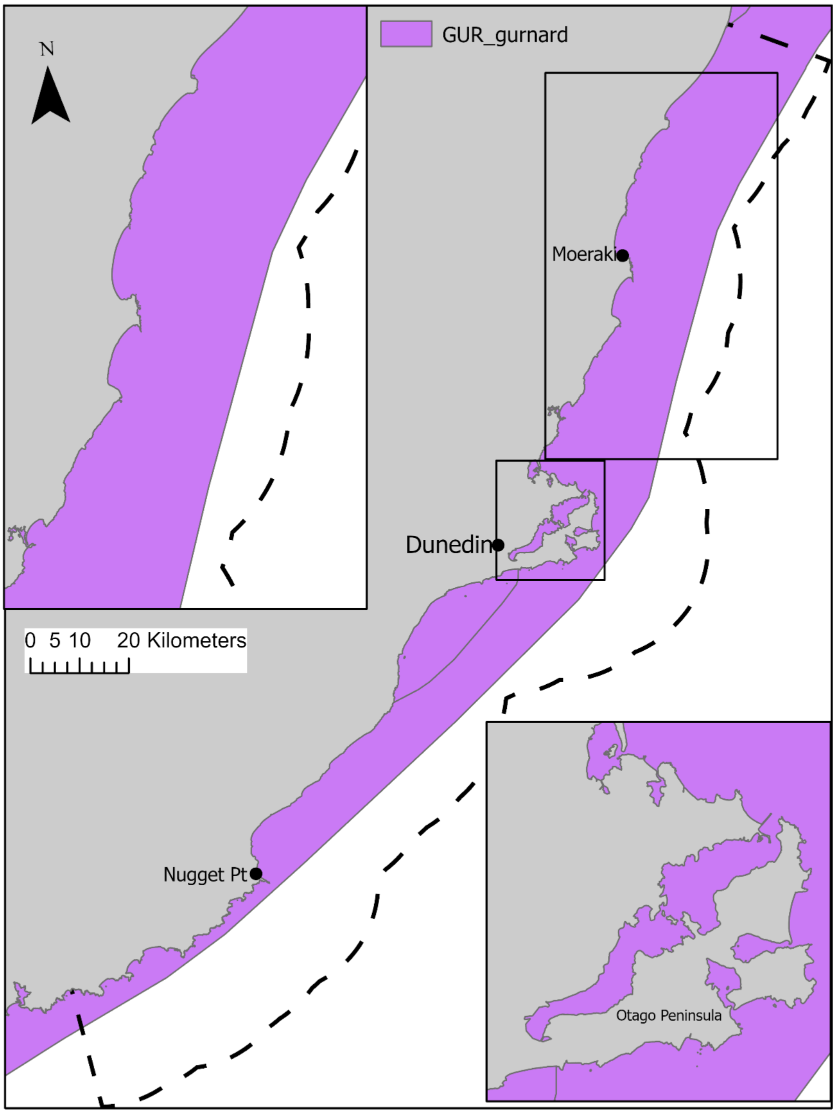

Figure 3-20: Spawning habitat for gurnard. Spawning habitat for gurnard (*Chelidonichthys kumu*), an example dataset for the demersal fish management class.

Significant areas

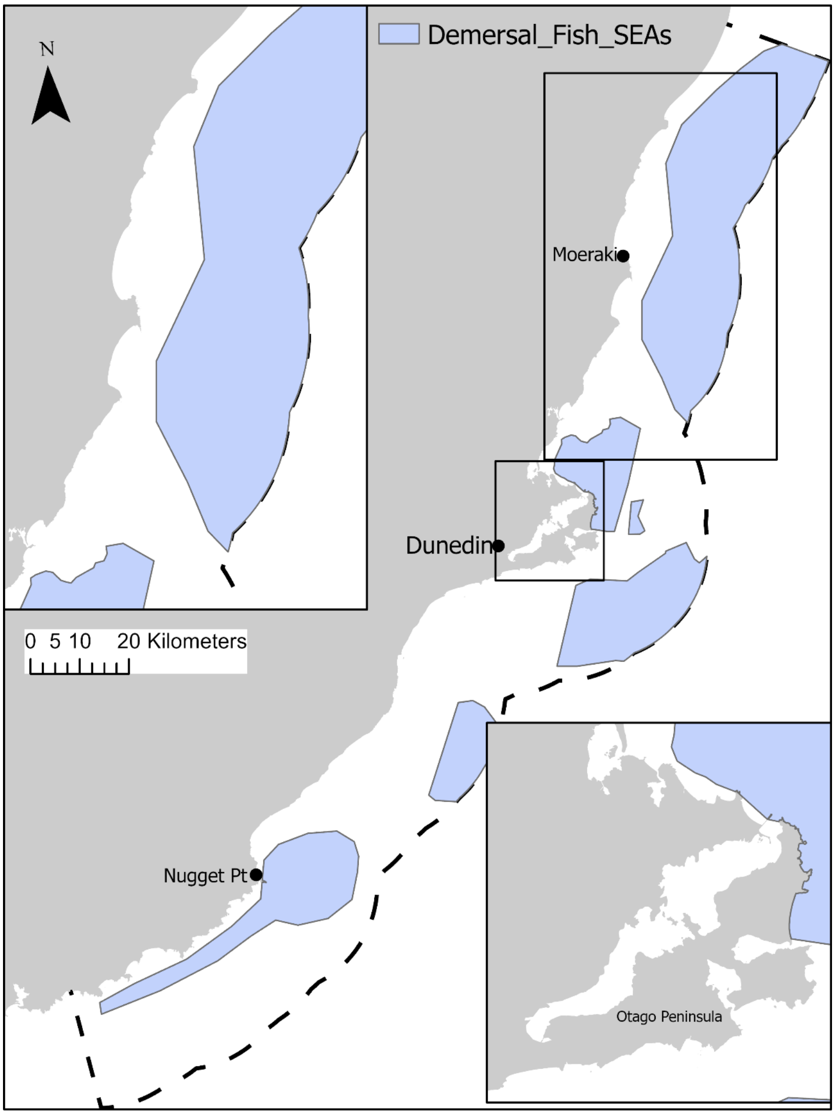

Figure 3-21: SEAs for the demersal fish management class.

Analysis of spatial data on important ecological features for demersal fish led to the identification of six SEAs throughout the Otago region. SEAs were located off the North Otago coast, the Otago Peninsula, the Catlins and offshore of Tokomairiro mouth. SEAs for this class consisted of areas of highly suitable habitat and spawning areas for numerous species, and occurrence of rare and threatened species.

3.7 Reef Fish

Datasets

There were two datasets that had useful information on the distribution of reef fish for the identification of SEAs. The national scale SDMs contained 42 expert-appraised species layers (Stephenson & Brough et al., submitted), and spatial data reporting the distribution (and value) of commercial harvesting for 13 reef fish species was provided by MPI.

Table 3-8: Datasets used for the reef fish management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
42 Reef Fish SDMs	National scale SDMs for Reef Fish. Expert appraised	Raster	KEA Database	3	6, 9	11 b (iii), b (ii), b (iv), b (v)
MPI spatial catch data - 13 species	Spatial fishing returns (catchKg) for key Otago species	Raster	MPI	5	5, 6, 9	11 b (iv)

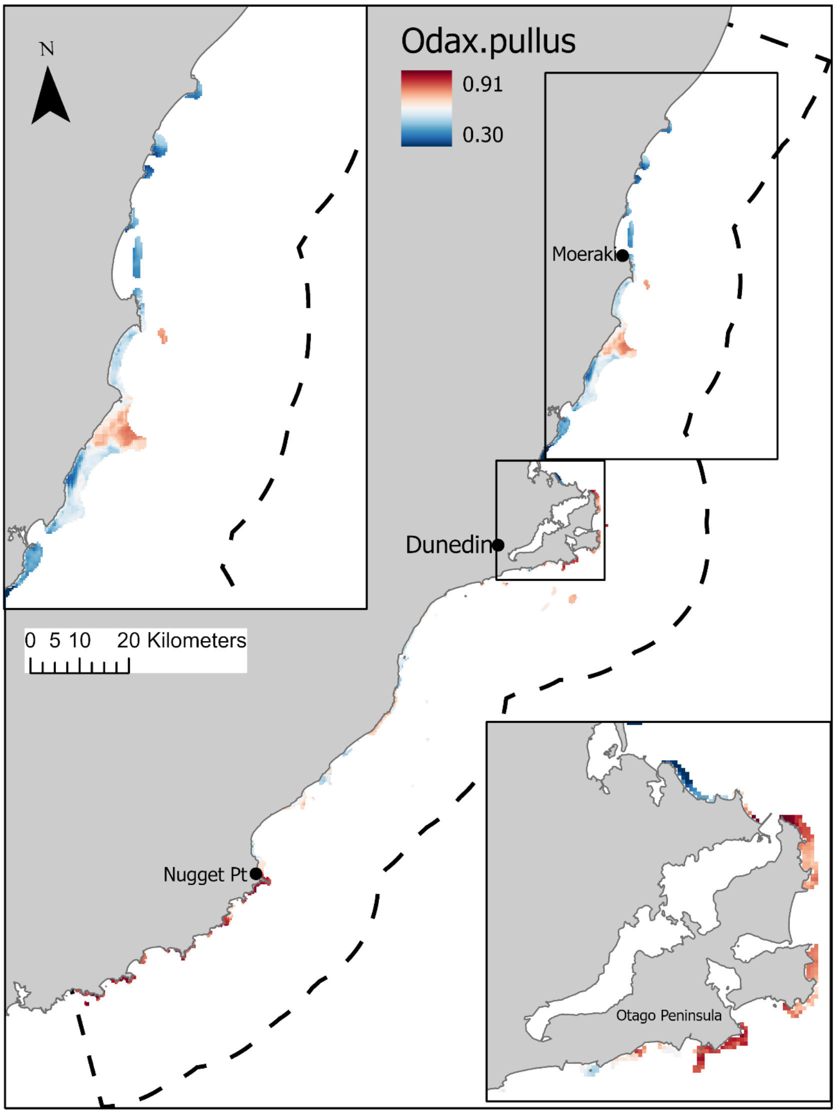

Figure 3-22: Example dataset from the reef fish management class. Species distribution model of butterfish (*Odax pullus*) with red indicating areas of high habitat suitability.

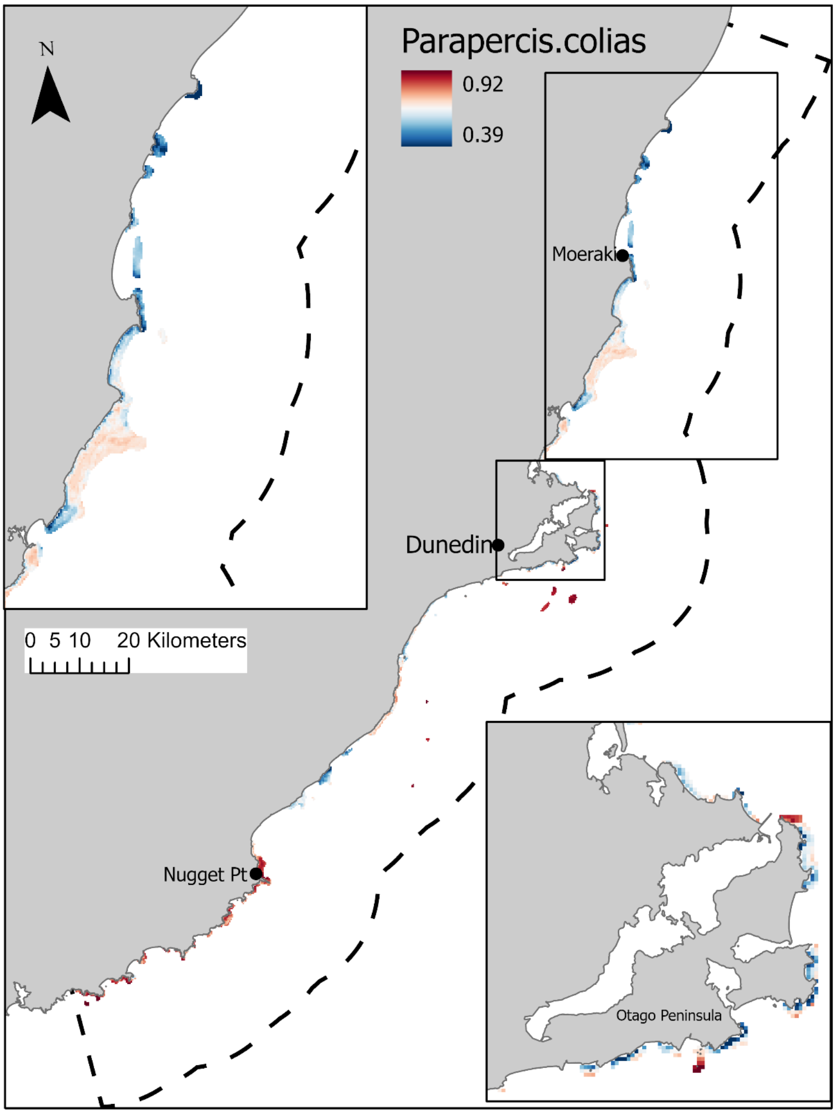

Figure 3-23: Example dataset from the reef fish management class. Species distribution model of blue cod (*Parapercis colias*) with red indicating areas of high habitat suitability.

Significant areas

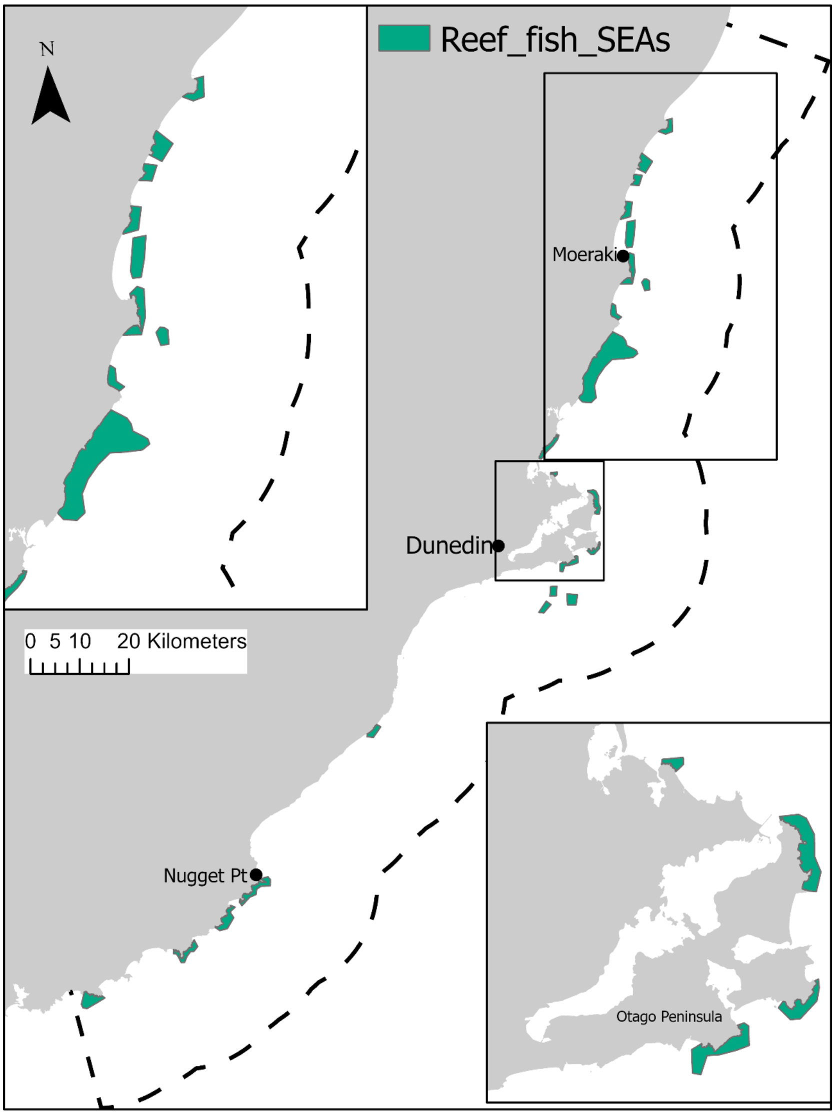

Figure 3-24: SEAs for the reef fish management class.

Analysis of spatial data on important ecological features for reef fish led to the identification of 22 SEAs throughout the Otago region. SEAs were located along most of the North Otago coast, the Otago Peninsula, the Catlins coast and at Tokomairiro mouth, with some offshore of Dunedin. SEAs for this class consisted of areas of highly suitable habitat for numerous reef fish species and occurrence of lobster and paua.

3.8 Kelp forest

Datasets

Five datasets contained useful information for the distribution of kelp forests for identifying SEAs. A national scale SDM provides a habitat suitability model of *Macrocystis pyrifera* (Stephenson & Brough et al., submitted). A further 12 national scale SDMs of canopy forming macroalgae were also used but down-weighted relative to the Macrocystis SDM. Port Otago provided a raster of mapped distribution of kelp forest in north Otago derived from satellite remote sensing. An ORC-held dataset maps the distribution of kelp forest north of the peninsula, and approximate distributions of kelp forest (*Macrocystis*) were obtained from the DOC SeaSketch database.

Table 3-9: Datasets used for the kelp forest management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Macrocystis SDM	National scale SDMs for canopy forming macroalgae. Expert appraised	Raster	KEA Database	3	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)
Other Canopy-forming macroalgae SDMs x12 (down-weighted)	National scale SDMs for canopy forming macroalgae. Expert appraised	Raster	KEA Database	3	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)
KelpBeds	ORC-held database on the distribution of kelp forest - north of peninsula	Polygon	ORC Marine Sh apefiles	5	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)
Kelpforest distribution_Port Otago	Mapped distribution of kelp forest derived from satellite remote sensing - northern Otago	Raster	Port Otago	5	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)
Biogenic_macrocystis	Approximate distribution of *Macrocystis* kelp forest from Fyffe et al. 1999	Polygon	Doc SeaSketch database	5	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)

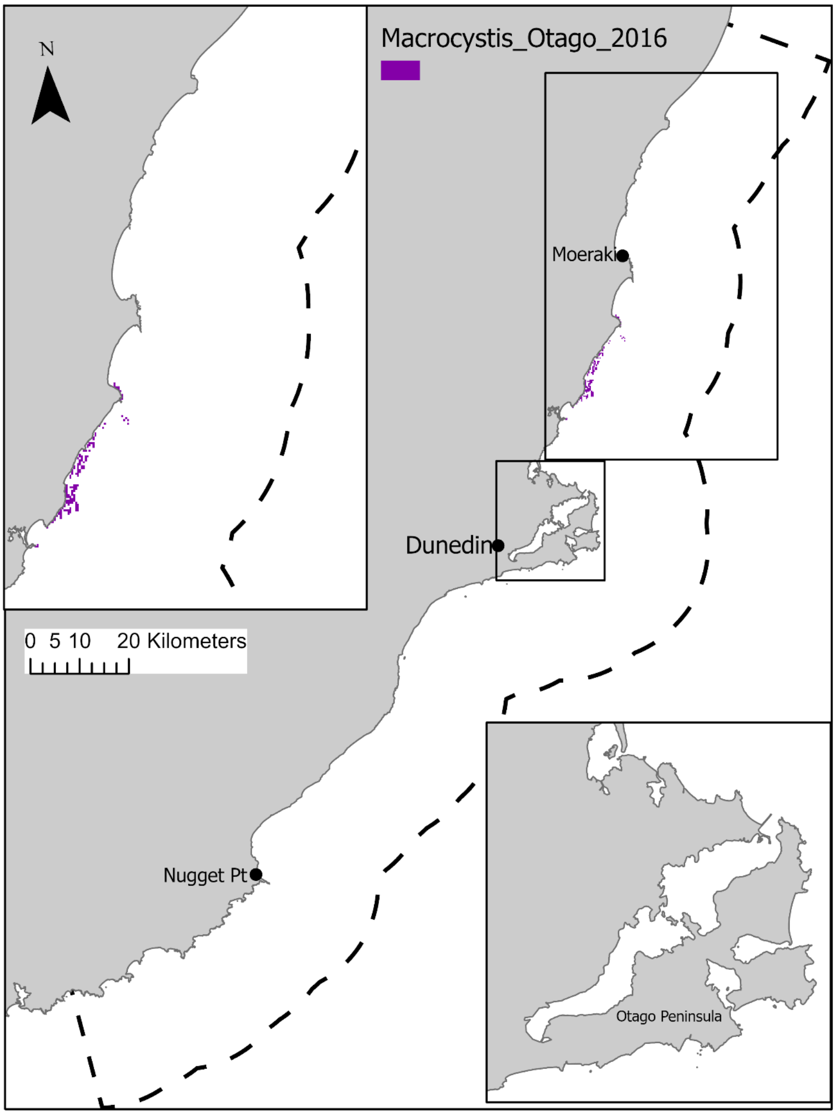

Figure 3-25: Distribution of *Macrocystis pyrifera* on the North Otago coast. Distribution of *Macrocystis pyrifera* derived from aerial mapping by Port Otago, an example dataset for the kelp forest management class.

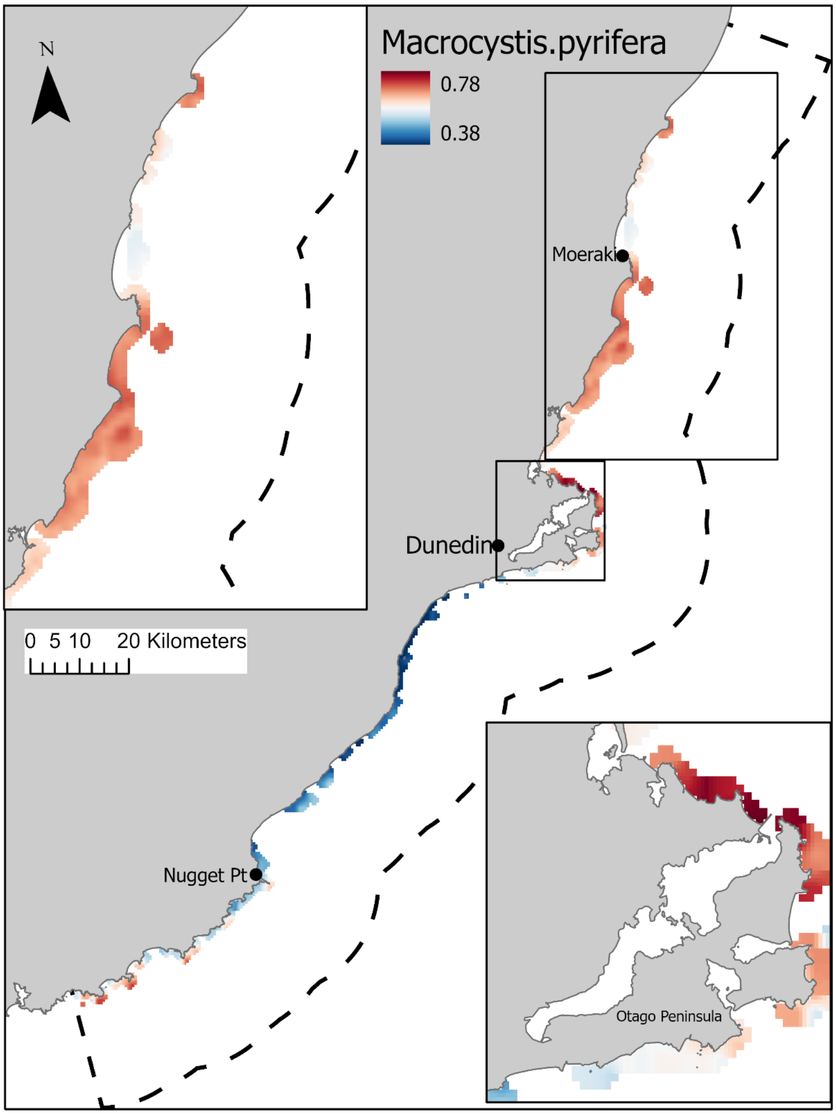

Figure 3-26: Species distribution model of *Macrocystis pyrifera*. Species distribution model of *Macrocystis pyrifera* with red indicating areas of high habitat suitability, and example dataset of the kelp forest management class.

Significant areas

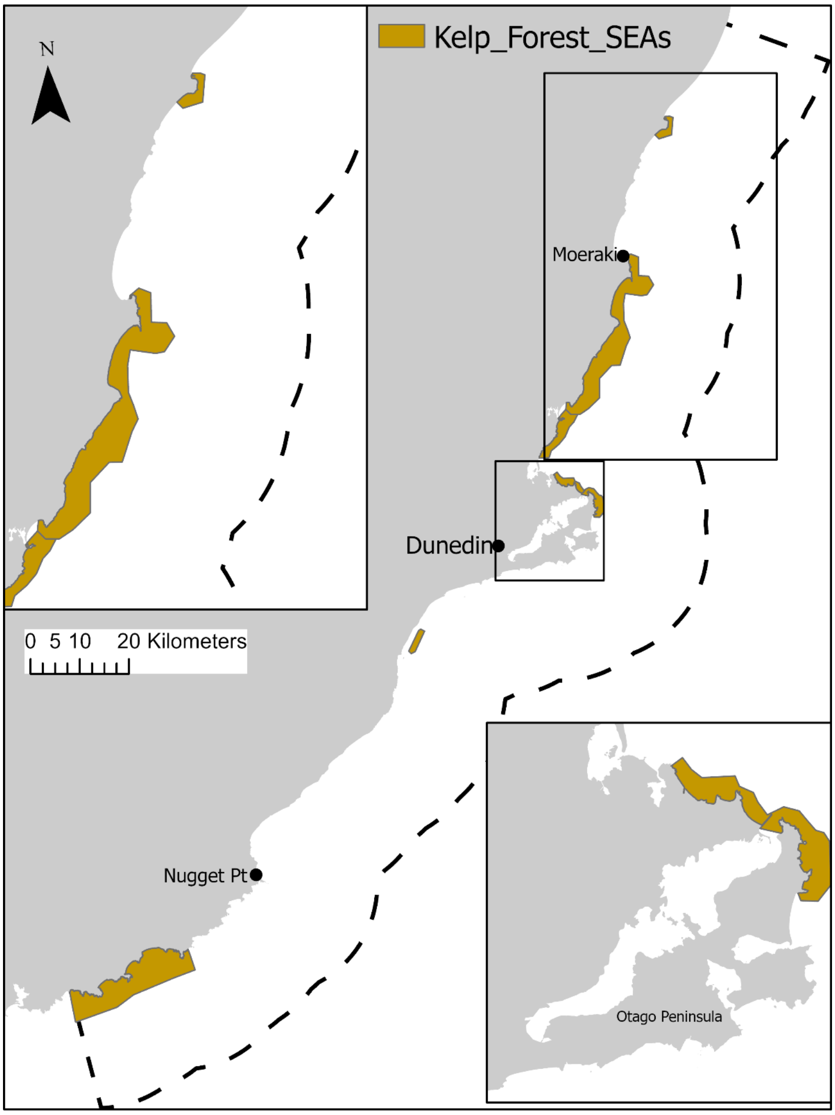

Figure 3-27: SEAs for the kelp forest management class.

Analysis of spatial data on important ecological features for kelp forests led to the identification of six SEAs throughout the Otago region. SEAs were located along the coast between Blueskin Bay and Moeraki, at the Otago Harbour mouth and surrounding coast, off Kuri Bush and along the south Catlins coast. SEAs for this class consisted of areas highly suitable habitat for and occurrence of *macrocystis* kelp forest and other canopy forming macroaglae.

3.9 Marine Flora

Datasets

There were 13 datasets that contained useful information for the identification of SEAs for the marine flora management class. The national scale SDM dataset had 41 expert appraised layers for canopy forming macro algae species (Stephenson & Brough et al., submitted). Nine datasets originated from ORC studies on mapping the locations of macroalgae (5) and seagrass (4) within estuarine environments. Another ORC-held dataset indicates the approximate distribution of seagrass in Otago estuaries that have not been formally mapped. The DOC SeaSketch database provided further approximate distribution of seagrass, and a point record dataset from Port Otago maps seagrass monitoring locations in Otago Harbour and Papanui Inlet.

Table 3-10: Datasets used for the marine flora management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
41 Marine Flora SDMs	National scale SDMs for non-canopy forming macroalgae. Expert appraised	Raster	KEA Database	3	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Blueskin2020_21_ Macroalgae	Mapped distribution of macroalgae within Blueskin Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	5, 8	11 b (i), b (ii), b (iii), b (vi)
Blueskin2020_21_ Seagrass	Mapped distribution of seagrass within Blueskin Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Catlins2016_ Macroalgae	Mapped distribution of macroalgae within Catlins Estuary	Polygon	ORC Otago GIS map packages, S alt Ecology	5	5, 8	11 b (i), b (ii), b (iii), b (vi)
Catlins2016_Seagrass	Mapped distribution of seagrass within Catlins Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Seagrass_ORCEstuary	Approximate seagrass distribution in Otago estuaries that have not been formally mapped	Polygon	ORC Marine Shapefiles	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Shag2016_Macroalgae	Mapped distribution of macroalgae within Shag Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	5, 8	11 b (i), b (ii), b (iii), b (vi)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Tokomairiro2018_ Macroalgae	Mapped distribution of macroalgae within Tokomairiro Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	5, 8	11 b (i), b (ii), b (iii), b (vi)
Tokomairiro2018_ Seagrass	Mapped distribution of seagrass within Tokomairiro Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Waikouaiti2017_ Macroalgae	Mapped distribution of macroalgae within Waikouaiti Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	5, 8	11 b (i), b (ii), b (iii), b (vi)
Waikouaiti2017_ Seagrass	Mapped distribution of seagrass within Waikouaiti Estuary	Polygon	ORC Otago GIS map packages, Salt Ecology	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
E3 Scientific seagrass dataset	Seagrass monitoring locations Otago Harbour and Papanui Inlet	Point	Port Otago/E3	5	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)
Seagrass_Jul2015	Approximate distribution of seagrass in Otago Harbour	Polygon	Doc SeaSketch database	3	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)

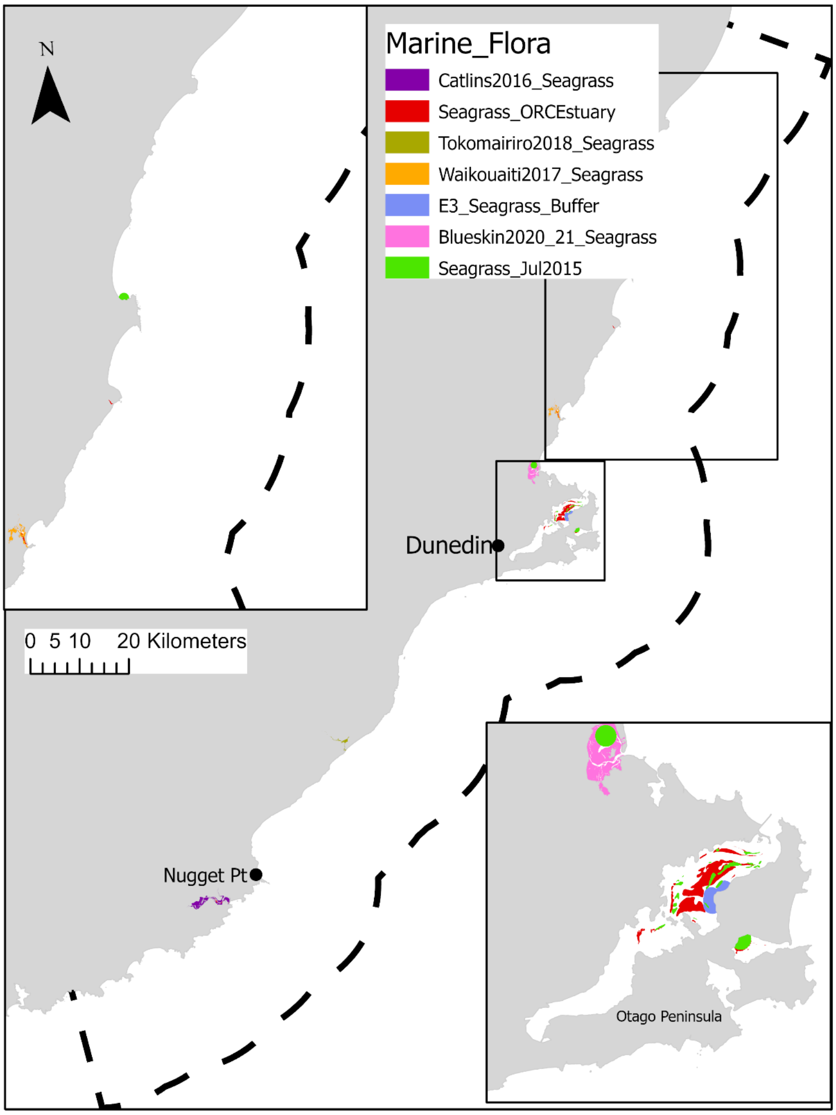

Figure 3-28: Occurrence of seagrass. Seagrass distribution mapped by the Otago regional council, DOC and Port Otago, example datasets for the marine flora management class.

Significant areas

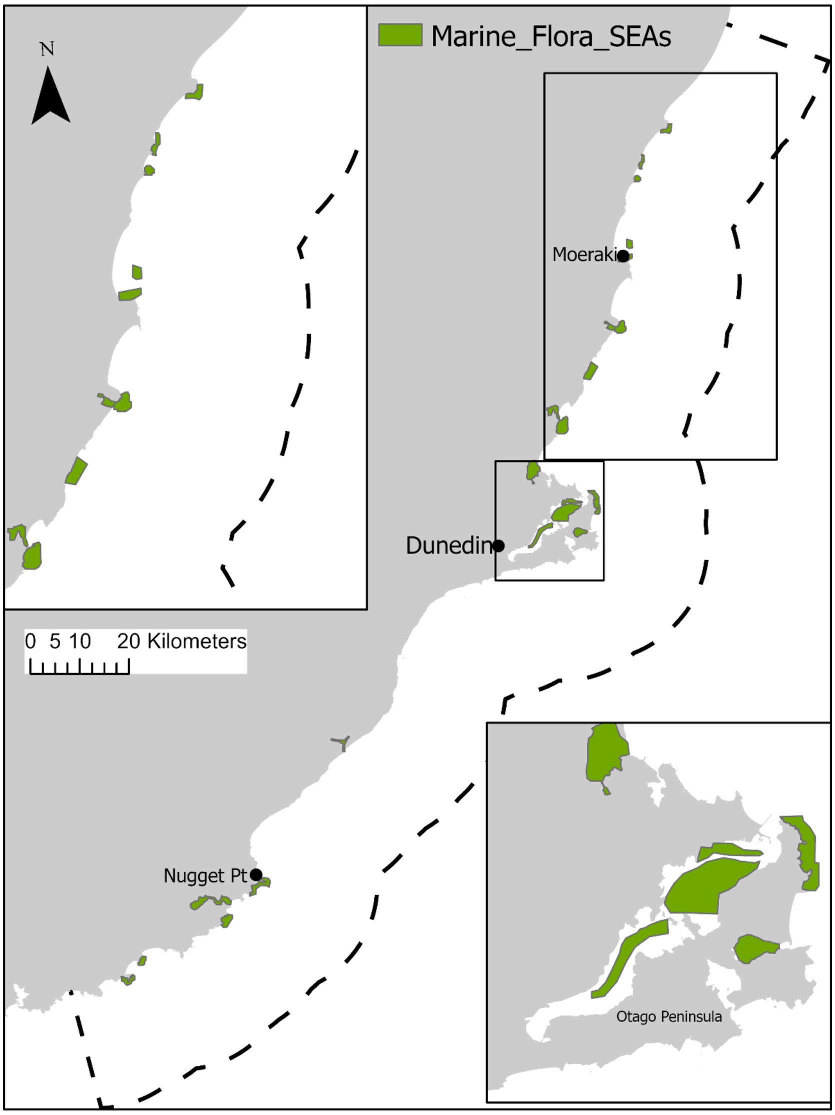

Figure 3-29: SEAs for the marine flora management class.

Analysis of spatial data on important ecological features for marine flora led to the identification of 22 SEAs throughout the Otago region. SEAs were located along the North Otago coast, Blueskin Bay, Otago Harbour and Peninsula, Tokomairiro and the Catlins coast. SEAs for this class consisted of areas of occurrence of seagrass and macroalgae.

3.10 Marine Mammal – Ocean

Datasets

There were eight datasets with useful information on the at-sea distribution of marine mammals for identifying SEAs. The national scale SDM dataset contained 13 expert-appraised cetacean species layers (Stephenson et al. 2020). Point records of Hector's dolphin sightings were provided by Otago university and Monarch wildlife tours (Turek et al. 2013). Approximate foraging range for fur seal and sealion were obtained from the KEA database, with mapped foraging range of female sea lions from Otago peninsula from the DOC SeaSketch database (Auge et al. 2009). Another point record dataset from Otago University maps cetacean sightings during canyon surveys.

Table 3-11: Datasets used for the oceanic marine mammals management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Cetacean SDMs (13)	National scale SDMs for cetaceans - selected species based on occurrence in Otago	Raster	KEA Database	3	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),
HWilliams_Nemo_ HectorsDolphin_ Sightings	Sightings dataset on Hector's dolphin from Otago University	Point	Hannah Williams, Otago University	4	2, 3, 4	11 a (i), a (ii), a (iv), a (vi), b (iv),
MARI429_Hectors Dolphin_Sightings	Sightings dataset on Hector's dolphin from Otago University	Point	Otago University	4	2, 3, 4	11 a (i), a (ii), a (iv), a (vi), b (iv),
Monarch_Hectors Dolphin_sightings	Sightings dataset on Hector's dolphin from Monarch Wildlife tours via Otago University	Point	Monarch Wildlife Crui ses via Otago Unive rsity	3	2, 3, 4	11 a (i), a (ii), a (iv), a (vi), b (iv),
NZ_FurSeal_Foraging Range	Approximate foraging range for fur seals	Polygon	KEA Database	2	3, 4	11 a (v), a (vi)
NZ_SeaLion_Foraging Range	Approximate foraging range for NZ sea lions	Polygon	KEA Database	2	2, 3, 4	11 a (i), a (ii), a (iv), a (vi), b (iv),

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
FemaleSeaLionForaging_2008to10_27_05_2015_FINAL	Mapped foraging range of female sea lions from Otago Peninsula (Auge et al. 2009)	Polygon	DOC SeaSketch database	5	2, 3, 4	11 a (i), a (ii), a (iv), a (vi), b (iv),
ALLCETACEANS 20162019	Sightings dataset on all cetaceans from surveys of the Otago Canyons	Point	Will Rayment, Otago University	4	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v)

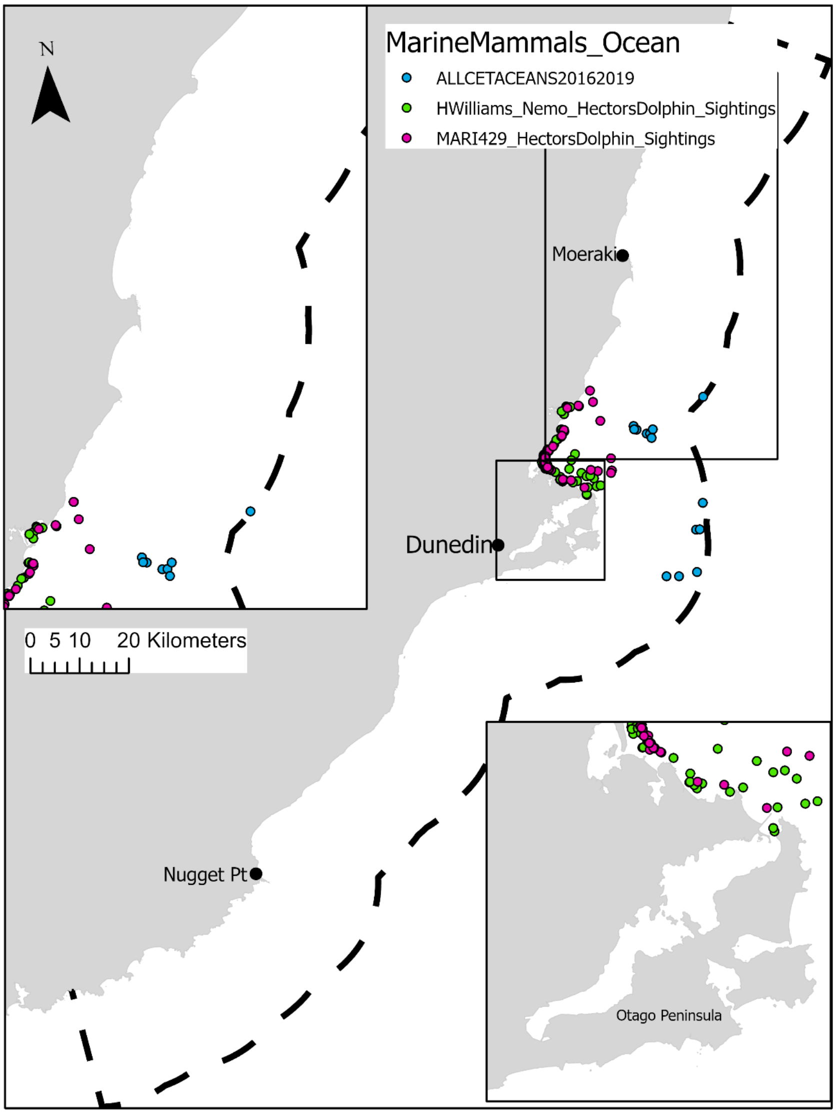

Figure 3-30: Point records of cetacean sightings. Sightings of various cetaceans on canyon surveys (blue) and Hector's dolphin by Otago university (green and pink), example datasets for the marine mammals - ocean management class.

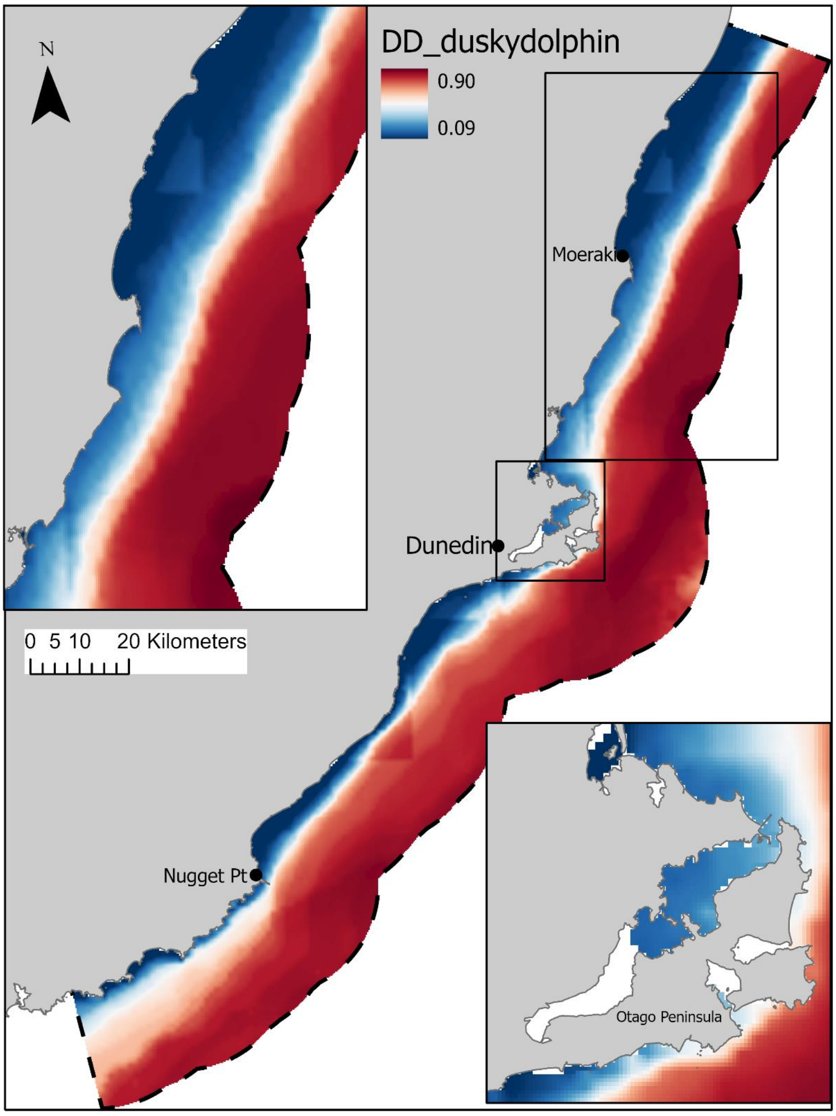

Figure 3-31: Example dataset of the marine mammal - ocean management class. Species distribution model of dusky dolphin (*Lagenorhynchus obscurus*) with red indicating areas of high habitat suitability.

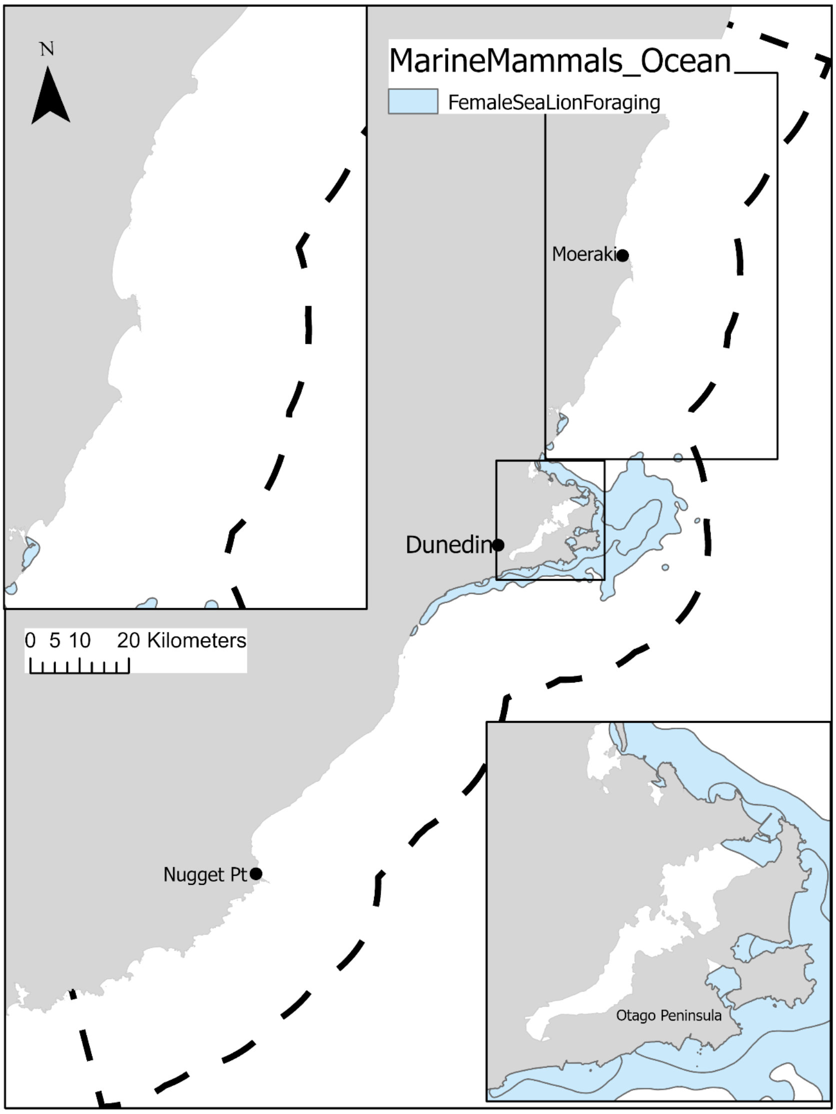

Figure 3-32: Female sealion foraging range. Polygons of female sealion foraging range, an example dataset for the marine mammals - ocean management class.

Significant areas

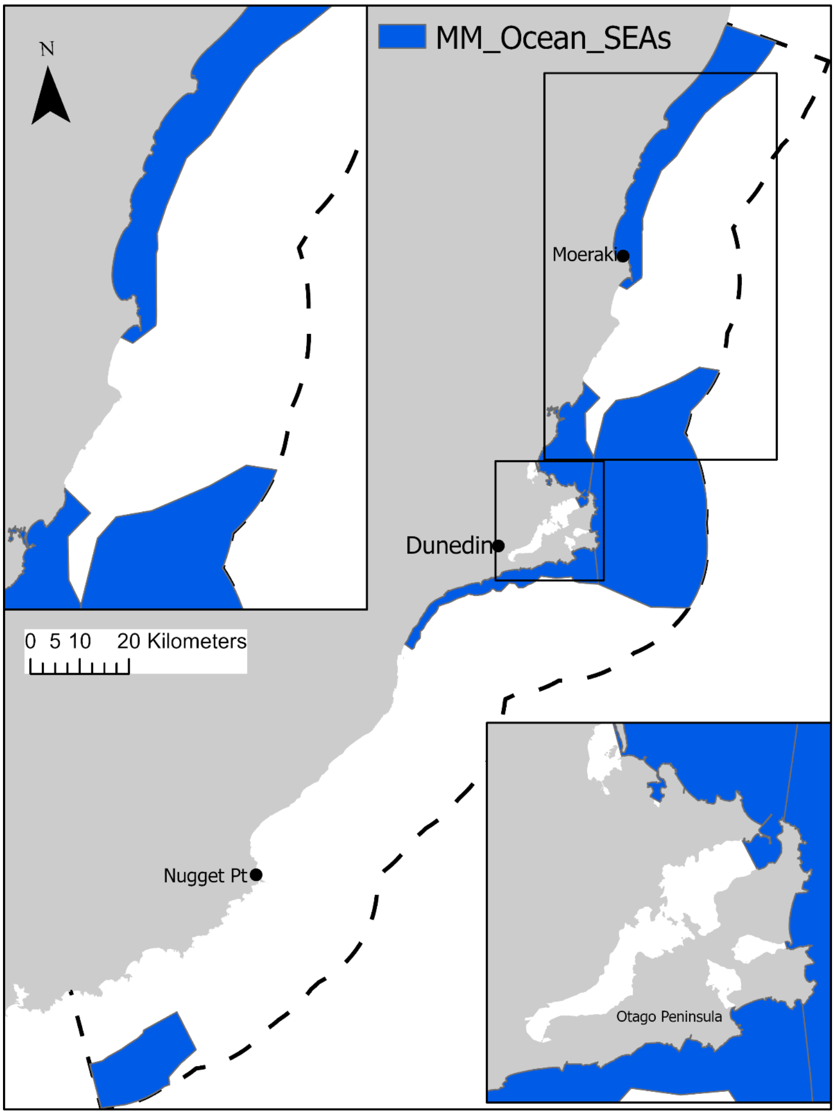

Figure 3-33: SEAs for the marine mammals – ocean management class.

Analysis of spatial data on important ecological features for marine mammals at sea led to the identification of five SEAs throughout the Otago region. SEAs were located along the coastline north of Moeraki, off the coast of Dunedin to the head of the Otago submarine canyons and offshore south of the Catlins. SEAs for this class consisted of areas of particular importance for sea lions and fur seals, highly suitable habitat for numerous cetacean species and occurrence of Hector's Dolphin.

3.11 Marine Mammal – Terrestrial

Datasets

There were five datasets with useful information for the identification of SEAs for the terrestrial marine mammal management class. From the KEA database we have national scale layers on the distribution of sea lion and fur seal breeding colonies as well as an extract from the Naturally Uncommon Ecosystems database maintained by Landcare Research on marine mammal haulouts (Stephenson et al. 2018; Lundquist et al. 2020). ORC also holds a database on fur seal colonies and haulouts, and the NZ Sea Lion Trust provided point records of sealion sightings from beach surveys.

Table 3-12: Datasets used for the terrestrial marine mammal management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
New_Zealand__Hookers__Sealion___Breeding_Colonies_Distribution	National scale layer on the distribution of sea lion colonies	Polygon	KEA Database	3	2, 3, 4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv),
New_Zealand_Fur_Seal___Breeding_Colonies_Distribution	National scale layer on the distribution of fur seal colonies	Polygon	KEA Database	3	3, 4	11 a (vi), b (ii)
NZSLT database sea-lions-sightings April 2022	Database of sightings from beach surveys by NZ sea lion trust	Point	NZLT	5	2, 3, 4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv),
ORC_Fur_seal	Database on fur seal colonies/haulouts maintained by ORC	Polygon	ORC Marine Shapefiles	3	3, 4	11 a (vi), b (ii)
GEOPHYSICAL_Naturally UncommonEcosystems - Marine mammal haulouts	Extract from Naturally Uncommon Ecosystems database maintained by Landcare Research on marine mammal haulouts	Polygon	KEA Database	3	3, 4	11 a (vi), b (ii)

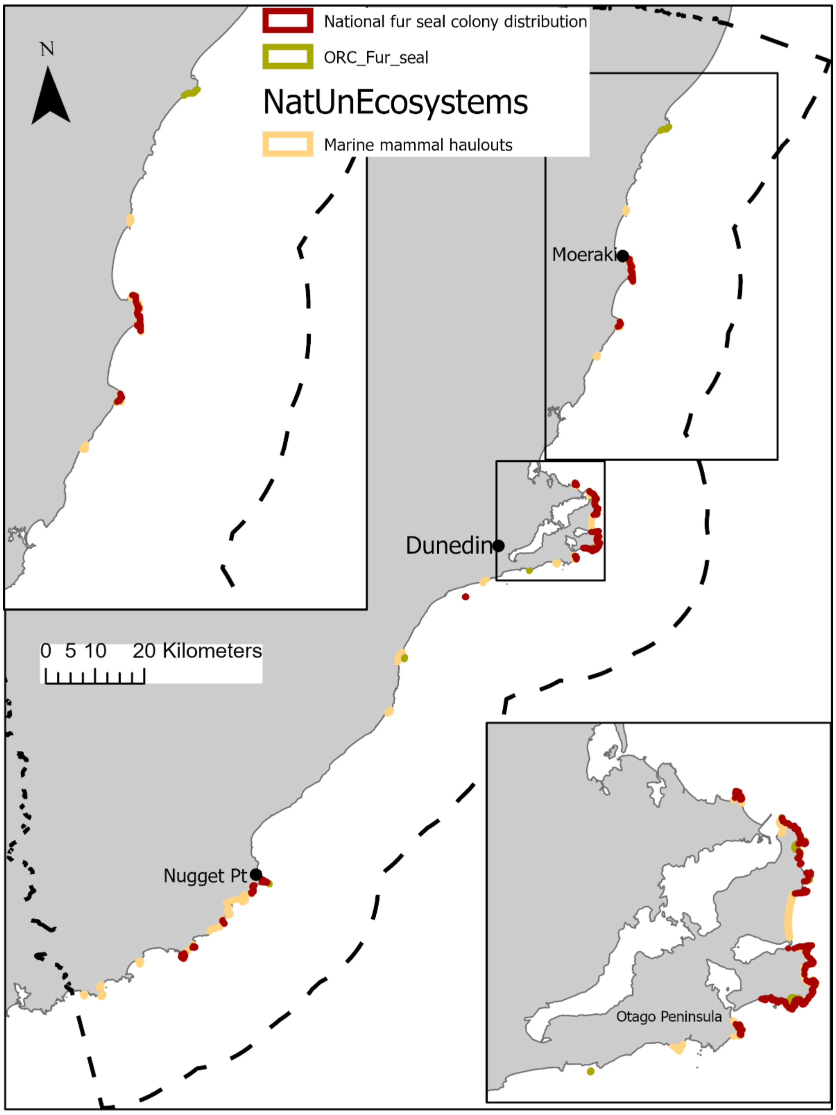

Figure 3-34: Fur seal colonies and haulouts. Occurrence of fur seal and sea lions from the naturally uncommon ecosystems database, locations of fur seal colonies from a national database and an ORC maintained database, example datasets for the terrestrial marine mammal management class. The outline of the features has been enlarged to help visualise smaller polygons.

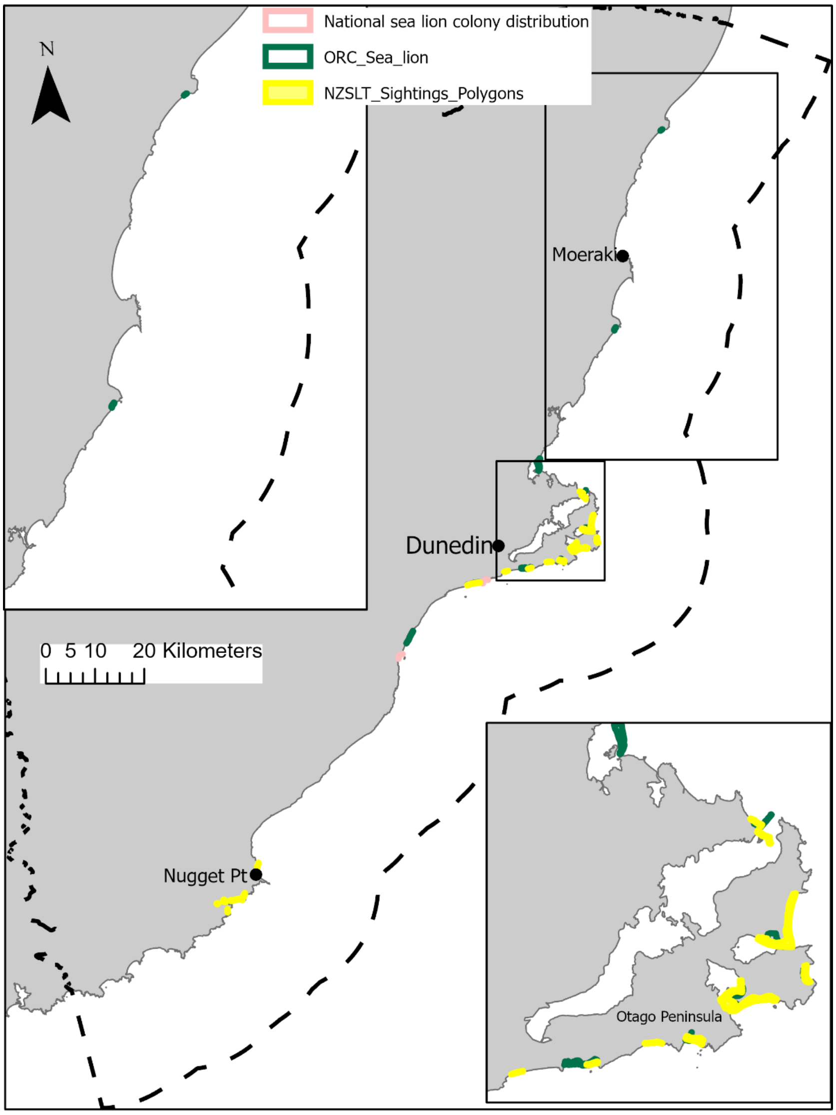

Figure 3-35: NZ sealion distribution. Locations of NZ sea lion haulouts/colonies from a national database and an ORC maintained database, and sightings from the NZ sea lion trust as example datasets for the terrestrial marine mammal management class. The outline of the features has been enlarged to help visualise smaller polygons.

Significant areas

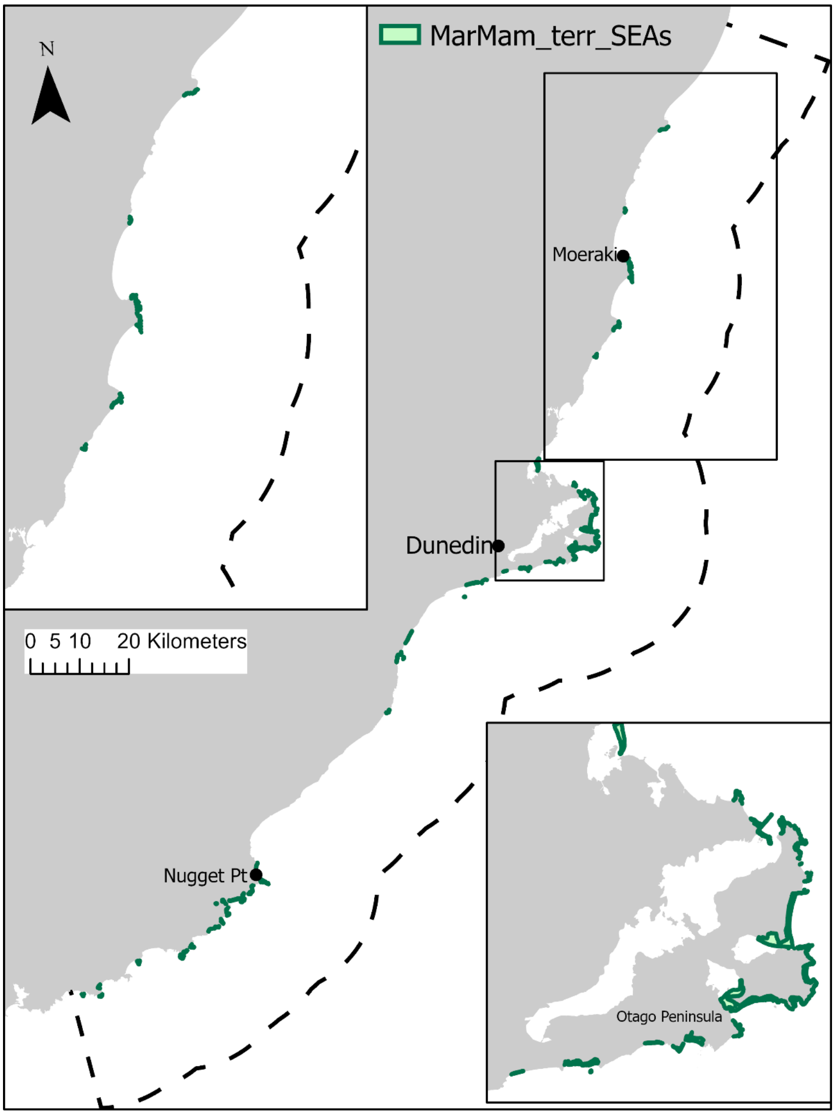

Figure 3-36: SEAs for the terrestrial marine mammal management class. Locations of SEAs for the terrestrial marine mammal management class. The outline of each feature has been enlarged to aid in the viewing of smaller features.

Spatial data on important ecological features for terrestrial marine mammals led to the identification of two SEAs, one for fur seals and one for sea lions, throughout the Otago region. Due to the very high numbers of individual colonies/haulouts for each species, individual SEAs were merged into one for each species for ease of reporting. Polygons can be separated and individually named by ORC if required. SEAs were located all along the Otago coast with large portions of Otago Peninsula, the Catlins and Moeraki considered important. SEAs for this class consisted of breeding colonies and haulouts for fur seals and sea lions.

3.12 Naturally uncommon ecosystems

Datasets

There is one dataset that provides useful information on the distribution of naturally uncommon ecosystems for identifying SEAs for this management class. This dataset is maintained by Landcare Research and summarise in the KEA database (Stephenson et al. 2018; Lundquist et al. 2020) and reports the occurrence and mapped extent (where undertaken) of rare coastal habitats - sand dunes, seabird burrowed soils, guano deposits, coastal cliffs and shingle beaches.

Table 3-13: Dataset used for the naturally uncommon ecosystems management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
GEOPHYSICAL_ Naturally Uncommon Ecosystems	Naturally Uncommon Ecosystems database maintained by Landcare Research - reports the occurrence and mapped extent of rare coastal habitats - sand dunes, seabird burrowed soils, guano deposits, coastal cliffs, shingle beaches	Polygon	KEA Database	3	2	11 a (iv), b (iii)

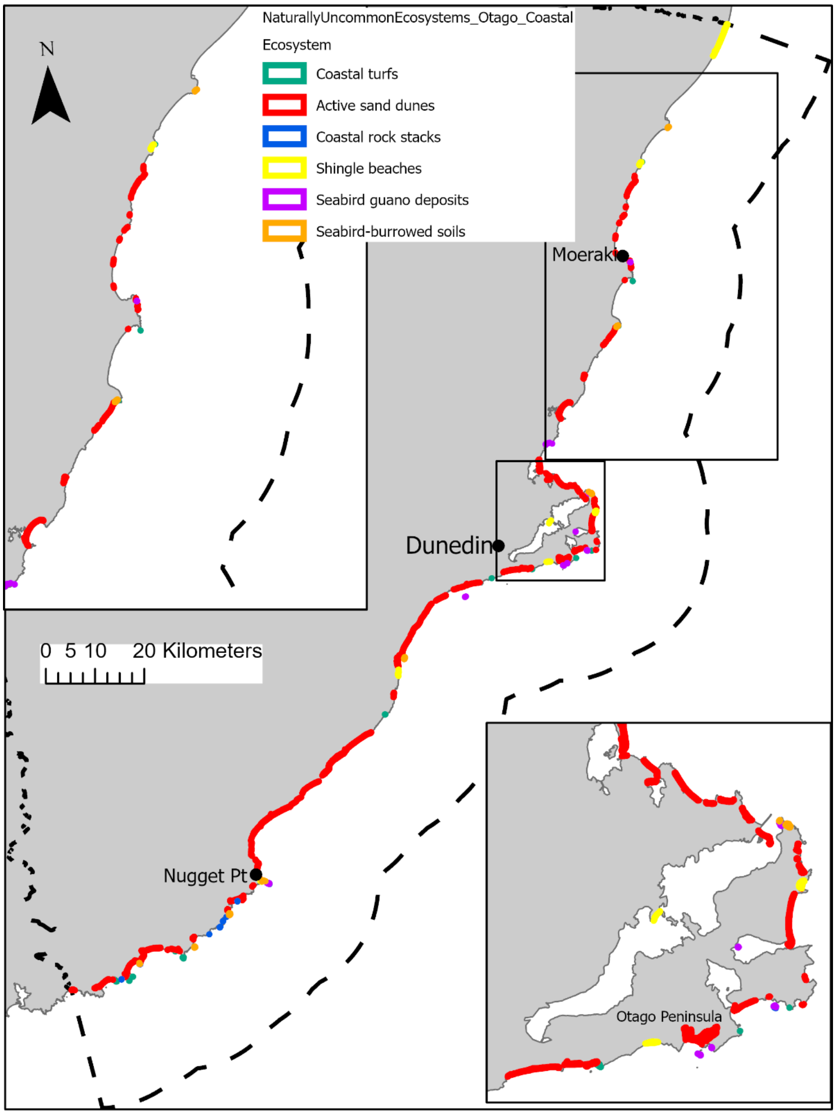

Figure 3-37: Locations of naturally uncommon ecosystems. Locations of the six different ecosystem types of naturally uncommon ecosystems, the dataset used for this management class. The outline of the features has been enlarged to help visualise smaller polygons.

Significant areas

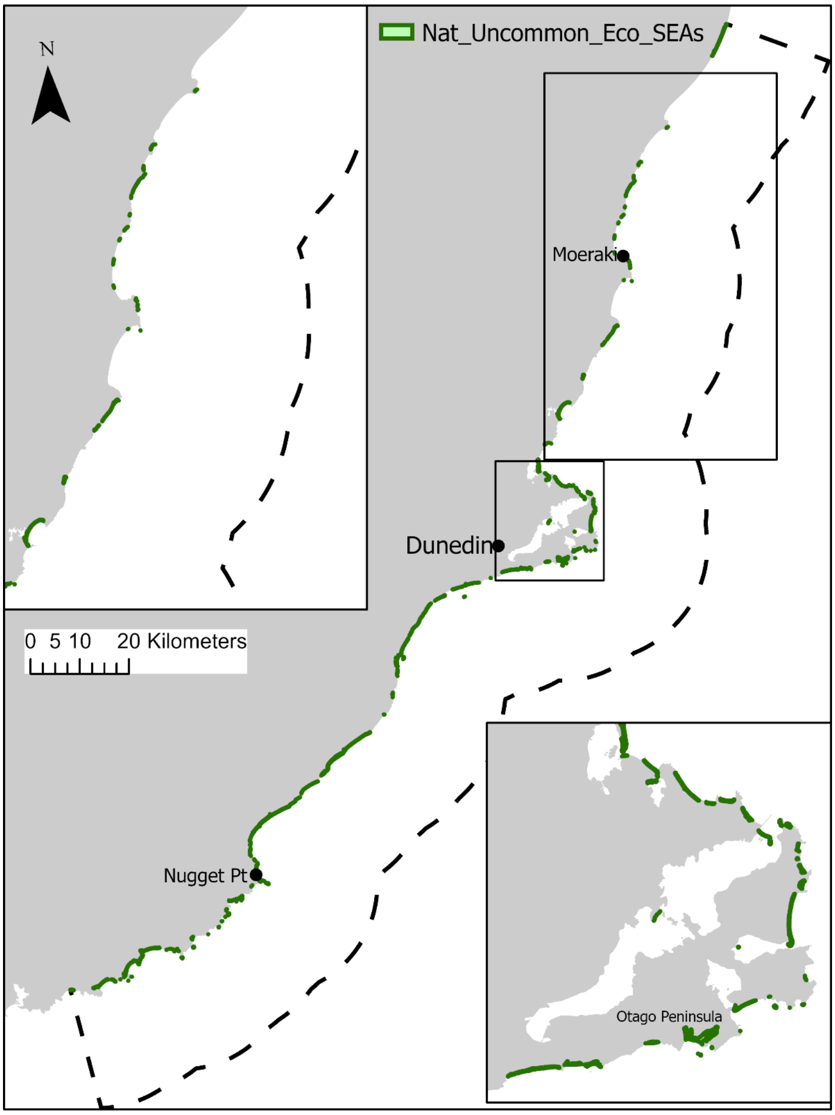

Figure 3-38: SEAs for the naturally uncommon ecosystems management class. Locations of SEAs for naturally uncommon ecosystems management class. The outline of each feature has been enlarged to aid in the viewing of smaller features.

Spatial data on ecological features for naturally uncommon ecosystems led to the identification of six SEAs throughout the Otago region. As for the terrestrial marine mammal management class, due to the high number of individual important areas, the SEAs were defined by all important areas belonging to a specific ecosystem category. SEAs were located along most of the Otago coast. SEAs for this class consisted of areas containing active sand dunes, coastal rock stacks, coastal turfs, shingle beaches, seabird guano deposits and seabird-burrowed soils.

3.13 Pelagic productivity

Datasets

There was one dataset that was used to identify SEAs for the pelagic productivity management class. The horizontal gradient in sea surface temperature is derived from remote sensing of sea surface temperature by satellite observation and reports average conditions over 20-years, providing a useful indication of persistent frontal features. The layer was developed as part of the seafloor community classification (Stephenson et al. 2022).

Table 3-14: Dataset used for the pelagic productivity management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
SSTGrad	The horizontal gradient in sea surface temperature derived from remote sensing of temperature by satellite observation, 20-year average conditions. Useful indication of persistent frontal features	Raster	KEA Database	3	2, 5, 8	11 a (v), b (vi)

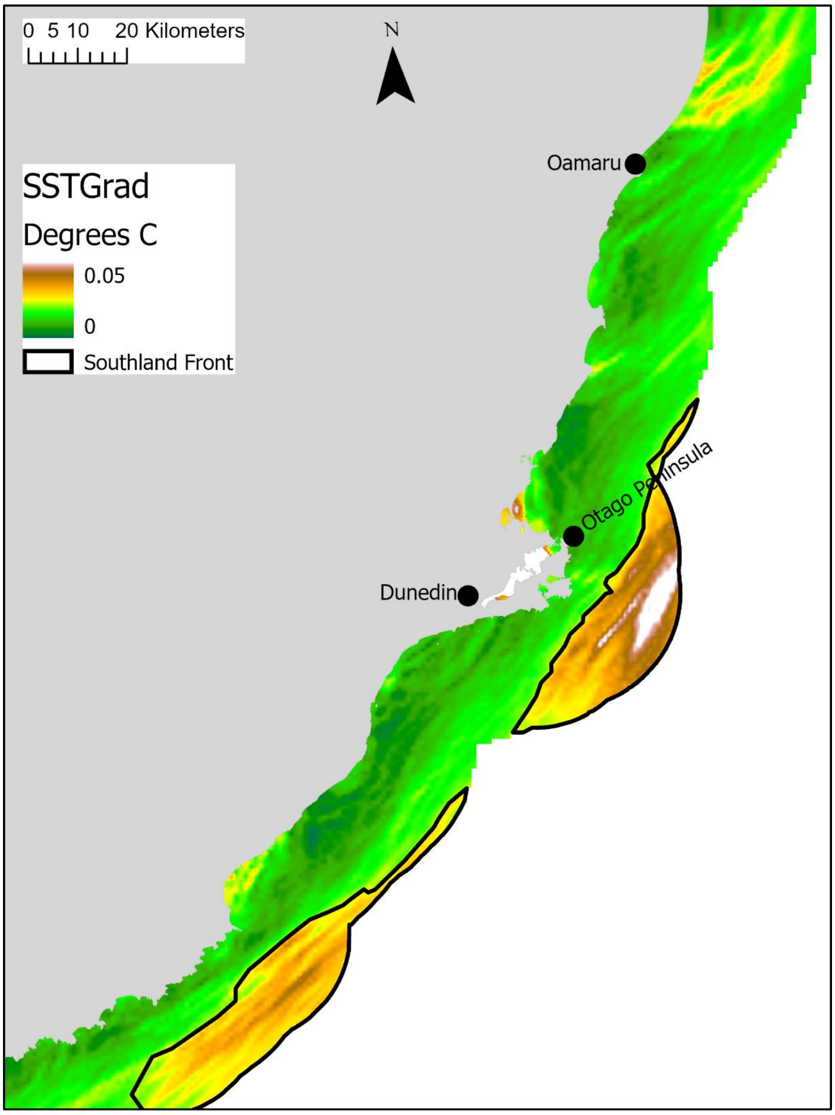

Figure 3-39: Approximate location of the Southland front. Sea surface temperature gradient, indicating approximate location of the Southland front, the dataset used for the pelagic productivity management class.

Significant areas

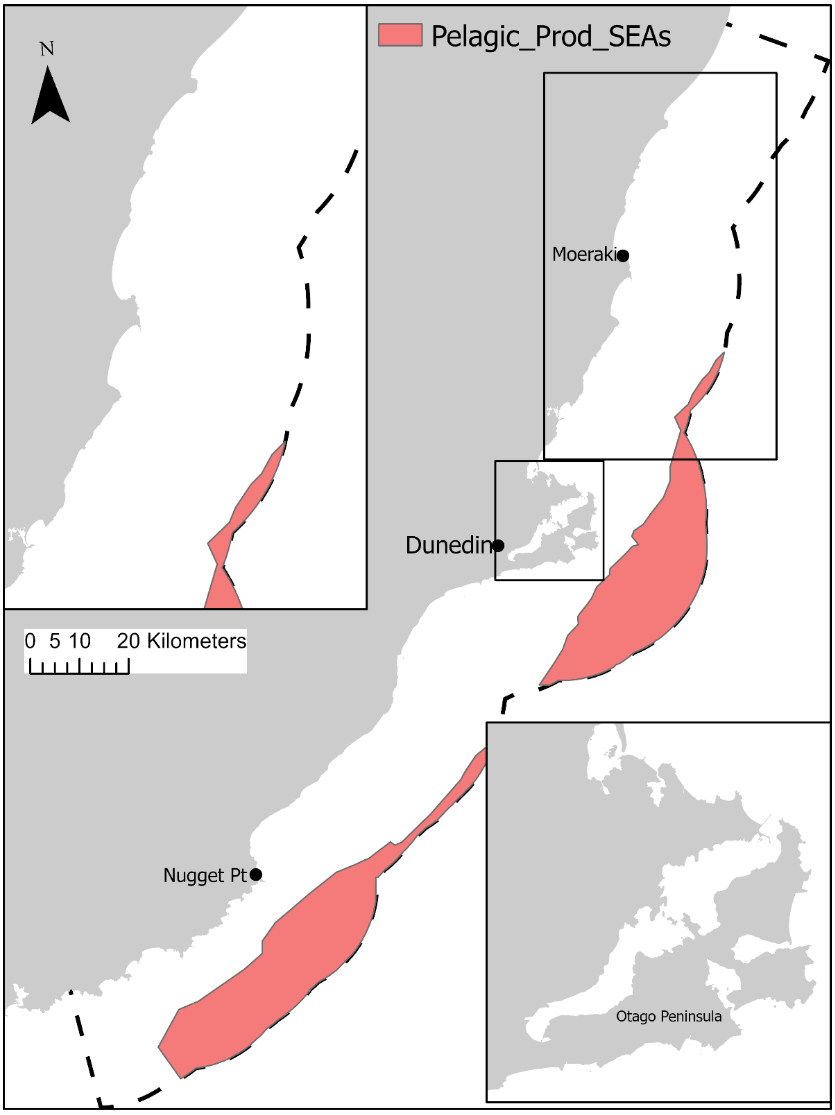

Figure 3-40: SEAs for the pelagic productivity management class.

Spatial data on important ecological features for pelagic productivity led to the identification of one SEA, that ranged offshore of the Catlins area through to Shag Point. The SEA for this class consists of the area containing persistent the frontal features of the Southland current.

3.14 Shore/seabirds – marine

Datasets

Ten datasets had useful information on the distribution of marine seabirds for identifying SEAs. The University of Otago provided point records of 12 GPS tracked northern royal albatross from the colony at Taiaroa head (Sugishita et al. 2015). An ORC-held dataset contains important bird areas, and iNaturalist and OBIS (Lundquist et al., 2020) provide point records of seabird sightings, with sightings around the Otago Canyons provided by the University of Otago. The national wader count survey by Birds NZ provided data on relative diversity and abundance for the survey locations in the Otago region, as well as an Otago Harbour survey of shorebirds. The foraging range of little blue penguin based on tracking data was obtained from the DOC SeaSketch database (Agnew et al. 2013) and a dataset of Hoiho tracking at sea was also provided by DOC (Mattern and Ellenberg 2018).

Table 3-15: Datasets used for the marine seabirds management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Tracked Albatross data, 12 individuals	Point locations from GPS tracked northern royal albatross tracked from the Taiaroa Head colony	Point	Junichi Sugishita, Otago University	4	3, 4	11 a (ii), a (iv), a (vi), b (ii), b (v)
Coastal_seabirds_ marine	Polygon dataset from ORC database on broad areas important for seabirds; hoiho and including Forest and Bird IBAs.	Polygon	ORC Marine Shapefiles	2	3, 4	11 a (iv), 11 a (vi), b (v)
iNaturalist_Birds	Database of citizen science, opportunistic seabird observations from iNaturalist	Point	KEA Database	3	2, 3, 4, 6	11 a (iv), 11 a (vi), b (v)
OBIS_Birds_4_2020_AE A_Clipped_to_EEZ	Dataset on seabird observations from diverse survey platforms stored in the OBIS database	Point	KEA Database	3	2,3,4, 6	11 a (iv), 11 a (vi), b (v)
Birds NZ Otago Harbour Survey	Survey observations of shorebirds from numerous sites within Otago Harbour - pooling data spanning several decades	Polygon	OSNZ	5	3, 4	11 a(i), a (ii), a (iv), a (vi), b (ii), b (v)
National Wader Count - abundance	Extract of survey data reporting relative abundance from the national wader count for the Otago region from Birds NZ.	Polygon	OSNZ	5	3,4	11 a(i), a (ii), a (iv), a (vi), b (ii), b (v)
National Wader Count - diversity	Extract of survey data reporting relative diversity from the national wader count for the Otago region from Birds NZ.	Polygon	Birds NZ	5	3, 4	11 a(i), a (ii), a (iv), a (vi), b (ii), b (v)

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Otago_BluePenguinRange_17_10_14_FINAL	Foraging range of blue penguins from the Oamaru colony sourced from tracking data.	Polygon	Doc SeaSketch database	4	3	11 a (i), a (vi), b (ii),
Seabirdsightings2019_01_canyons_Kde	Dataset of seabird observations from systematic surveys of the Otago canyons area.	Point	Will Rayment, Otago University	4	2,3,4,6	11 a(i), a (ii), a (iv), a (vi), b (ii), b (v)
DOC_HoihoTracking	Dataset of Hoiho distribution at sea from tracking data - DOC/CSP funded.	Point	DOC	4	2,3,4	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)

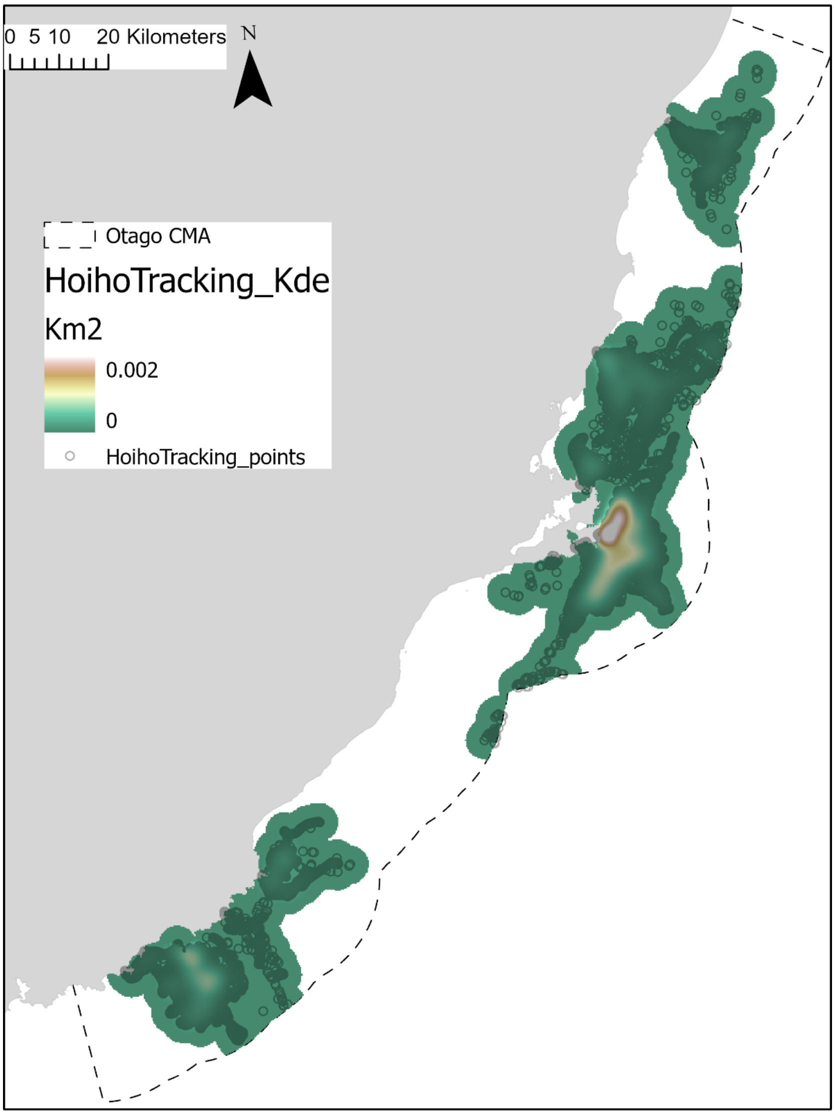

Figure 3-41: Hoiho tracking data with kernel density. Point layer of hoiho tracking data (hollow dots) overlaid upon kernel density raster (gradient with red indicating high density), an example dataset for the marine seabirds management class.

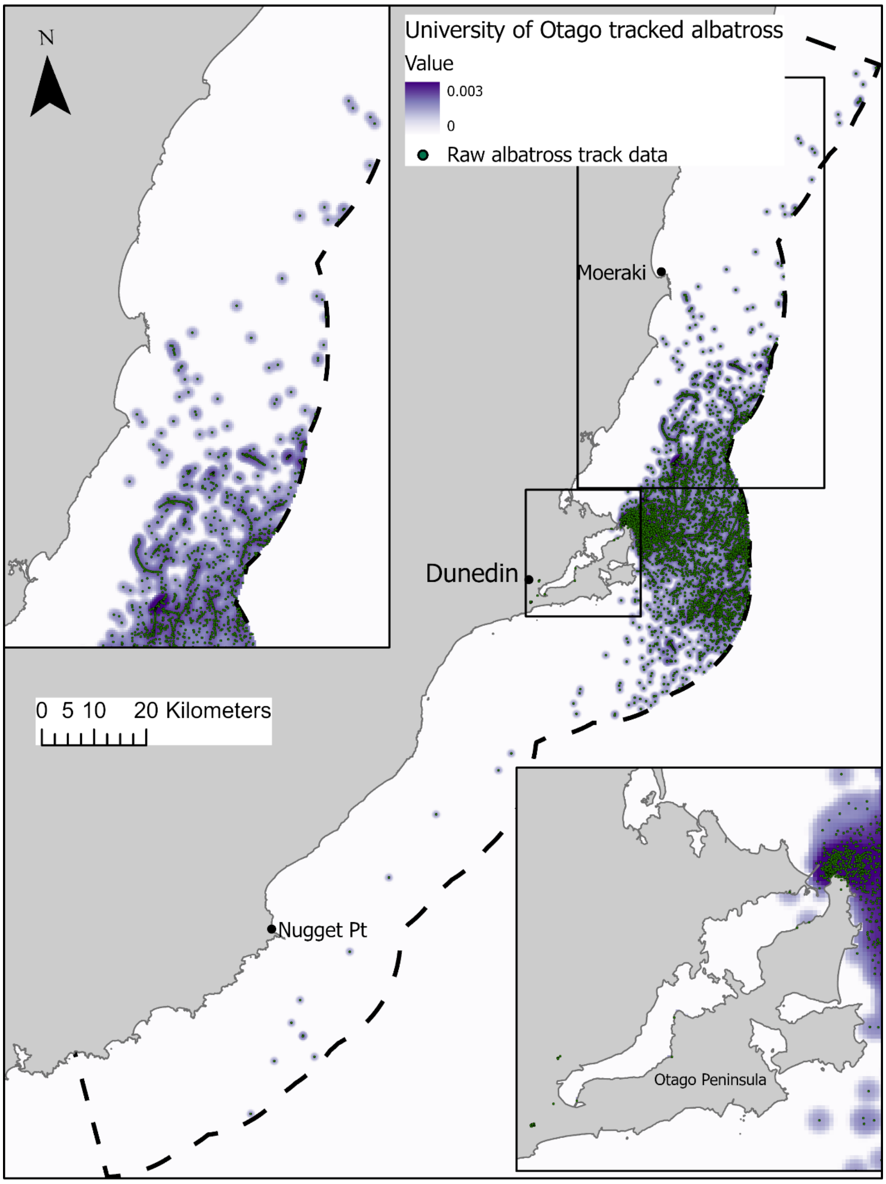

Figure 3-42: Point records for tracked albatross and kernel density. Tracked albatross data (green dots) overlaid upon the kernel density raster (gradient with blue indicating high density), an example dataset for the marine seabird management class.

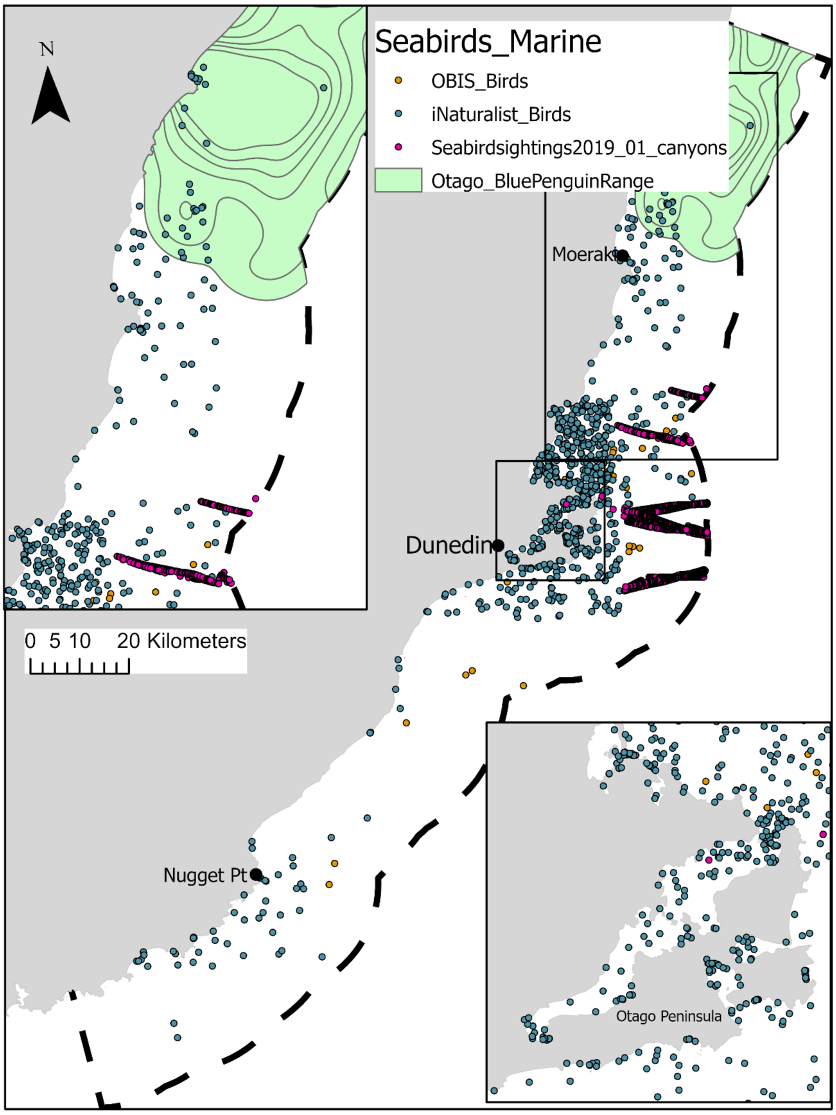

Figure 3-43: Seabird sightings and foraging range of little blue penguins. Points layers of seabird sightings from OBIS (orange), iNaturalist (blue) and Otago University canyon surveys (pink), and foraging range (green polygons) of little blue penguins, example datasets for the marine seabird management class.

Significant areas

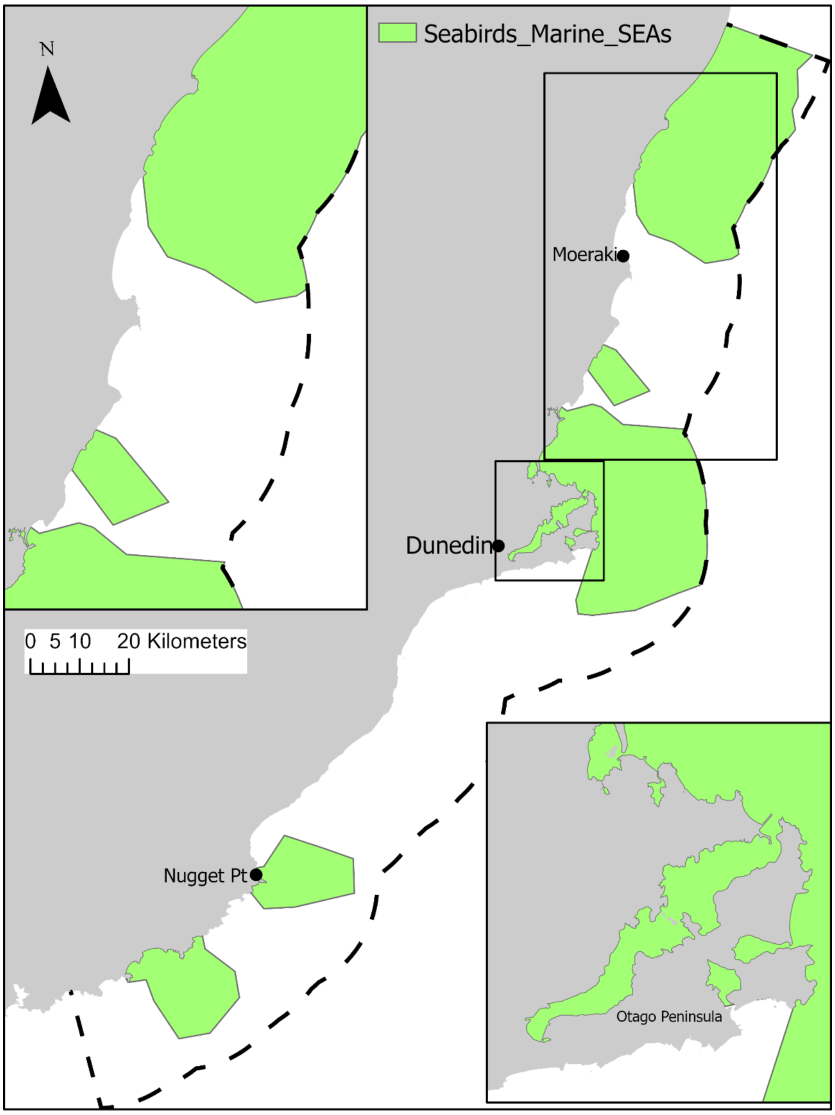

Figure 3-44: SEAs for the marine seabirds management class.

Analysis of spatial data on important ecological features for marine shore/seabirds led to the identification of five SEAs throughout the Otago region. SEAs were located offshore of Oamaru, off the Otago Peninsula and Blueskin Bay, at Nugget Point and further south into the Catlins – all extending into most of the width of the CMA. Another smaller SEA was identified at Bobby's Head.

SEAs for this class consisted of areas of particular importance and/or occurrence for Hoiho, albatross, little blue penguin and other seabirds.

3.15 Shore/seabirds – terrestrial

Datasets

There were four datasets with useful information for the identification of SEAs for the terrestrial seabirds management class. Locations of known Hoiho colonies and their size were provided by the Yellow-Eyed Penguin Trust. Further datasets on seabird colonies were sourced from ORC, a Forest and Bird important bird areas (IBA) dataset from the KEA database (Stephenson et al. 2018; Lundquist et al., 2020) and a dataset compiled by Otago University stored in DOC SeaSketch database (Hand 2013).

Table 3-16: Datasets used for the terrestrial shore/seabirds management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Hoiho Colonies	Locations of known Hoiho colonies for the Otago coast with information on colonies size (n pairs) from the yellow eyed penguin trust	Point	YEPT	5	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)
ORC Bird Colonies	ORC held dataset on the location of key seabird colonies along the Otago coast	Point	KEA Database	4	1,2,3,4	11 a (vi), b (ii), b (v)
NZ_IBA_Bird_Colonies	Point records from national scale layer on the distribution of seabird colonies. Sourced from forest and bird IBA dataset	Point	KEA Database	3	1,2,3,4	11 a (vi), b (ii), b (v)
Otago_SeabirdColonies_21_11_14_FINAL	Point records from local dataset on the distribution of seabird colonies on the Otago coast - produced through surveys, literature review and expert knowledge (UoO - Katherine Hand)	Point	DOC SeaSketch database	5	1,2,3,4	11 a (vi), b (ii), b (v)

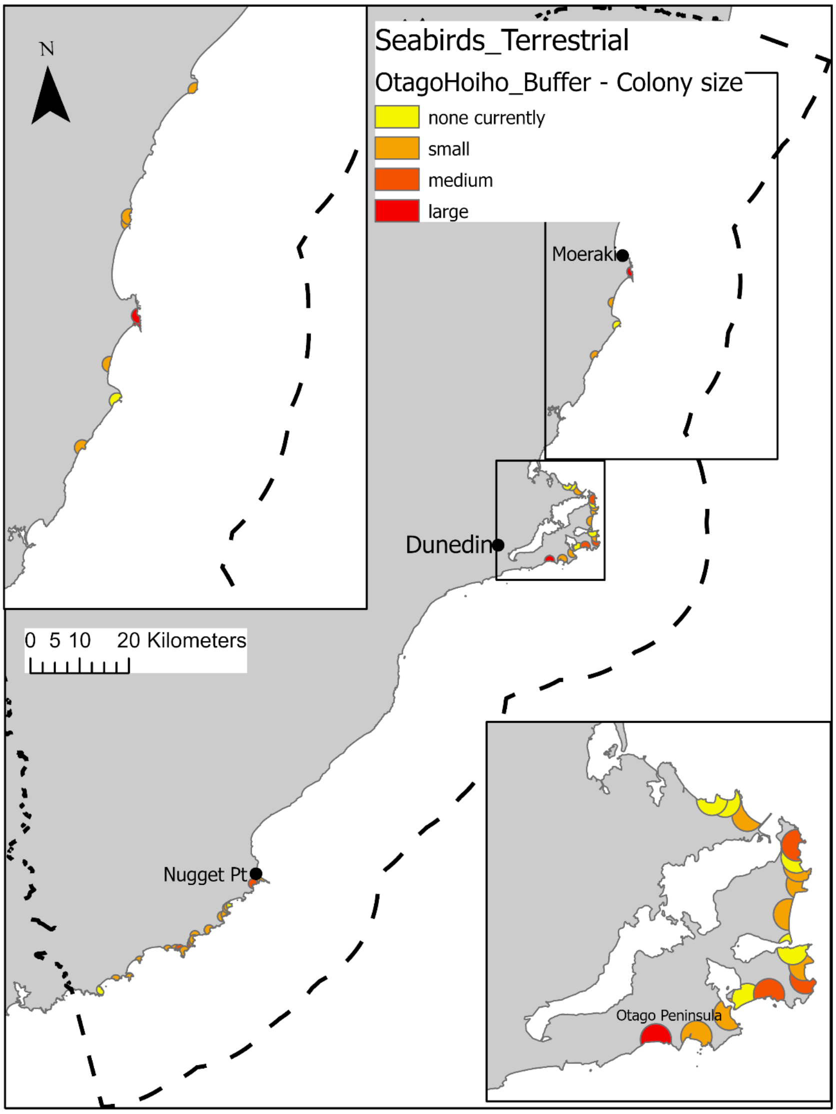

Figure 3-45: Locations of hoiho colonies. Approximate locations (1 km buffer) and relative size (indicated by colour) of hoiho colonies based on data provided by the Yellow-Eyed Penguin Trust, an example dataset for the terrestrial seabirds management class.

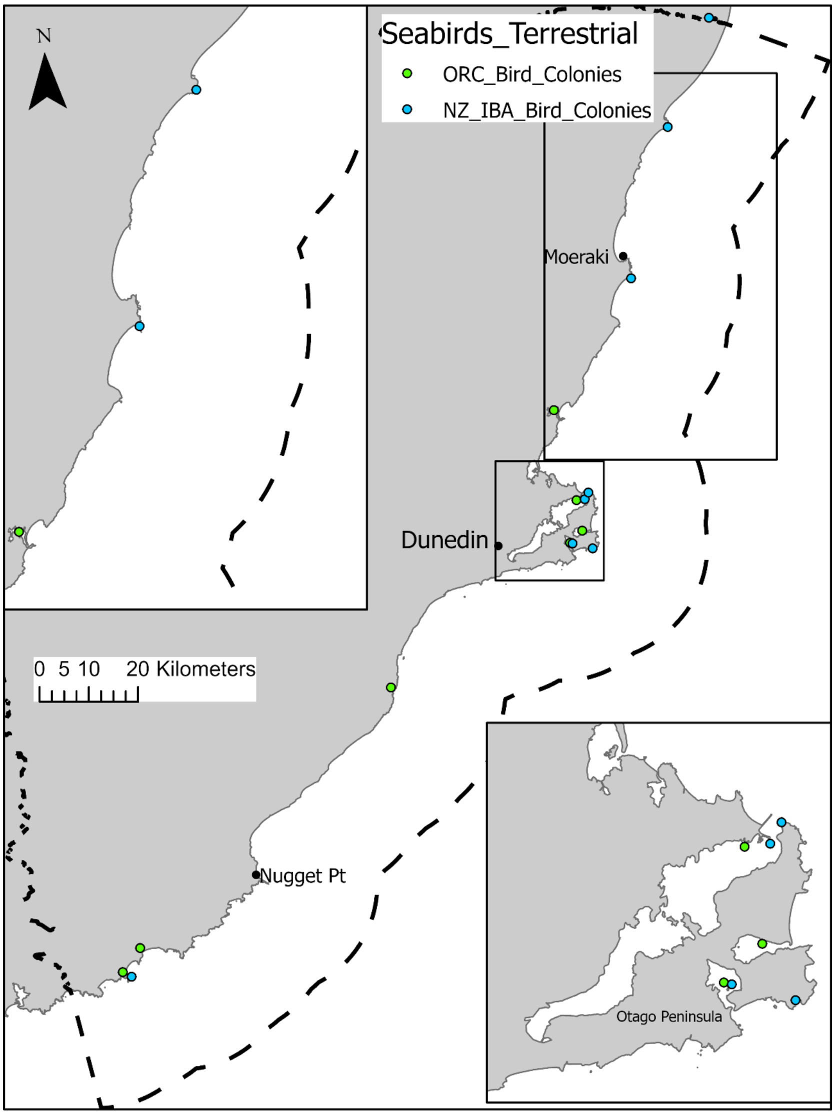

Figure 3-46: Locations of terrestrial seabird colonies. Point records of terrestrial seabird colonies from the Otago regional council (blue) and the forest and bird IBA dataset (green), example datasets for the terrestrial seabird management class.

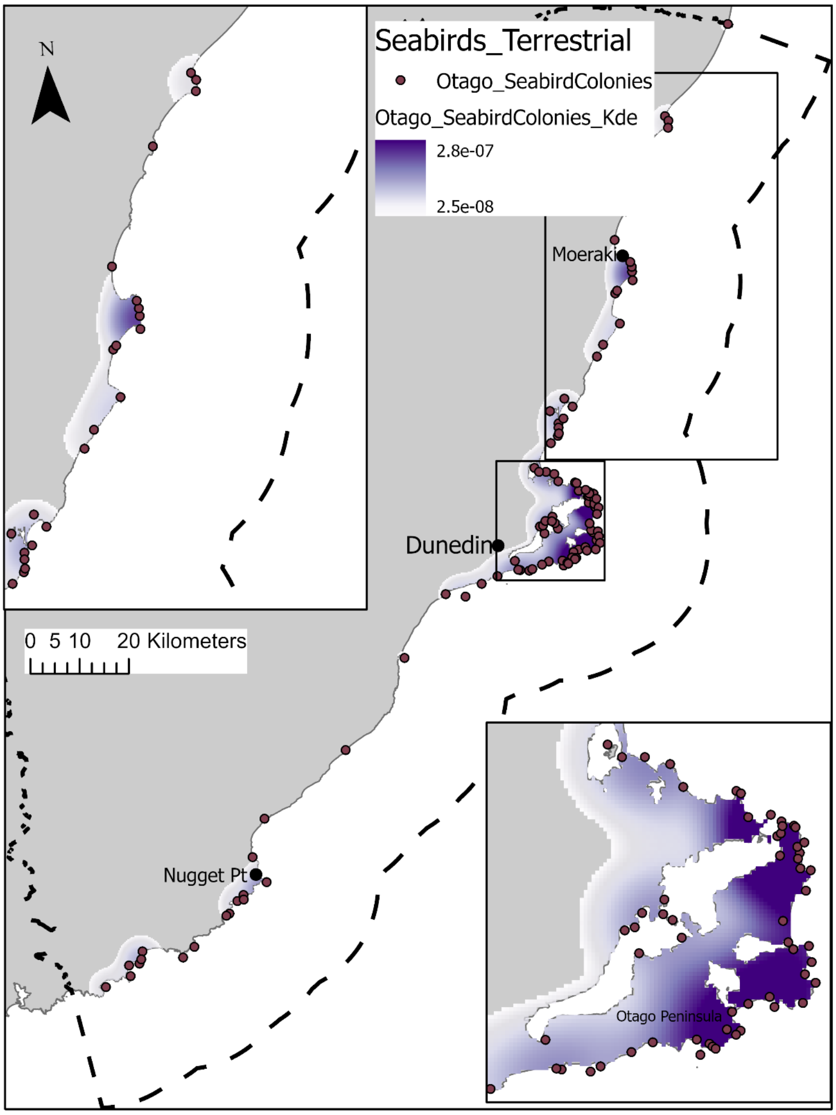

Figure 3-47: Locations of seabird colonies and kernel density. Point records of seabird colonies from the DOC SeaSketch database (Hand 2013) (brown dots) and generated kernel density (gradient with dark blue indicating high density), example datasets for the terrestrial seabird management class.

Significant areas

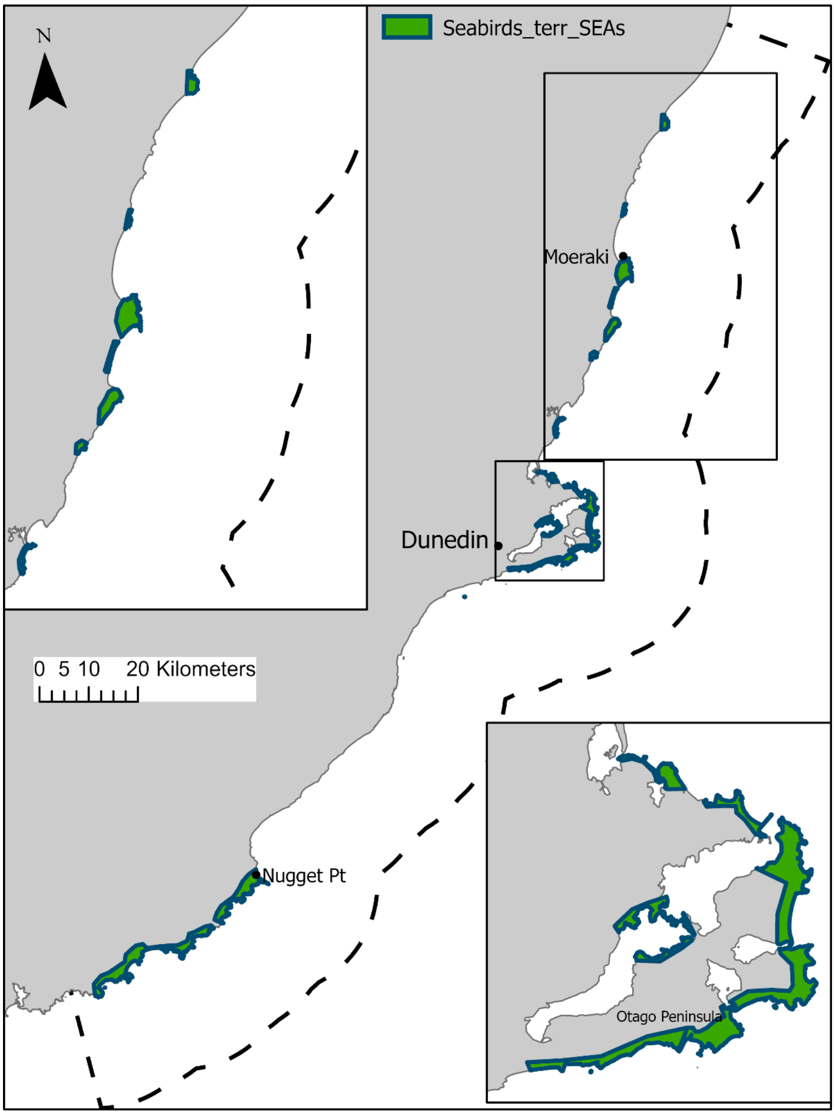

Figure 3-48: SEAs for the terrestrial seabirds management class.

Analysis of spatial data on important ecological features for shore/seabirds in terrestrial habitat led to the identification of fifteen SEAs throughout the Otago region. SEAs were located mostly on the Otago Peninsula and the Catlins coast, with some SEAs along the North Otago coast and on Green Island. SEAs for this class consisted of areas containing breeding colonies for hoiho and other seabirds.

3.16 Seafloor geomorphological features

Datasets

There were four datasets with useful information on seafloor geomorphological features for identifying SEAs. The national scale bathymetry layer was obtained from the KEA database (Lundquist et al. 2020). Datasets on rocky reef extent were sourced from the KEA database and ORC from DOC's MPA habitat classification. A further dataset from the DOC SeaSketch database provides bathymetry of the shipping lane along the Otago coast with a resolution of 25m.

Table 3-17: Datasets used for the seafloor geomorphological features management class.

Dataset	Description	Format	Origin	Data quality score	KEA criteria	Section 11 criteria
Bathymetry	National scale layer on seabed bathymetry pooling data from a range of seabed surveys; 250m resolution	Raster	KEA Database	3	2, 5, 6, 9	11 a (iv), a (v), b (v), b (vi)
DOC_Rocky_Reef	National rocky reef layer reporting the extent of rocky reef habitat	Polygon	KEA Database	3	2,5,6	11 b (ii), b (iii), b (iv), b (vi)
MPA_Habitat_Reefs	Rocky reef layer from DOCs MPA habitat classification - pools surveys observations, charting info, expert opinion	Polygon	ORC Marine Sh apefiles	3	2,5,6	11 b (ii), b (iii), b (iv), b (vi)
LINZ_MPPF_25mDEM	Bathymetry product from a LINZ contracted survey of the shipping lane along the Otago coast; 25m resolution	Raster	DOC SeaSketch database	5	2,5,6	11 b (ii), b (iii), b (iv), b (vi)

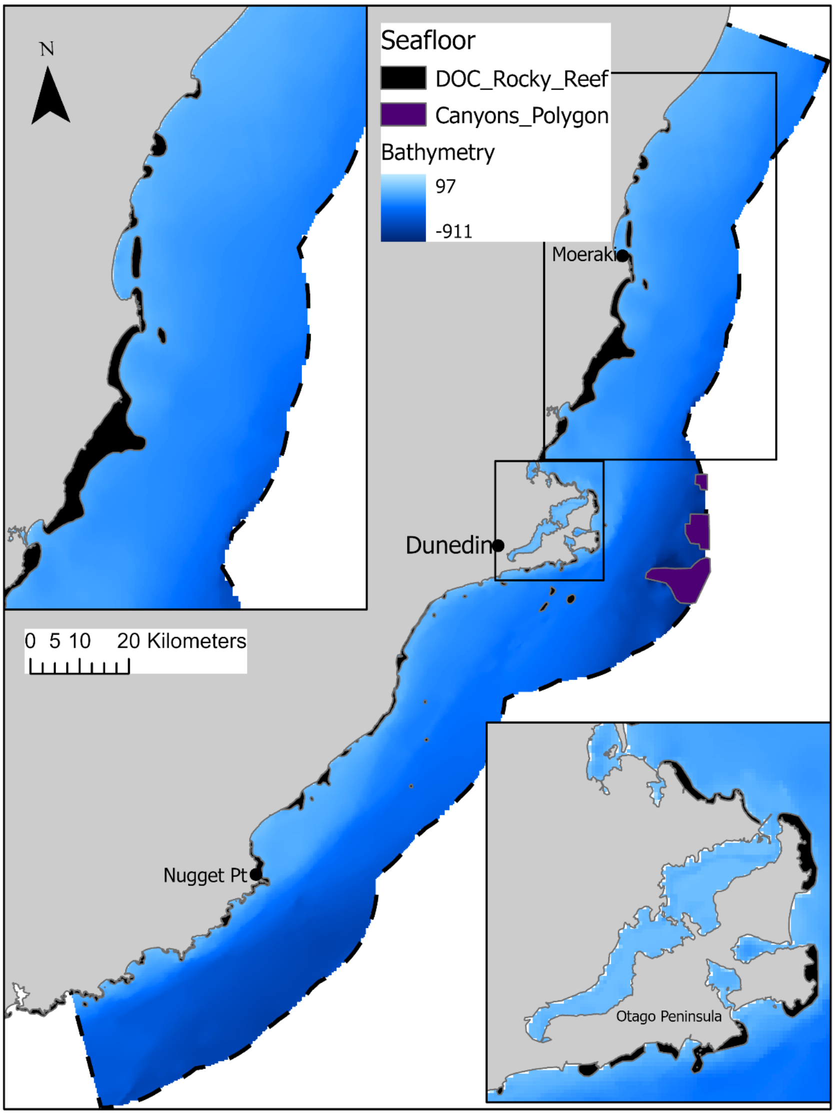

Figure 3-49: Bathymetry and locations of rocky reef and the submarine canyons. Bathymetry (gradient with dark blue indicating greater depth) and locations of rocky reef (black polygons) and the submarine canyons (purple polygons), example datasets for the seafloor geomorphological features management class.

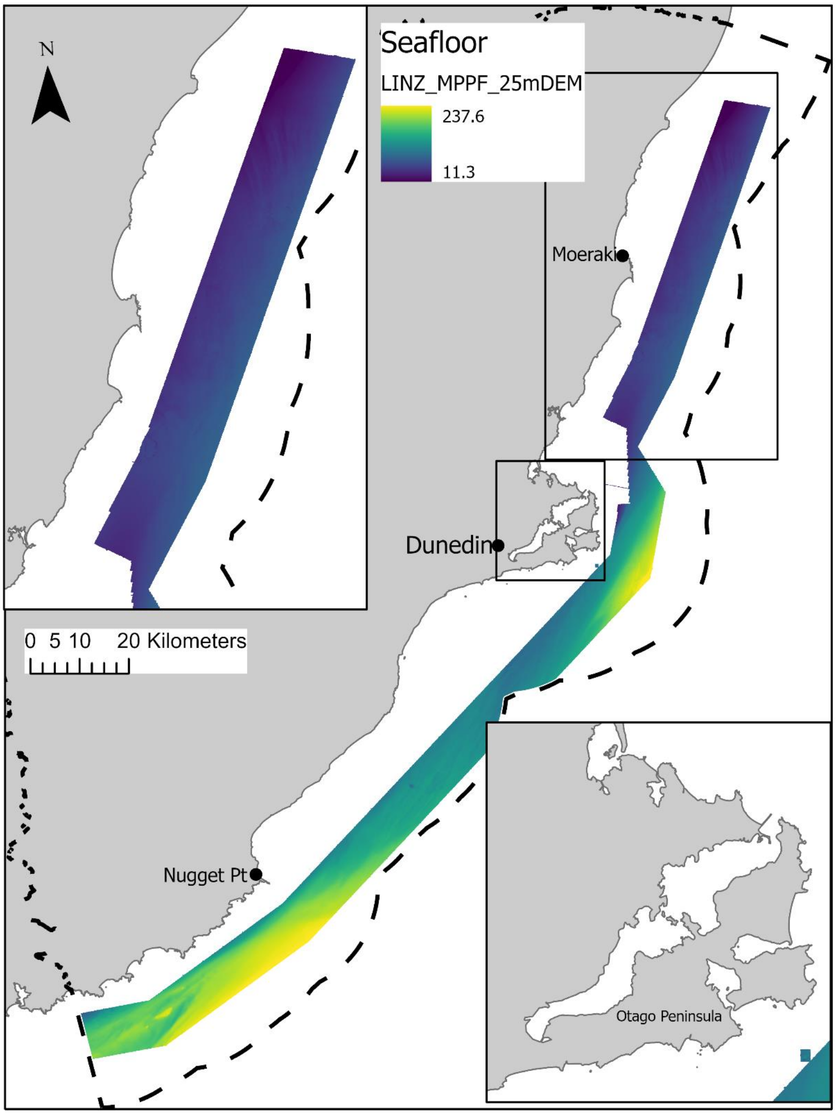

Figure 3-50: Bathymetry within the shipping lane. High resolution (25m) bathymetry within the shipping lane, with yellow indicating greater depth, an example dataset for the seafloor geomorphological features management class.

Significant areas

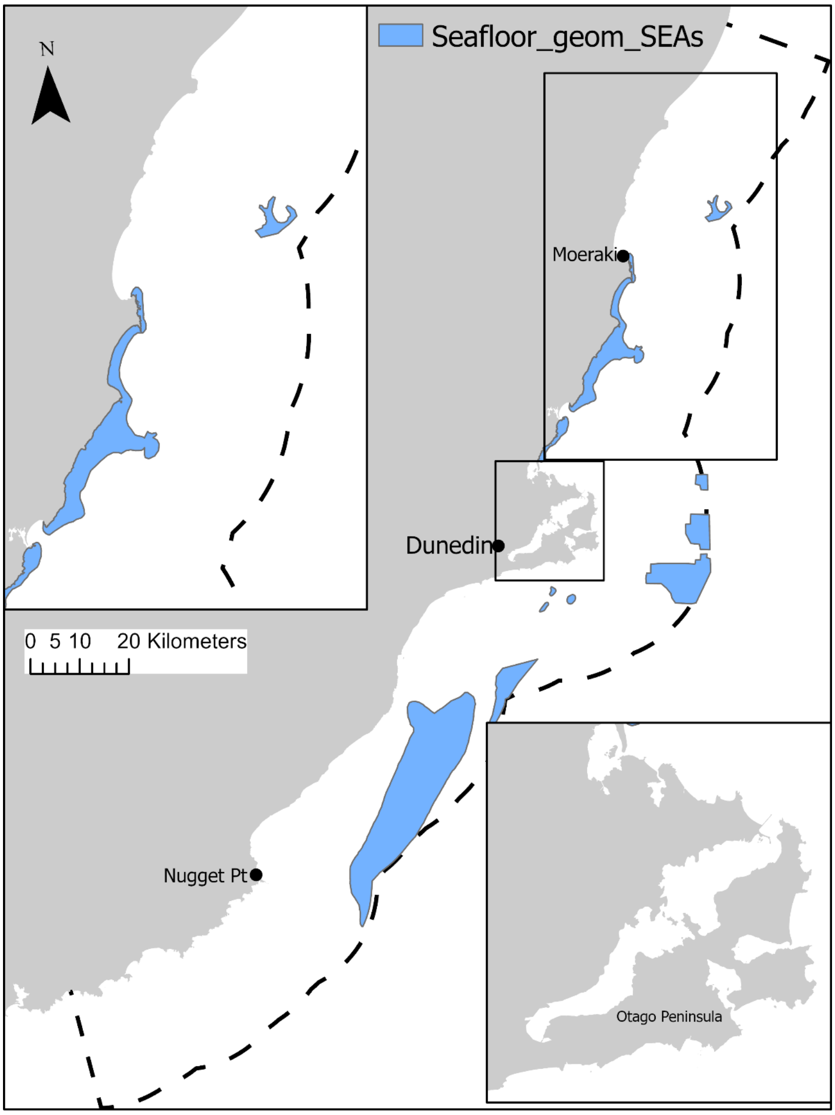

Figure 3-51: SEAs for the seafloor geomorphological features management class.

Spatial data on important ecological features for seafloor geomorphological features led to the identification of nine SEAs throughout the Otago region. SEAs were located offshore of Wainakarua, along the coast from Blueskin Bay to Moeraki, the head of the Saunders, Papanui and Taiaroa Canyons, offshore of Maori Head and a large offshore SEA between the Catlins and Dunedin. SEAs for this class consisted of areas containing reef systems and submarine canyons.

4 Threats

Based on an extensive literature review of the threats posed from anthropogenic stressors to the ecological features under each management class (McCartain et al. 2021), we have provided a matrix to guide ORC on the management of adverse impacts to the indigenous biodiversity of each class. The review, initially undertaken for a project on identifying SEAs for Environment Southland, drew on national and international studies published in the primary literature and scientific reports for government agencies. The matrix showcases the severity of adverse impacts upon each management class from a broad suite of stressors that are typically present in coastal ecosystems. The severity of stressors is indicated as high, medium, low or not applicable (when it is unlikely a stressor will have a direct impact on the features within each class). The only changes to the initial matrix provided by McCartain et al (2021) were the removal of the management class ‘Fiord habitat’ (not relevant in Otago).

Table 4-1: Management class and threat matrix. The severity of threats from anthropogenic stressors to the ecological features within each management classes. Severity is ranked as high (H), medium (M), low (L), very low (VL) and not applicable (-) based on a literature review for coastal management classes by MacCartain et al. 2021.

Potential threat	Climate change		Food harvesting (commercial and recreational)				Pollution						Coastal hardening and development		Resource extraction		Recreational access		Other			
SEA management class	**Sea level rise**	**Storm frequency and intensity**	**Seafloor disturbance (benthic trawling, dredging,**	**Over-fishing and exploitation**	**Bycatch (Corals, marine mammals, seabirds)**	**Pelagic fishing**	**Oil spills**	**Litter and Microplastics**	**Nutrients and Organics**	**Heavy metals and Pesticides**	**Terrigenous sediment**	**Noise**	**Habitat loss**	**Weed and pest control**	**Sand extraction, dredging and disposal**	**Freshwater abstraction and re-diversion**	**Foot and vehicle traffic**	**Boating impacts**	**Invasive species, Disease**	**Artificial structures (pipelines, Jettys etc)**	**Aquaculture**	**Grazing**
Benthic invertebrates- intertidal	L	L	VL	H	-	-	H	L	M	M	H	-	M	-	H	H	H	-	M	L	-	M
Benthic invertebrates- subtidal	-	VL	H	H	H	VL	H	L	M	L	L	-	H	-	H	-	-	-	M	-	M	-
Biogenic habitats - invertebrates	-	L	H	-	H	-	H	L	M	M	M	-	-	-	H	-	-	-	L	-	M	-
Coastal vegetation	M	M	-	-	-	-	M	L	M	M	M	-	H	H	-	L	H	-	M	H	-	H
Estuaries/coastal lagoons/wetlands	H	H	-	-	-	-	H	-	H	M	H	-	H	-	-	H	M	-	H	-	L	H
Fish (Demersal/Reef)	-	-	H	H	-	M	M	M	-	-	M	VL	-	-	H	-	-	H	-	-	M	-
Kelp forests	-	H	M	-	-	VL	H	L	M	M	H	-	L	VL	M	-	-	L	M	L	L	-
Marine flora	-	H	H	-	-	VL	H	L	H	M	H	-	L	L	H	-	M	L	L	L	M	L

Potential threat	Climate change		Food harvesting (commercial and recreational)				Pollution						Coastal hardening and development		Resource extraction		Recreational access		Other			
SEA management class	**Sea level rise**	**Storm frequency and intensity**	**Seafloor disturbance (benthic trawling, dredging,**	**Over-fishing and exploitation**	**Bycatch (Corals, marine mammals, seabirds)**	**Pelagic fishing**	**Oil spills**	**Litter and Microplastics**	**Nutrients and Organics**	**Heavy metals and Pesticides**	**Terrigenous sediment**	**Noise**	**Habitat loss**	**Weed and pest control**	**Sand extraction, dredging and disposal**	**Freshwater abstraction and re-diversion**	**Foot and vehicle traffic**	**Boating impacts**	**Invasive species, Disease**	**Artificial structures (pipelines, Jettys etc)**	**Aquaculture**	**Grazing**
Marine Mammals ocean	-	-	-	M	H	M	M	M	-	-	-	M	-	-	-	-	L	H	-	M	M	-
Marine Mammals terrestrial	-	-	-	-	-	-	M	M	-	-	-	M	H	M	-	-	H	L	-	M	M	-
Naturally uncommon ecosystems	M	H	-	-	-	-	M	L	-	-	L	-	M	-	-	-	M	-	-	L	-	H
Pelagic productivity	-	M	-	-	-	-	H	L	H	-	H	-	-	L	-	-	-	-	-	-	M	-
Seabirds/shorebirds ocean	-	L	L	M	M	M	M	H	-	L	L	M	-	-	-	-	-	M	-	-	M	L
Seabirds/shorebirds terrestrial	M	L	-	-	-	-	M	M	-	L	-	M	H	M	-	-	H	L	-	M	-	M
Seafloor geomorphological features	-	-	H	-	-	VL	H	-	-	-	L	-	-	-	H	-	-	-	M	-	M	-

5 Habitat classification

A deliverable for this project was the classification of the CMA using a published habitat classification. Such a classification provides ORC with information on the broader distribution of biodiversity within the CMA and provides the opportunity to investigate the representativity of SEAs (Brough et al. 2021a). There is currently no published or uniformly used thematic habitat classification for NZ, although the development of such is being prioritised (DOC, pers. comm). Thus, for this project we have used the NZ seafloor community classification (SCC) (Stephenson et al. 2022), a numerical habitat classification that describes the distribution of distinct seafloor-associated communities throughout NZ. The SCC is based on modelled rates of species turnover across environmental gradients defined by high-resolution environmental datasets and provides the best available information on the broad distribution of seafloor community assemblages (Stephenson et al. 2022). The current version of the SCC is available as 75-group classification and has been clipped to the Otago CMA for this project (Figure 5-1) and will be made available to ORC. Further, we have provided a summary of the proportion of the CMA occupied by each group as an indication of the dominant/more rare groups within the CMA (Table 5-1).

It should be noted that the use of the SCC at regional scales has not yet been fully explored, and future work to optimise the number of groups for regional scale spatial planning within the territorial sea is required.

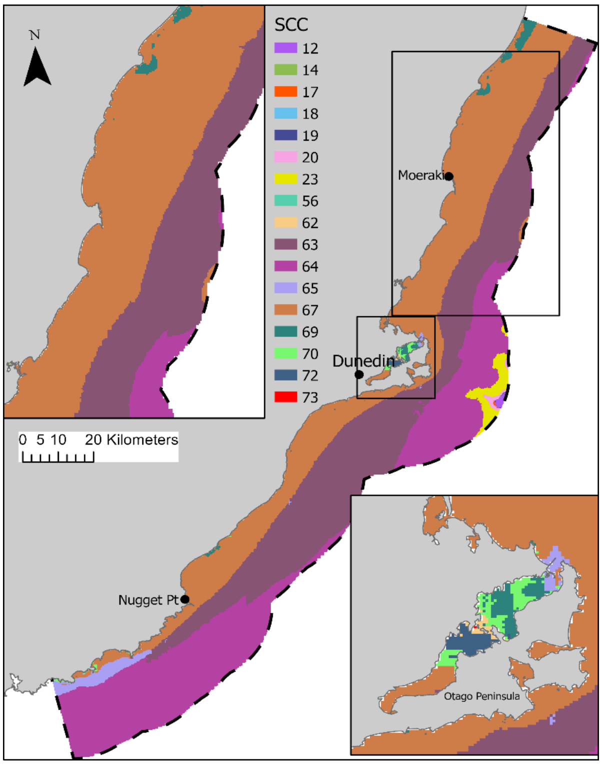

Figure 5-1: Distribution of SCC groups. The distribution of SCC groups within the Otago CMA.

Table 5-1: SCC groups in Otago. The % coverage of all SCC groups found within the Otago CMA.

SCC group	% of CMA
12	0.12
14	<0.00
17	0.01
18	<0.00
19	0.01
20	0.22
23	1.40
56	<0.00
62	0.03
63	32.77
64	29.80
65	1.44
67	32.97

SCC group	% of CMA
69	0.86
70	0.24
72	0.12
73	<0.00

6 Discussion

This project has pooled a substantial amount of information on the distribution of marine biodiversity within the Otago region. The volume of information reflects the region's richness in biodiversity and is a valuable resource for marine spatial planning. The current identification of SEAs provides the most up to date account of important areas for the various classes of biodiversity – using the best available information. However, it should be noted that substantial gaps exist in our understanding of the distribution of marine biodiversity in Otago, which means certain areas and/or management classes are not well represented. Understanding these gaps is challenged by a lack of information on where surveys/observations have occurred but did not record effort or the distribution of sampling (i.e., absence data). In this way, the majority of information collated in this report can be considered as presence data only - i.e., it contains no information on locations where surveys have occurred, but found no observations of ecological features that may inform SEAs. Thus, areas with a consistent absence of SEAs may reflect a paucity of information rather than a true absence of important ecological features. In the following section, we identify areas and ecological components within each management classes with a consistent lack of spatial data that may guide future survey effort.

6.1 Knowledge gaps

Data gaps on the distribution of intertidal benthic invertebrates were significant in all areas beyond the immediate surrounds of Dunedin and the Otago Peninsula. In general, there was better information for estuarine intertidal communities than for rocky reef, however such estuarine data was limited to the distribution of cockles (*Austrovenus stutchburyii*). Additional data collection should focus on characterising intertidal bivalve beds (oyster, mussel and pipi and *Macomona*), and other functionally important habitat that occur throughout the region. Further, mapping the remaining four estuaries that have not received formal habitat mapping should be a priority. Spatially, there is limited data on intertidal benthic invertebrates within the Catlins area (except Catlins estuary), both in terms of soft sediment and rocky reef communities. Further, with the exception of Kakanui, there are no data on benthic invertebrates for the North Otago region – with critical gaps at areas with significant rocky reef habitat (Shag Point and Moeraki).

Data on subtidal benthic invertebrates were available from national scale spatial models for the entire Otago CMA. However, the utility of these model predictions for regional spatial planning is uncertain. Datasets on the occurrence of important features for subtidal invertebrates are limited to the comparatively well sampled areas around Otago Peninsula. There is a paucity of data south of the Peninsula, and limited data for inshore areas north of Blueskin Bay. This data scarcity is particularly relevant for invertebrates of rare, threatened, or unique status and those with important functional traits. Other than commercial catch data, there are no datasets that report the distribution of recreationally, culturally, and commercially important subtidal invertebrates (e.g., paua, rock lobster). The offshore (> ca. 3 miles) CMA between Dunedin and Nugget Point has a particular scarcity of data for subtidal invertebrates.

A large number of datasets were pooled under the biogenic - invertebrates management class, yet several spatial gaps and absences for particular habitats were evident. Several datasets informed the well-known biogenic habitats (i.e., bryozoan thickets) offshore of Otago Peninsula. A range of datasets suggested biogenic habitat offshore of Moeraki. The southern CMA, south of Taieri Mouth, was poorly represented by the available data with the exception of likely bivalve biogenic habitat (i.e., queen scallops) offshore of the Catlins. Further, the distribution of key biogenic habitats including sponge gardens, sea tulips, rhodoliths, horse mussel and oyster beds remains poorly characterised for the majority of the region.

The distribution of saltmarsh and pingao were the major contributors to the coastal vegetation management class. While saltmarsh was relatively well-mapped in the monitored estuaries, there remains at least three estuaries where the distribution of saltmarsh remains unknown. Further, saltmarsh habitat associated with coastal lagoons and wetlands (see Estuaries/lagoons/wetlands management class) has not been characterised. The available data on pingao is likely an inaccurate representation of the current distribution of this important and threatened habitat, with observations most prevalent on Otago Peninsula. Pingao is known to occur on beaches from Warrington to North Otago and in the Catlins – further surveys should target these areas to log the occurrence and extent of pingao.

In general, the demersal fish management class was comparatively well represented. This class was populated with a large number of national scale spatial models, though local occurrence data was used to generate these models and they were supported by occurrence data on rare, threatened, unique fish, fish spawning areas and a large volume of data on commercial fisheries catch. Regional-scale species distribution models could be fit for the key species of the Otago demersal fish community, using locally sourced occurrence/abundance data which would greatly improve the confidence in our understanding of areas of importance for this management class.

A relatively limited number of datasets was used to inform the reef fish management class – with a strong reliance on the national scale species distribution models for these taxa. The data underpinning these models are sparce in Otago and thus substantial ground-truthing is required of SEAs in this class (see below). Our confidence in the understanding of SEAs for reef fish would be greatly improved by region-wide surveys of key, representative reef habitats. Significant reef systems offshore of Shag Point and Moeraki (e.g., Danger/Fish reef) remain un-surveyed and the significant coastal reef habitat between Matanaka and Shag Point is poorly represented. Further, surveys of deep, offshore reef systems south of Otago Peninsula, Taieri mouth/Akatore and the reef systems along the Catlins Coast would substantially increase of knowledge on the distribution of reef fish in Otago.

The distribution of kelp forest was well represented within important areas north of Otago Peninsula, however more accurate mapping (e.g., extent definition) is required in key locations; between Warrington and Karitane, Moeraki and Kakanui. South of the peninsula, there is no accurate data on the distribution of kelp forest. Historically, significant kelp forest was located between Taieri Island and Bruce Rocks, Akatore and between Tokomariro and the Clutha river mouth (Glover 2021). Surveys of these areas to determine the current extent and potential recovery of kelp forest should be undertaken. The extent of kelp forest around Nugget Point (Glover 2021) is also not represented by the available datasets and should be a target of future surveys along with exploration of kelp forest occurrence in suitable habitat along the Catlins coast.

The seagrass component of the marine flora management class was well characterised, particularly in the mapped estuaries and within Otago Harbour. Data on the distribution of seagrass should be acquired within the remaining four unmapped estuaries and within coastal lagoons where it is known to occur. In contrast, macroalgae (outside of the mapped estuaries) was not represented by regional data, with evidence for this component being sourced from national scale models. Otago has a rich macroalgal diversity (Neill and Nelson 2016), and surveys of both rocky reef and soft-sediment communities should be undertaken in representative habitats throughout the region.

The marine mammal – ocean management class was informed by local occurrence data within Blueskin Bay, around the peninsula and at the Otago Canyons. There have also been systematic surveys of cetaceans in coastal areas south of the peninsula to Taieri Mouth and north to Moeraki (Turek et al. 2013). Thus, the absence of data in these areas are true absences. There is a significant lack of survey effort for cetaceans, NZ sea lions and fur seals for all offshore areas (> ca 3 miles from shore) in the CMA with the exception of the Otago Canyons area (indicated by an SEA offshore of the peninsula; Figure 3-34). Foraging areas for NZ sea lions is a key contributor to this class and remains poorly represented for animals along the Catlins coast. No data on foraging distribution for fur seals was available with the exception of occurrence data from the heads of the Otago Canyons.

Terrestrial habitat for marine mammals (i.e., pinniped colonies/haulouts) was a well-represented management class, with data spanning the full extent of the region. Gaps concern the importance of each site to populations of marine mammals and may be ascertained by surveys of the number of animals using each site and determining their importance for breeding/nursing.

A single dataset on naturally uncommon ecosystems was used to inform the distribution of SEAs in this class which includes diverse ecological features originally designated 'uncommon' under by Landcare Research/Manaaki Whenua. Individual features (e.g., coastal turfs, rock stacks) have variable extent definition and some of the information originally used to map the features is outdated and may contain inaccuracies. Thus, features (and subsequent SEAs) in this class should be reviewed and have ground-truthing and/or extent definition applied when necessary. Targeting uncertain features may also allow ORC to prioritise certain areas with particularly outstanding features (e.g., in terms of size/quality) for management of adverse impacts.

The pelagic productivity management class was defined by a single dataset used to represent the location of the southland front. While informative, other areas of pelagic productivity are not captured by this dataset. More thorough analysis of data on primary production from phytoplankton (e.g., Chlorophyll *a* concentration), may identify other areas of importance for pelagic productivity including features such as the Blueskin Bay eddy (Murdoch et al. 1990).

The available data for the seabirds/shorebirds – marine management class spanned the entire CMA, however gaps for key species and areas are present. Additional tracking data for hoiho is required from each of the known colonies to accurately represent the extent of foraging habitat for this endangered species; data from the colony at Katiki Point is a critical gap. At sea distribution for seabirds is well represented off the Otago Peninsula and in Blueskin Bay, but is sparce in all other areas. The southland current (see pelagic productivity) is likely a nationally significant feeding area for seabirds (UoO unpublished data) and should be the focus of surveys to accurately characterize its importance. Foraging areas for shorebirds are poorly represented in all areas except those in close proximity to Dunedin city. Additional surveys for foraging shorebirds should prioritise coastal lagoons and estuaries south of Taieri Mouth and north of Karitane.

For terrestrial habitat of seabirds/shorebirds, four datasets contained information on important areas. Of these, two had high quality scores and contain the most up to date information on seabird colonies currently available. However, some SEAs are based on older information and it is important that these areas receive ground-truthing. Further, there is no information on the accurate extent of any seabird colony; this knowledge would enable more accurate management of threats to this important class. Further investigations involving historical information and/or spatial modelling approaches could also predict suitable habitats for the restoration and recovery of seabird colonies along coastal Otago.

The four datasets used to inform seafloor geomorphic features identified some clear gaps in our understanding for this class. The key information required to identify notable seafloor features are high resolution (e.g., <20m) bathymetric and backscatter data sourced from seafloor mapping surveys. Such data are unavailable for large portions of the CMA and areas with likely significant rocky reef habitat (e.g., offshore of Shag Point, Moeraki, Bobby's Head, Akatore, Taieri Island) should be prioritised. Inshore reef habitat around Otago Peninsula and the Catlins, and deeper reef to the south of the peninsula are also poorly characterised. An area of uneven seafloor topography offshore of Tautuku peninsula should also be prioritised to determine the occurrence of unique shoaling/light foul habitat (Figure 3-51)

The estuaries/wetland/lagoons management class was represented by datasets that define the extent of these important coastal features. The extent of the mapped estuaries is well known; the remaining four should have their extent mapped as a priority. Further, additional review of satellite data may reveal coastal lagoons and wetlands not included in the national or ORC layers used in this study. There are currently no data with which to distinguish between features in this class in terms of 'quality' or 'naturalness'. Should ORC wish to prioritise between the various estuaries/wetlands/lagoons, additional datasets on ecosystem health indicators will need to be acquired.

6.2 Ground-truthing and extent definition

While this study used the best available information to identify SEAs across the sixteen management classes, some SEAs were inevitably based on information that requires ground-truthing. Such cases occur when the best available information is either 1) older than recommended, or 2) based on modelled or highly interpolated evidence. In addition, some SEAs are based on information that may be lacking or have inaccurate spatial information that can be used to define the extent of the underlying ecological features. For example, these may include SEAs that draw heavily on point records that contain no information on the boundaries of a particular feature (e.g., records for bird colonies, rare species). Extent definition may also be required for contiguous physical features (e.g., reef systems, estuaries) that have good evidence on their occurrence but have not been accurately mapped. In these cases, we recommend targeted surveys to determine the true extent of these areas which will provide management with the best information with which to manage adverse impacts.

We have reviewed the contributing evidence for each SEA to determine those that require ground-truthing and extent definition and have provided this information in Table 6-1. Further, the attributes table of each SEA GIS layer has fields indicating whether a SEA requires ground-truthing (validation) or extent definition.

Table 6-1: SEAs requiring validation. The number of SEAs for each management class that require ground-truthing or extent definition to ensure their validity.

Management class	n SEAs	Ground-truthing	Extent definition
Benthic Invertebrates Intertidal	16	11	14
Benthic Invertebrates Subtidal	8	5	8
Biogenic Habitats - Invertebrate	8	5	8
Coastal vegetation	22	12	16
Demersal Fish	6	2	6
Reef Fish	22	22	22
Kelp Forest	6	4	6
Marine Flora	22	12	17
Marine Mammal Ocean	5	2	3
Marine Mammal Terrestrial	6	0	2*
Naturally Uncommon Ecosystems	273	273	273**
Pelagic	1	0	0
Seabirds Marine	5	0	0
Seabirds Terrestrial	15	0	14
Seafloor geomorphic	9	6	9
Wetlands/Estuaries/Lagoons	41	0	5

*Combines numerous locations for two species of pinniped. **Combines numerous locations for six distinct uncommon ecosystems.

6.3 Monitoring

The candidate SEAs identified in this project will require ongoing monitoring to determine they continue to meet the relevant ecological significance criteria and to ensure any mitigation of adverse impacts is effective. The additional data acquired during monitoring programmes may also help to refine the identification of SEAs that is likely to be reviewed under future iterations of the Otago coastal plan. Monitoring the highly diverse suite of SEAs that span the full extent of the Otago CMA will be a challenging undertaking and will require input and partnerships from various research providers, manawhenua and government agencies. It is recommended that, where possible, monitoring techniques that utilise state-of-the-art and emerging technology be used to monitor SEAs in an efficient and cost-effective manner.

Satellite remote sensing

Satellite remote sensing methods have been adapted for surveys of a range of biological, geophysical and oceanographic applications. Within the Otago SEA context, remote sensing methods may yield particularly productive results for monitoring coastal water quality and habitat condition, kelp forest and macroalgal communities, coastal vegetation, marine mammals, and seabird colonies. The opportunities afforded by satellite derived sensing for consistent, long-term monitoring at high temporal frequencies makes the technique ideally suited to cost-effective monitoring.

Remote operated vehicles

Remotely operated vehicles (ROVs) include diverse platforms designed to survey a broad range of marine ecosystem components. Platforms include; gliders that yield information on physical oceanography, acoustics and water column biodiversity, drones that provide high-resolution aerial imagery on a range of coastal invertebrate and algal species, marine mammal and seabird colonies, autonomous surface vehicles that can sample a broad range of biological and physical components such as fish and algal distribution, and seafloor habitat. Traditional, piloted ROVs are regularly used to capture information on the distribution of benthic habitats and associated species (fish, macroalgae, invertebrates). All classes of ROV greatly improve the cost-effectiveness of sampling due to minimisation of the number of field personnel required and increased operational capacity.

Artificial intelligence

Technological advancements in artificial intelligence are often applied to field datasets to greatly improve the efficiency and cost-effectiveness of processing/analysing large datasets. For monitoring in the Otago region, such technology may include image/footage classification of raw datasets on fish, macroalgae and invertebrates and seafloor features that may greatly improve the cost effectiveness of monitoring.

Advanced spatial modelling

Sampling across the range of management classes in a holistic monitoring and ground-truthing programme will provide high quality data with which to construct accurate, regional-scale spatial models. Such models will provide opportunities accurately represent the distribution of biodiversity in the Otago region, the impact of stressors and explore the effectiveness of management scenarios that limit those stressors.

6.4 Conclusions

This project has brought together a substantial amount of information on marine biodiversity within the Otago region and has made important contributions to the identification of SEAs in this area with very high biodiversity values. With ongoing validation and monitoring, the work presented here will provide significant opportunities for both ORC and other stakeholders to implement meaningful management of adverse impacts to biodiversity in this unique region.

7 Acknowledgements

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Appendix A Agenda for workshop 1

Workshop title: Identification of significant marine ecological areas on the Otago Coast.

When	**Tuesday 7 December 2021. 1230pm – 4:00pm**
Where	Otago Regional Council Chambers. Level 2, Philip Laing House, 2/144 Rattray Street, Dunedin. Zoom link provided for video-conferencing below
Attendees	Korako Edwards, Greig Funnell, Kat Manno, Marine Richarson, Bruce McKinlay, Mark Geytenbeek, Gaya Gnanalingam, Tom McCowan, Brendan Flack, Carolyn Lundquist, Kate Hesson, Rebecca McGrouther, Sarah Cumming, Mike Bentjes, Trudi Webster, Sam Thomas, Tom Brough, others tbc
Apologies	tbc

Significant Marine Ecological Areas (SEAs) are required to be identified and implemented under the national coastal policy statement and form an important component of regional coastal plans. The aim of this workshop is to begin a dialogue on the identification of significant marine ecological areas (SEAs) on the Otago Coast, that may be implemented during the review of Otago's coastal plan in 2024. The workshop will engage stakeholders with significant interest and experience on the biodiversity of Otago's coastal environment to discuss the process of SEA identification. We will also explore opportunities for the pooling of spatial datasets that can be used to identify SEAs using systematic spatial planning methodologies. Policy-based discussion on the management options for SEAs will not be part of this workshop, and will be incorporated into the review process of Otago's coastal plan in 2024.

Agenda

1. 12:35pm – Welcome and Introductions
2. 12:45pm – Introduction to project and ORC requirements – Sam Thomas (ORC)
3. 1:00pm – Project methodology and spatial mapping – Tom Brough (NIWA)
4. 1:30pm – Introduction to spatial management tools – Carolyn Lundquist (NIWA
5. 2:00pm – Break
6. 2:15pm – Identification and discussion of spatial datasets to aid identification of significant ecological areas (All)
7. 3:50pm - Wrap up and next steps – Sam Thomas (ORC)

Appendix B Significant ecological areas - metadata

Benthic invertebrates – intertidal

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Otago Harbour invertebrate SEA	BiInt_001	Occurrence of significant cockle habitat	Cockles_ORCEstuary, MPI spatial catch data - clams, E3_scientific_cockles	1, 2, 8, 9	11 a (v), 11 b (iii), b (iv)	No	Yes
Papanui Inlet invertebrate SEA	BiInt_002	Occurrence of cockle habitat	Cockles_ORCEstuary	1, 2, 8, 9	11 b (iii), b (iv)	No	Yes
Purakaunui invertebrate SEA	BiInt_003	Occurrence of significant cockle habitat	Cockles_ORCEstuary	1, 2, 8, 9	11 b (iii), b (iv)	No	Yes
Blueskin Bay invertebrate SEA	BiInt_004	Occurrence of significant cockle habitat	Cockles_ORCEstuary, Blueskin2020_21_Substrate, MPI spatial catch data - clams	1, 2, 8, 9	11 a (v), 11 b (iii), b (iv)	Yes	Yes
Puddingstone invertebrate SEA	BiInt_005	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Cape Saunders invertebrate SEA	BiInt_006	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Sandymount invertebrate SEA	BiInt_007	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Tomahawk invertebrate SEA	BiInt_008	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Tunnel beach invertebrate SEA	BiInt_009	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Kuri bush invertebrate SEA	BiInt_010	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Hays gap invertebrate SEA	BiInt_011	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Warrington invertebrate SEA	BiInt_012	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Huriawa invertebrate SEA	BiInt_013	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Kakaho invertebrate SEA	BiInt_014	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Cape Wanbrow invertebrate SEA	BiInt_015	Occurrence of green-lipped mussel	Perna_presence	1, 2, 8, 9	11 b (iii), b (iv)	No	No
Catlins River Invertebrate SEA	BiInt_016	Occurrence of cockle habitat	Catlins2016_Substrate_Biogenic, Cockles_ORCEstuary	1, 2, 8, 9	11 b (iii), b (iv)	No	Yes

Benthic invertebrates – subtidal

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Otago Peninsula offshore subtidal benthic invertebrate SEA	BiSub _001	Important habitat for rare, threatened, unique species. Highly suitable habitat for numerous benthic invertebrate species. Importance for benthic invertebrate functional groups	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset. Benthic invertebrate function groups.	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	Yes
Catlins subtidal benthic invertebrate SEA	BiSub _002	Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	No
Otago Harbour subtidal benthic invertebrate SEA	BiSub _003	Occurrence of rare, threatened, unique species. Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	No
Blueskin Bay subtidal benthic invertebrate SEA	BiSub _004	Occurrence of rare, threatened, unique taxa. Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	No
Shag Point offshore subtidal benthic invertebrate SEA	BiSub _005	Important habitat for rare, threatened, unique species. Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	Yes
North Otago coastal subtidal benthic invertebrate SEA	BiSub _006	Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	No
Waianakarua offshore subtidal benthic invertebrate SEA	BiSub _007	Highly suitable habitat for numerous benthic invertebrate species	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	No
Cape Saunders subtidal benthic invertebrate SEA	BiSub _008	Important habitat for rare, threatened, unique species. Highly suitable habitat for numerous benthic invertebrate species. Importance for benthic invertebrate functional groups	Species distribution models for benthic invertebrate species. Rare/threatened/ unique/endemic dataset. Benthic invertebrate function groups.	1, 2, 4, 6, 8	11 a (i), a (v), b (ii), b (iii), b (vi)	No	Yes

Biogenic Habitats – invertebrates

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Otago Peninsula biogenic SEA	Biog_ 001	Occurrence of biogenic habitat formers - bryozoans, bivalves, sponges. Highly suitable habitat for numerous biogenic habitat and threatened deepwater corals	biogenic_bryozoan. Habitat suitability models for biogenic habitat forming species and protected coral species. Bryozoans_AMSmith_merged tsp. Obis_clip_keybiv2. Wood_Biogenic_habitats_ review. obis_clip_keybryo. specify_clip_keyspg. tepapa_clip_keybiv.	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	Yes
Waikouaiti offshore biogenic SEA	Biog_ 002	Occurrence of biogenic habitat formers - bryozoans, bivalves, sponges. Highly suitable habitat for numerous biogenic habitat and threatened deepwater corals	biogenic_bryozoan. Habitat suitability models for biogenic habitat forming species and protected coral species. Bryozoans_AMSmith_merged tsp. Obis_clip_keybiv2. specify_clip_keyspg. obis_clip_keyspg	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	Yes
Moeraki biogenic SEA	Biog_ 003	Occurrence of biogenic habitat forming species - sponges. Highly suitable habitat for numerous biogenic habitat-forming species and protected corals	Habitat suitability models for biogenic habitat forming species and protected coral species. specify_clip_keyspg. obis_clip_keyspg	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No
Cape Wanbrow biogenic SEA	Biog_ 004	Highly suitable habitat for numerous biogenic habitat-forming species and threatened deepwater corals	Habitat suitability models for biogenic habitat forming species and protected coral species	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No
Southern Catlins biogenic SEA	Biog_ 005	Highly suitable habitat for numerous biogenic habitat-forming species and protected coral species	Habitat suitability models for biogenic habitat forming species and protected coral species	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No
Waitaki biogenic SEA	Biog_ 006	Highly suitable habitat for numerous biogenic habitat-forming species and protected coral species	Habitat suitability models for biogenic habitat forming species and protected coral species	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No
Tokomairaro offshore biogenic SEA	Biog_ 007	Occurrence of biogenic habitat forming species - bivalves, bryozoans. Highly suitable habitat for numerous biogenic habitat-forming species and protected corals	Obis_clip_keybiv2. Bryozoans_AMSmith_merged tsp. Habitat suitability models for biogenic habitat forming species and protected coral species	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Northern Catlins biogenic SEA	Biog_ 008	Highly suitable habitat for numerous biogenic habitat-forming species and protected coral species	Habitat suitability models for biogenic habitat forming species and protected coral species	1, 2, 4, 6, 7, 8	11 a (ii), a (iii), b (ii), b (iii), b (vi)	No	No

Coastal vegetation

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Shag River coastal vegetation SEA	CoVeg_ 001	Contains areas of saltmarsh	Shag2016_SaltMarsh. MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Bobby's Head coastal vegetation SEA	CoVeg_ 002	Occurrence of pingao habitat	iNaturalistPingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Pleasant River Estuary coastal vegetation SEA	CoVeg_ 003	Contains areas of saltmarsh	Saltmash_ORCWetlands. MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Waikouaiti Beach coastal vegetation SEA	CoVeg_ 004	Occurrence of pingao habitat	iNaturalistPingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Waikouaiti Estuary coastal vegetation SEA	CoVeg_ 005	Contains areas of saltmarsh	Waikouaiti2017_ SaltMarsh. Saltmash_ORCWetlands. MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Blueskin Bay coastal vegetation SEA	CoVeg_ 006	Contains areas of saltmarsh	Blueskin2020_21_ SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Aramoana coastal vegetation SEA	CoVeg_ 007	Contains areas of saltmarsh	Saltmash_ORCWetlands. MPA_Habitat_SaltMarsh. E3_Saltmarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Te Rauone Beach coastal vegetation SEA	CoVeg_ 008	Historical pingao occurrence	Otago Peninsula Pingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Pipikaretu Beach coastal vegetation SEA	CoVeg_ 009	Historical pingao occurrence	Otago Peninsula Pingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Ryans Beach coastal vegetation SEA	CoVeg_ 010	Historical pingao occurrence	Otago Peninsula Pingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Victory Beach coastal vegetation SEA	CoVeg_ 011	Historical pingao occurrence	Otago Peninsula Pingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Papanui Inlet coastal vegetation SEA	CoVeg_ 012	Contains areas of saltmarsh	Saltmarsh_ORC_ Wetlands	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Allans Beach coastal vegetation SEA	CoVeg_ 013	Occurrence of pingao habitat	Otago Peninsula Pingao. iNaturalistPingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Hoopers Inlet coastal vegetation SEA	CoVeg_ 014	Contains pingao and areas of saltmarsh	iNaturalistPingao. MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Sandfly Bay coastal vegetation SEA	CoVeg_ 015	Occurrence of pingao habitat	Otago Peninsula Pingao. iNaturalistPingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Smaills Beach coastal vegetation SEA	CoVeg_ 016	Historical pingao occurrence	Otago Peninsula Pingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
St Kilda coastal vegetation SEA	CoVeg_ 017	Occurrence of pingao habitat	Otago Peninsula Pingao. iNaturalistPingao	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	Yes
Kaikorai Lagoon coastal vegetation SEA	CoVeg_ 018	Contains areas of saltmarsh	Kaikorai2018_SaltMarsh. MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Tokomairaro coastal vegetation SEA	CoVeg_ 019	Contains areas of saltmarsh	Tokomairiro2018 _SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Catlins River coastal vegetation SEA	CoVeg_ 020	Contains areas of saltmarsh	Catlins2016_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	Yes	Yes
Tahakopa coastal vegetation SEA	CoVeg_ 021	Contains areas of saltmarsh	MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No
Tautuku coastal vegetation SEA	CoVeg_ 022	Contains areas of saltmarsh	MPA_Habitat_SaltMarsh	1, 2, 4, 8	11 a (iii), b(i), b (ii), b (iii), b (v), b (vi)	No	No

Estuaries/Coastal Lagoons and Wetlands

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Hawksbury coastal lagoon	EstLagWet_ 001	Hawksbury coastal lagoon	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	No	Yes
Wangaloa coastal lagoon	EstLagWet_ 002	Wangaloa coastal lagoon	nz-lake-polygons-topo_LINZ	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	No	Yes
Washpool coastal lagoon	EstLagWet_ 003	Washpool coastal lagoon	nz-lake-polygons-topo_LINZ	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	No	Yes
Tomahawk coastal lagoon	EstLagWet_ 004	Tomahawk coastal lagoon	nz-lake-polygons-topo_LINZ	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	No	Yes
All Day Bay Lagoon	EstLagWet_ 005	All Day Bay Lagoon	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Clutha Matau Wetlands	EstLagWet_ 006	Clutha Matau Wetlands	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Clutha River Mouth Lagoon	EstLagWet_ 007	Clutha River Mouth Lagoon	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
False Islet Wetland Management Area	EstLagWet_ 008	False Islet Wetland Management Area	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Hoopers Inlet Swamp	EstLagWet_ 009	Hoopers Inlet Swampe	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Hukihuki Swamp	EstLagWet_ 010	Hukihuki Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Jennings Creek Marsh	EstLagWet_ 011	Jennings Creek Marsh	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Kaikorai Lagoon Swamp	EstLagWet_ 012	Kaikorai Lagoon Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Kakaho Creek Swamp	EstLagWet_ 013	Kakaho Creek Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Kemp Road Lagoon	EstLagWet_ 014	Kemp Road Lagoon	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Lake Wilkie Swamp	EstLagWet_ 015	Lake Wilkie Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Lenz Reserve Wetlands	EstLagWet_ 016	Lenz Reserve Wetlands	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Coutts Gully Swamp	EstLagWet_ 017	Coutts Gully Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Lower Otokia Creek Marsh	EstLagWet_ 018	Lower Otokia Creek Marsh	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Maclennan River Podocarp Swamp Complex	EstLagWet_ 019	Maclennan River Podocarp Swamp Complex	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
McGregor Swamp	EstLagWet_ 020	McGregor Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
McLachlan Road Marsh	EstLagWet_ 021	McLachlan Road Marsh	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Measly Beach Wetland Complex	EstLagWet_ 022	Measly Beach Wetland Complex	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Molyneux Bay Swamp	EstLagWet_ 023	Molyneux Bay Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Okia Flat Wetland Management Area	EstLagWet_ 024	Okia Flat Wetland Management Area	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Shag Point Dam Margins	EstLagWet_ 025	Shag Point Dam Margins	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Tahakopa Bay Podocarp Swamp	EstLagWet_ 026	Tahakopa Bay Podocarp Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Tautuku River Mouth Marsh	EstLagWet_ 027	Tautuku River Mouth Marsh	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Te Matai Marsh Complex	EstLagWet_ 028	Te Matai Marsh Complex	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Tokomairiro River Swamp	EstLagWet_ 029	Tokomairiro River Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Waianakarua River Estuary Swamp	EstLagWet_ 030	Waianakarua River Estuary Swamp	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Waikouaiti River Estuary Wetland Complex	EstLagWet_ 031	Waikouaiti River Estuary Wetland Complex	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Whareakeake Marsh	EstLagWet_ 032	Whareakeake Marsh	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Tavora Wetland	EstLagWet_ 033	Tavora Wetland	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Pleasant River Estuary	EstLagWet_ 034	Pleasant River Estuary	ORC wetlands dataset	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	No	Yes
Waikouaiti Estuary	EstLagWet_ 035	Waikouaiti Estuary - subtidal & intertidal	Waikouaiti2017_ Estuary_ORC mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Tokomairiro Estuary	EstLagWet_ 036	Tokomairiro Estuary - subtidal & intertidal	Tokomairiro2018 _Estuary_ORC mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Kakanui Estuary	EstLagWet_ 037	Kakanui Estuary - subtidal & intertidal	Kakanui2021_ Estuary_ORC_ mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Shag Estuary	EstLagWet_ 038	Shag Estuary - subtidal & intertidal	Shag2016_ Estuary_ORC_ mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Kaikorai Estuary	EstLagWet_039	Kaikorai Estuary - subtidal & intertidal	Kaikorai2018_Estuary_ORC_mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Catlins Estuary	EstLagWet_040	Catlins Estuary - subtidal & intertidal	Catlins2016_Estuary_ORC_mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes
Blueskin Estuary	EstLagWet_041	Blueskin Estuary - subtidal & intertidal	Blueskin2020_21_Estuary_ORC_mapping	1, 3, 4, 5, 8, 9	11 a (iii), b (ii), b (iii), b (iv), b (v), b (vi)	Yes	Yes

Demersal Fish

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Taiaroa Head demersal fish SEA	FishDF_001	Occurrence of rare and threatened species, highly suitable habitat and spawning areas for numerous demersal fish species	NZ_fish_point_records_rarity. Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	1, 2, 3, 4, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	No	Yes
Wickliffe Bay offshore demersal fish SEA	FishDF_002	High abundance, highly suitable habitat and spawning areas for numerous demersal fish species	Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	3, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	No	No
Cape Saunders offshore demersal fish SEA	FishDF_003	Occurrence of rare and threatened species, high abundance, highly suitable habitat and spawning areas for numerous demersal fish species	NZ_fish_point_records_rarity. Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	1, 2, 3, 4, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	No	Yes
Catlins demersal fish SEA	FishDF_004	Occurrence of rare and threatened species, high abundance and highly suitable habitat and spawning areas for numerous demersal fish species	NZ_fish_point_records_rarity. Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	1, 2, 3, 4, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	No	Yes
North Otago demersal fish SEA	FishDF_005	Important location for rare and threatened species, high abundance and highly suitable habitat and spawning areas for numerous demersal fish species	NZ_fish_point_records_rarity. Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	1, 2, 3, 4, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	Yes	Yes
Tokomairiro offshore demersal fish SEA	FishDF_006	Occurrence of rare and threatened species, high abundance, highly suitable habitat and spawning areas for numerous demersal fish species	NZ_fish_point_records_rarity. Demersal fish species distribution models. MPI spatial catch data. Finfish Spawning areas.	1, 2, 3, 4, 5, 6, 9	11 a (iii), b (ii), b (iv), b (v)	No	No

Reef Fish

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Lookout bluff reef fish SEA	FishRF_001	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Cape Wanbrow reef fish SEA	FishRF_002	High abundance of reef fish, lobster and paua, high habitat suitability for numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Orore Point reef fish SEA	FishRF_003	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Kakanui reef fish SEA	FishRF_004	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Hampden reef fish SEA	FishRF_005	High abundance of reef fish and lobster, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Taki-a-Maru reef fish SEA	FishRF_006	High abundance of reef fish and lobster, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Shag point reef fish SEA	FishRF_007	High abundance of reef fish, lobster and paua, high habitat suitability for numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Moeraki reef fish SEA	FishRF_008	High abundance of reef fish, lobster and paua, high habitat suitability for numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Bobby's Head reef fish SEA	FishRF_009	High abundance of reef fish, lobster and paua, high habitat suitability for numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Omimi reef fish SEA	FishRF_010	High abundance of reef fish and lobster, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Potato Point reef fish SEA	FishRF_011	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Taiaroa Head reef fish SEA	FishRF_012	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Cape Saunders reef fish SEA	FishRF_013	High abundance of reef fish and lobster, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Harakeke Point reef fish SEA	FishRF_ 014	High abundance of reef fish and lobster, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Dunedin offshore south reef fish SEA	FishRF_ 015	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Dunedin offshore east reef fish SEA	FishRF_ 016	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Dunedin offshore north reef fish SEA	FishRF_ 017	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Bull Creek reef fish SEA	FishRF_ 018	highly suitable habitat for numerous reef fish	Reef fish species distribution models	6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Nuggets reef fish SEA	FishRF_ 019	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Jack's Bay reef fish SEA	FishRF_ 020	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Long Point reef fish SEA	FishRF_ 021	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No
Makati reef fish SEA	FishRF_ 022	High abundance of reef fish and paua, high habitat suitability of numerous reef fish	Reef fish species distribution models. MPI spatial catch data	5, 6, 9	11 b (iii), b (ii), b (iv), b (v)	No	No

Kelp Forest

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Cape Wanbrow kelp forest SEA	Kelp_001	Occurrence of kelp forest habitat	biogenic_macrocystis. KelpBeds. Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	No
North Otago coast kelp forest SEA	Kelp_002	Occurrence of kelp forest habitat	Kelp forest distribution_Port Otago. biogenic_macrocystis. KelpBeds. Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	Yes
Puketeraki kelp forest SEA	Kelp_003	Occurrence of kelp forest habitat	Kelp forest distribution_Port Otago. biogenic_macrocystis. KelpBeds. Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Otago Harbour kelp forest SEA	Kelp_004	Highly suitable habitat for canopy-forming macroalgae	Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	No
Kuri Bush kelp forest SEA	Kelp_005	Occurrence of kelp forest habitat	KelpBeds. Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	No
Catlins kelp forest SEA	Kelp_006	Occurrence of kelp forest habitat	KelpBeds. Species distribution models for canopy-forming macroalgae	1, 2, 3, 4, 5, 6, 8	11 a (v), b (i), b (ii), b (iii), b (iv), b (vi)	No	No

Marine Flora

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Cape Wanbrow marine flora SEA	MarFlor_001	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Kakanui marine flora SEA	MarFlor_002	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Orore Point marine flora SEA	MarFlor_003	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Hampden marine flora SEA	MarFlor_004	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Moeraki marine flora SEA	MarFlor_005	Occurrence of seagrass habitat	Seagrass_Jul2015. Macroalgae species distribution models	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	Yes
Shag River Estuary marine flora SEA	MarFlor_006	Occurrence of seagrass habitat	Shag2016_Macroalgae. Seagrass_ORCEstuary. Macroalgae species distribution models	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	Yes	Yes
Shag Point marine flora SEA	MarFlor_007	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Goodwood coast marine flora SEA	MarFlor_008	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Waikouaiti Estuary marine flora SEA	MarFlor_009	Occurrence of seagrass and macroalgae	Seagrass_ORCEstuary. Waikouaiti2017_Macroalgae Waikouaiti2017_Seagrass. Macroalgae species distribution models	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	Yes	Yes
Puketeraki marine flora SEA	MarFlor_010	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Blueskin Bay marine flora SEA	MarFlor_011	Occurrence of seagrass and macroalgae	Blueskin2020_21_Macroalgae. Blueskin2020_21_Seagrass. Macroalgae species distribution models. Seagrass_Jul2015. MPA_Habitat_BiogenicSeagrass.	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	Yes	Yes
Otakou marine flora SEA	MarFlor_012	Occurrence of seagrass habitat	Seagrass_Jul2015. E3 Scientific seagrass dataset. MPA_Habitat_BiogenicSeagrass. Seagrass_ORCEstuary. Macroalgae species distribution models.	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	Yes
Lower Otago Harbour marine flora SEA	MarFlor_013	Occurrence of seagrass habitat	Seagrass_Jul2015. MPA_Habitat_BiogenicSeagrass. Seagrass_ORCEstuary. Macroalgae species distribution models.	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	Yes
Upper Otago Harbour marine flora SEA	MarFlor_014	Occurrence of seagrass habitat	Seagrass_Jul2015. MPA_Habitat_BiogenicSeagrass. Seagrass_ORCEstuary. Macroalgae species distribution models.	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	Yes
Taiaroa Head marine flora SEA	MarFlor_015	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Papanui inlet marine flora SEA	MarFlor_016	Occurrence of seagrass habitat	Seagrass_Jul2015. E3 Scientific seagrass dataset. MPA_Habitat_BiogenicSeagrass. Seagrass_ORCEstuary. Macroalgae species distribution models.	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	Yes
Tokomairiro marine flora SEA	MarFlor_017	Occurrence of seagrass and macroalgae	Tokomairiro2018_Macroalgae. Tokomairiro2018_Seagrass. Macroalgae species distribution models	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	Yes	Yes
Catlins River marine flora SEA	MarFlor_018	Occurrence of seagrass and macroalgae	Catlins2016_Macroalgae. Catlins2016_Seagrass. Seagrass_ORCEstuary. MPA_Habitat_BiogenicSeagrass. Macroalgae species distribution models	1, 3, 5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	Yes	Yes
Penguin Bay marine flora SEA	MarFlor_019	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Nugget Point marine flora SEA	MarFlor_020	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Tautuku marine flora SEA	MarFlor_021	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No
Skeleton Point marine flora SEA	MarFlor_022	Highly suitable habitat for numerous macroalgae species	Macroalgae species distribution models	5, 6, 8	11 b (i), b (ii), b (iii), b (vi)	No	No

Marine Mammal – Ocean

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Blueskin Bay marine mammal ocean SEA	MMOcean_001	Occurrence and highly suitable habitat for Hector's dolphin and other cetaceans, important areas for sea lion foraging	Cetacean species distribution models. NZ_FurSeal_ForagingRange. HWilliams_Nemo_HectorsDolphin_Sightings. MARI429_HectorsDolphin_Sightings. Monarch_HectorsDolphin_sightings. NZ_SeaLion_Foraging Range. FemaleSeaLionForaging_2008to10_27_05_2015_FINAL.	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),	Yes	Yes
North coast marine mammal ocean SEA	MMOcean_002	Highly suitable habitat for numerous cetaceans, fur seal foraging	Cetacean species distribution models. NZ_FurSeal_ForagingRange	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),	No	No
South Dunedin coast marine mammal ocean SEA	MMOcean_003	Highly suitable habitat for numerous cetaceans, important sea lion and fur seal foraging	Cetacean species distribution models. NZ_FurSeal_ForagingRange. FemaleSeaLionForaging_2008to10_27_05_2015_FINAL	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),	No	No
Catlins marine mammal ocean SEA	MMOcean_004	Highly suitable habitat for numerous cetaceans, fur seal foraging	Cetacean species distribution models. NZ_FurSeal_ForagingRange	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),	No	No
Otago Peninsula marine mammal ocean SEA	MMOcean_005	Occurrence and highly suitable habitat for Hector's dolphin and other cetaceans, Important sea lion and fur seal foraging habitat	Cetacean species distribution models. NZ_FurSeal_ForagingRange. HWilliams_HectorsDolphin. MARI429_HectorsDolphin. Monarch_HectorsDolphin_sightings. NZ_SeaLion_ForagingRange. FemaleSeaLionForaging. ALLCETACEANS20162019.	3, 4, 6, 8	11 a (i), a (ii), a (iv), a (vi), b (iv), b (v),	Yes	Yes

Marine Mammal – Terrestrial

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Fur Seal SEAs	MMTerr_001	Haulouts and breeding colonies for fur seals	New_Zealand_Fur_Seal___Breeding_Colonies_Distribution. ORC_Fur_seal. GEOPHYSICAL_NaturallyUncommon Ecosystems - Marine mammal haulouts.	3, 4	11 a (vi), b (ii)	Yes	Yes
Sea Lion SEAs	MMTerr_002	Haulouts and breeding colonies for sea lions	New_Zealand_Hookers_Sealion_Breeding_Colonies_Distribution. NZSLT database sea-lions-sightings April 2022. GEOPHYSICAL_NaturallyUncommon Ecosystems - Marine mammal haulouts. ORC_Sea_lion.	2, 3, 4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv),	Yes	Yes

Naturally Uncommon Ecosystems

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Active sand dunes - Otago wide SEA	NatUnc_001	Occurrence of active sand dunes	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No
Coastal rock stacks - Otago wide SEA	NatUnc_002	Occurrence of coastal rock stacks	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No
Coastal turfs - Otago wide SEA	NatUnc_003	Occurrence of coastal turfs	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No
Shingle beaches - Otago wide SEA	NatUnc_004	Occurrence of shingle beaches	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No
Seabird guano deposits - Otago wide SEA	NatUnc_005	Occurrence of seabird guano deposits	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No
Seabird-burrowed soils - Otago wide SEA	NatUnc_006	Occurrence of seabird-burrowed soils	GEOPHYSICAL_NaturallyUncommon Ecosystems	2	11 a (iv), b (iii)	No	No

Pelagic Productivity

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Southland front pelagic SEA	PelProd_001	Indication of persistent frontal features (Southland current) based on gradient in sea surface temperature	SSTGrad	2, 5, 8	11 a (v), b (vi)	Yes	Yes

Shore/seabirds - Marine

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Oamaru seabird marine SEA	BirdMar_001	Important habitat for foraging Hoiho, albatross, Little Blue Penguin and other seabirds	Tracked Albatross data. Coastal_seabirds_marine. iNaturalist_Birds. DOC_HoihoTracking. Otago_BluePenguinRange_17_10_14_FINAL	2, 3, 4, 6	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)	Yes	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Dunedin seabird marine SEA	BirdMar_002	Important habitat for foraging Hoiho, albatross, Little Blue Penguin, wading birds and other seabirds	Tracked Albatross data. Coastal_seabirds_marine. iNaturalist_Birds. DOC_HoihoTracking. Otago_BluePenguinRange. Birds NZ Otago Harbour Survey. National Wader Count - abundance & biodiversity. Seabirds_canyons. OBIS_Birds	2, 3, 4, 6	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)	Yes	Yes
Tirohanga seabird marine SEA	BirdMar_003	Important habitat for foraging Hoiho and other seabirds	Coastal_seabirds_marine. iNaturalist_Birds. DOC_HoihoTracking.	2, 3, 4, 6	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)	Yes	Yes
Catlins seabird marine SEA	BirdMar_004	Important habitat for foraging Hoiho and other seabirds	Coastal_seabirds_marine. iNaturalist_Birds. DOC_HoihoTracking.	2, 3, 4, 6	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)	Yes	Yes
Bobby's Head seabird marine SEA	BirdMar_005	Important habitat for foraging Hoiho, albatross and other seabirds	Tracked Albatross data. Coastal_seabirds_marine. iNaturalist_Birds. DOC_HoihoTracking.	2, 3, 4, 6	11 a (i), a (ii), a (iv), a (vi), b (ii), b (iv)	Yes	Yes

Shore/seabirds - Terrestrial

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Cape Wanbrow terrestrial seabird SEA	BirdTerr_001	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. NZ_IBA_Bird_Colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Lookout Bluff terrestrial seabird SEA	BirdTerr_002	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Moeraki terrestrial seabird SEA	BirdTerr_003	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. NZ_IBA_Bird_Colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Katiki Beach terrestrial seabird SEA	BirdTerr_004	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Shag Point terrestrial seabird SEA	BirdTerr_005	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Bobby’s Head terrestrial seabird SEA	BirdTerr_006	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Puketeraki terrestrial seabird SEA	BirdTerr_ 007	Contains seabird breeding colonies	Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), b (ii), b (iv)	No	Yes
Purakaunui terrestrial seabird SEA	BirdTerr_ 008	Contains seabird breeding colonies	Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), b (ii), b (iv)	No	Yes
Otago Peninsula terrestrial seabird SEA	BirdTerr_ 009	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. NZ_IBA_Bird_Colonies. Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Otago Harbour terrestrial seabird SEA	BirdTerr_ 010	Contains seabird breeding colonies	Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), b (ii), b (iv)	No	Yes
South Dunedin terrestrial seabird SEA	BirdTerr_ 011	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Green Island terrestrial seabird SEA	BirdTerr_ 012	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	Yes	Yes
Northern Catlins terrestrial seabird SEA	BirdTerr_ 013	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Southern Catlins terrestrial seabird SEA	BirdTerr_ 014	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. NZ_IBA_Bird_Colonies. Otago_SeabirdColonies_21_ 11_14_FINAL. ORC Bird Colonies	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes
Aramoana terrestrial seabird SEA	BirdTerr_ 015	Contains Hoiho and other seabird breeding colonies	YEPT Hoiho colonies. Otago_SeabirdColonies_21_ 11_14_FINAL	1,2,3,4	11 a (i), a (ii), a (iv), a (v), a (vi), b (ii), b (iv)	No	Yes

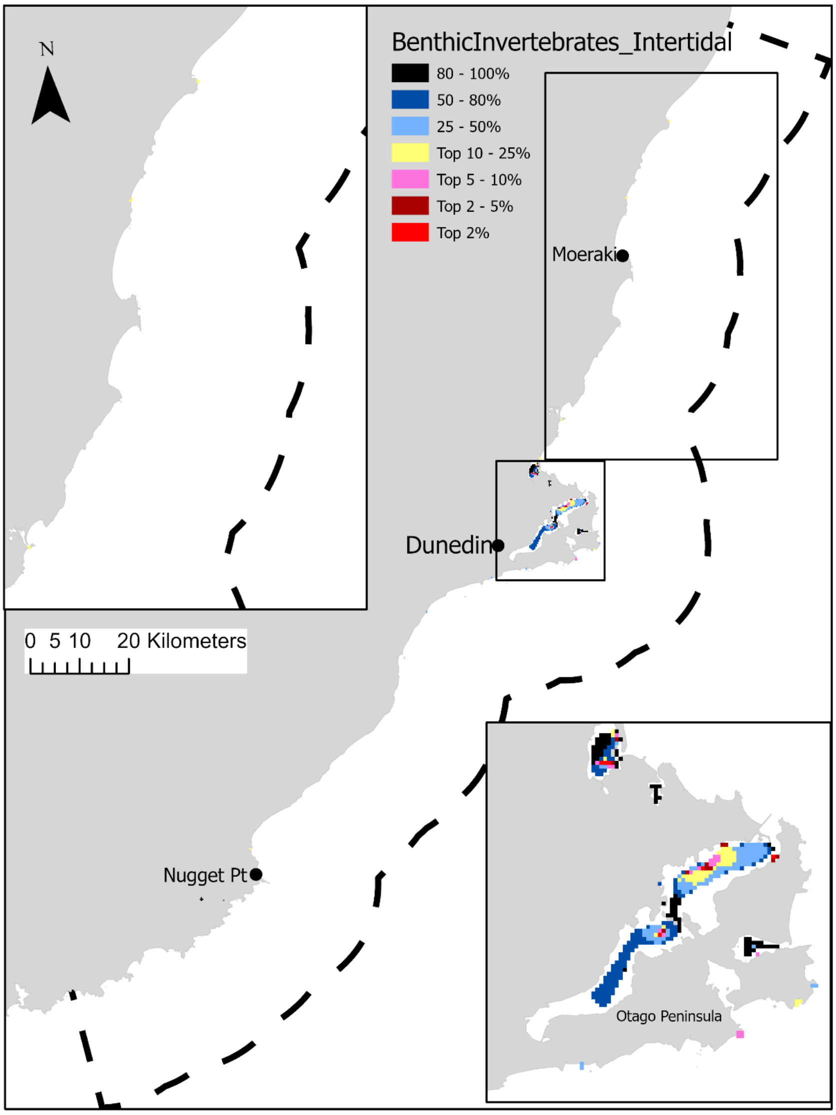
Seafloor geomorphological features

Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
Head of Saunders Canyon seafloor SEA	SeaFlr_001	Head of Saunders Canyon	NIWA Bathymetry	2, 5, 6, 9	11 a (iv), a (v), b (v), b (vi)	No	Yes
Head of Papanui Canyon seafloor SEA	SeaFlr_002	Head of Papanui Canyon	NIWA Bathymetry	2, 5, 6, 9	11 a (iv), a (v), b (v), b (vi)	No	Yes
Head of Taiaroa Canyon seafloor SEA	SeaFlr_003	Head of Taiaroa Canyon	NIWA Bathymetry	2, 5, 6, 9	11 a (iv), a (v), b (v), b (vi)	No	Yes
Taieri reef system seafloor SEA	SeaFlr_004	Highly variable bathymetry - possible reef system	LINZ_MPPF_25mDEM	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No

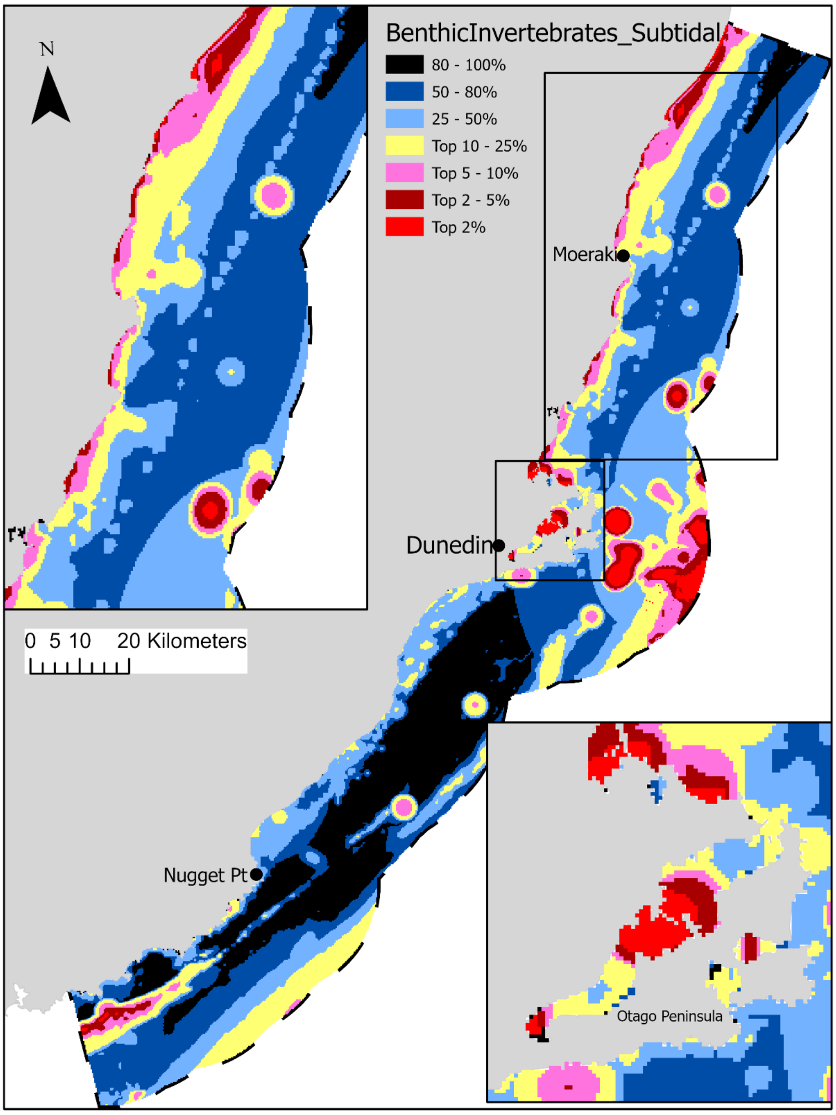
Name	Code	Features	Evidence	KEA criteria	Policy11 criteria	Extent defined	Validated
North Coast reef platform seafloor SEA	SeaFlr_005	Significant contiguous coastal reef platform	DOC Rocky Reef. LINZ_MPPF_25mDEM	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No
Waianakarua offshore deep reef seafloor SEA	SeaFlr_006	Rare offshore deep reef	LINZ_MPPF_25mDEM	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No
Maori Head offshore deep reef seafloor SEA	SeaFlr_007	Rare offshore deep reef	DOC_Rocky_Reef. LINZ_MPPF_25mDEM	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No
Puketeraki coastal reef platform seafloor SEA	SeaFlr_008	Significant contiguous coastal reef platform	DOC Rocky Reef	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No
South Coast offshore seafloor SEA	SeaFlr_009	Areas of foul and papa rock	MPA_Habitat_Rocky Reef	2,5,6	11 b (ii), b (iii), b (iv), b (vi)	No	No

Appendix C Zonation prioritisation outputs

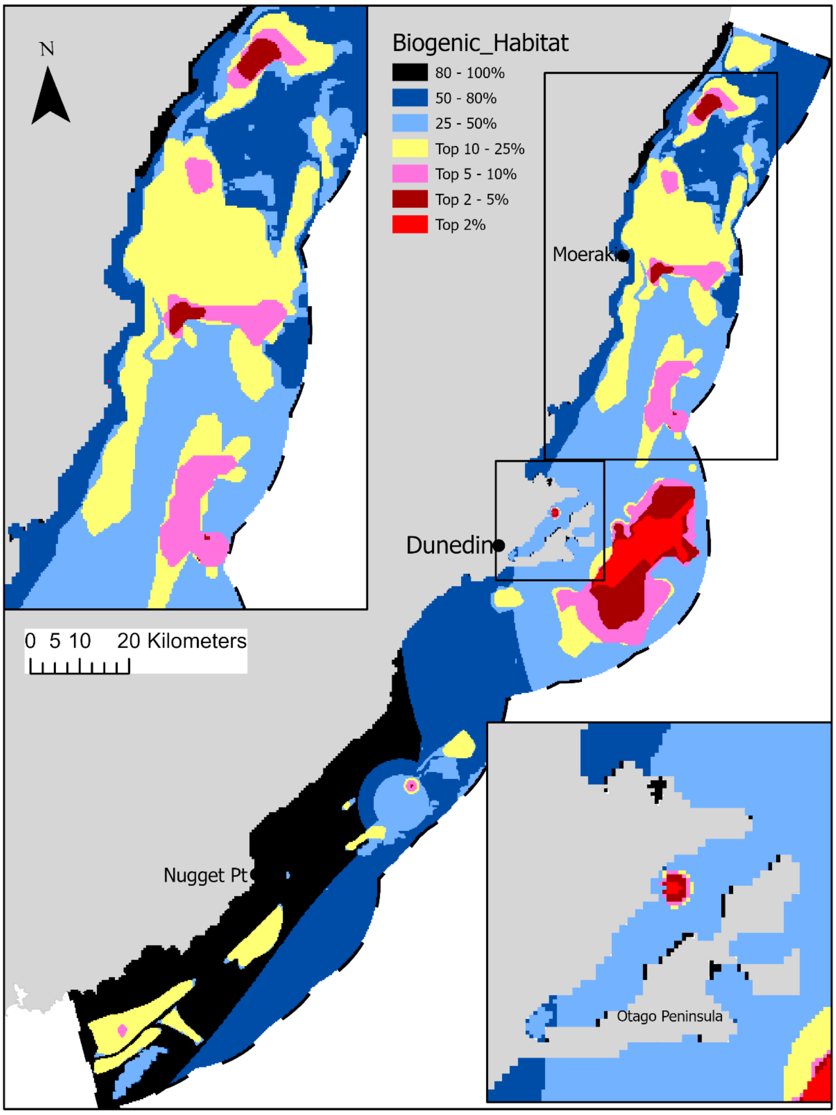
Benthic Invertebrates - Intertidal



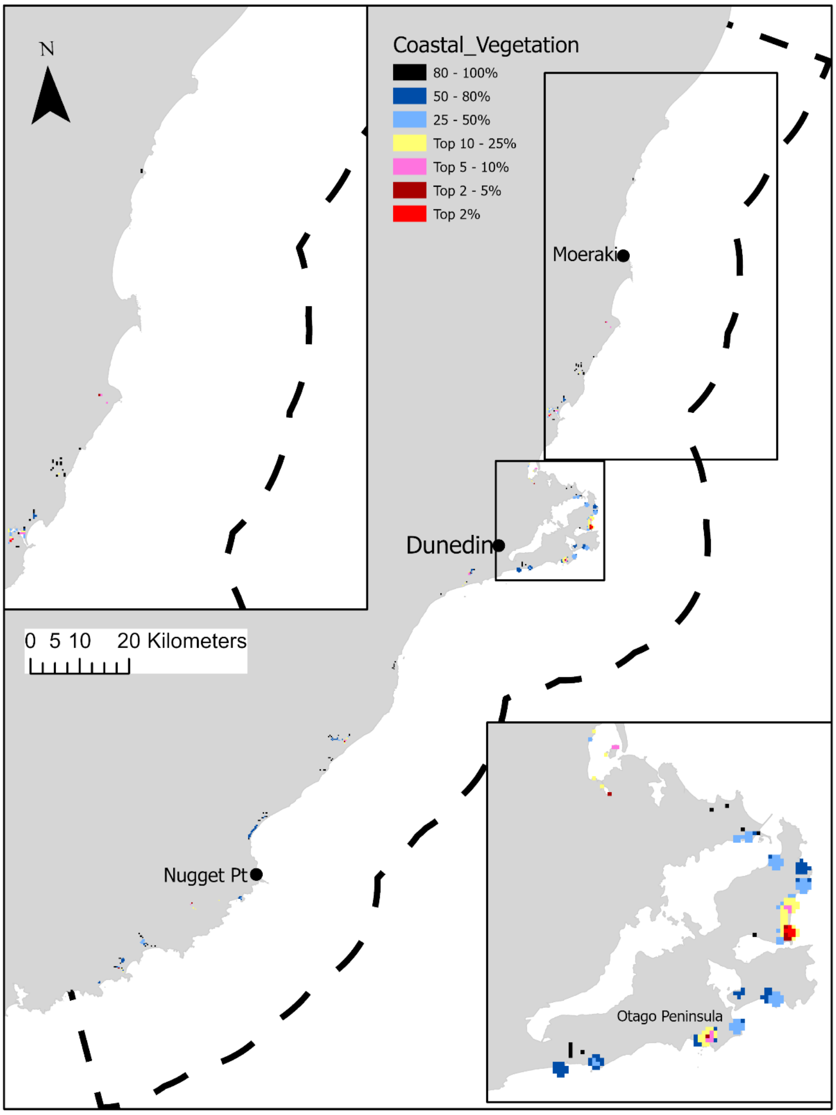
Benthic Invertebrates - Subtidal



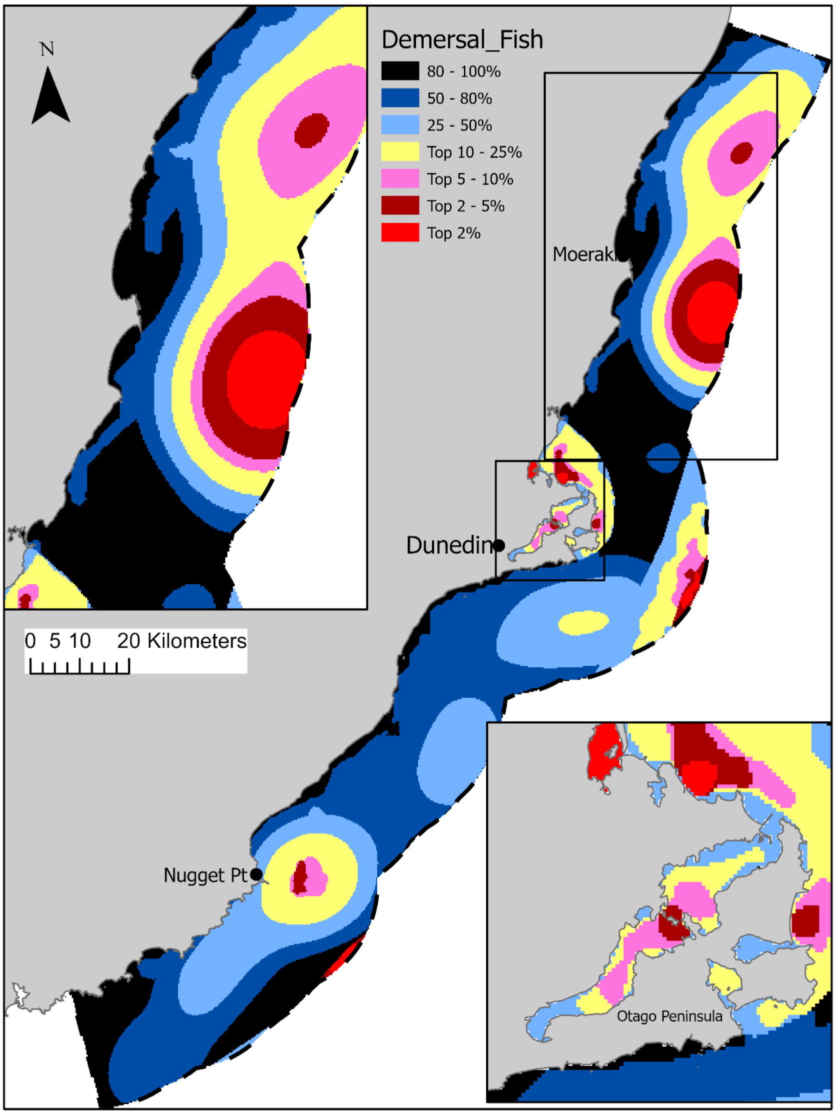
Biogenic Habitats – Invertebrates



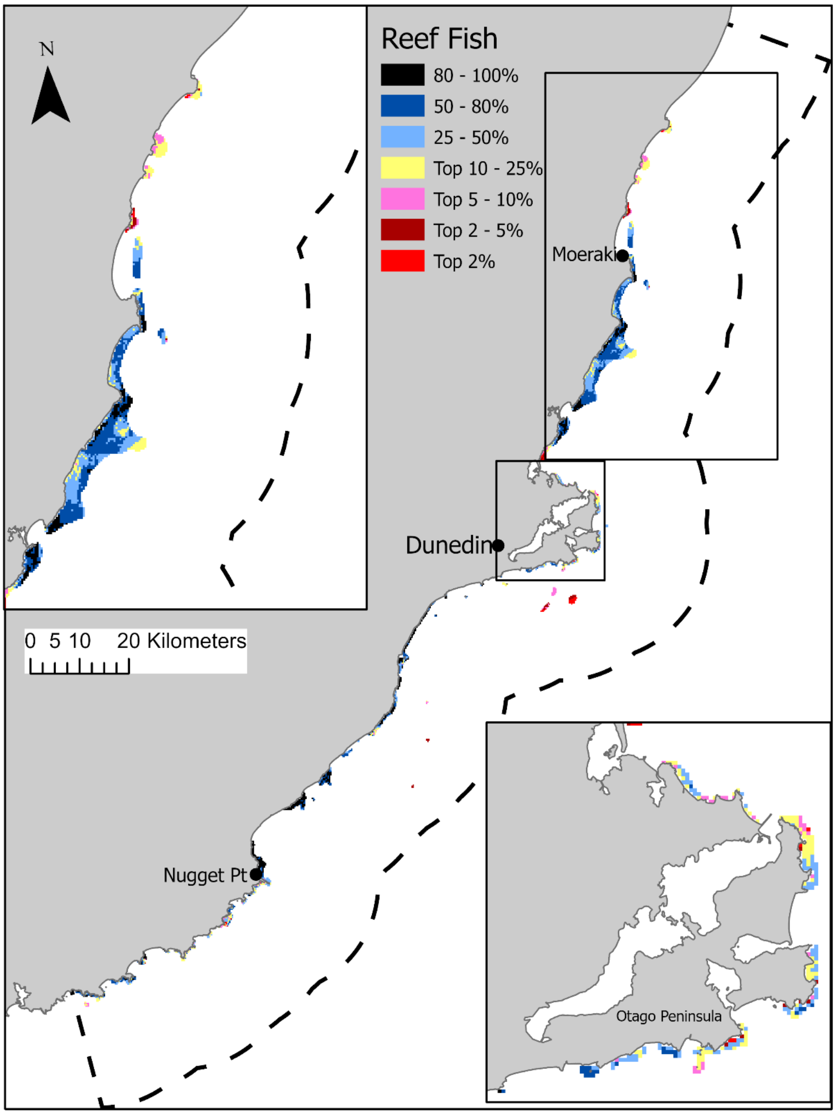
Coastal Vegetation



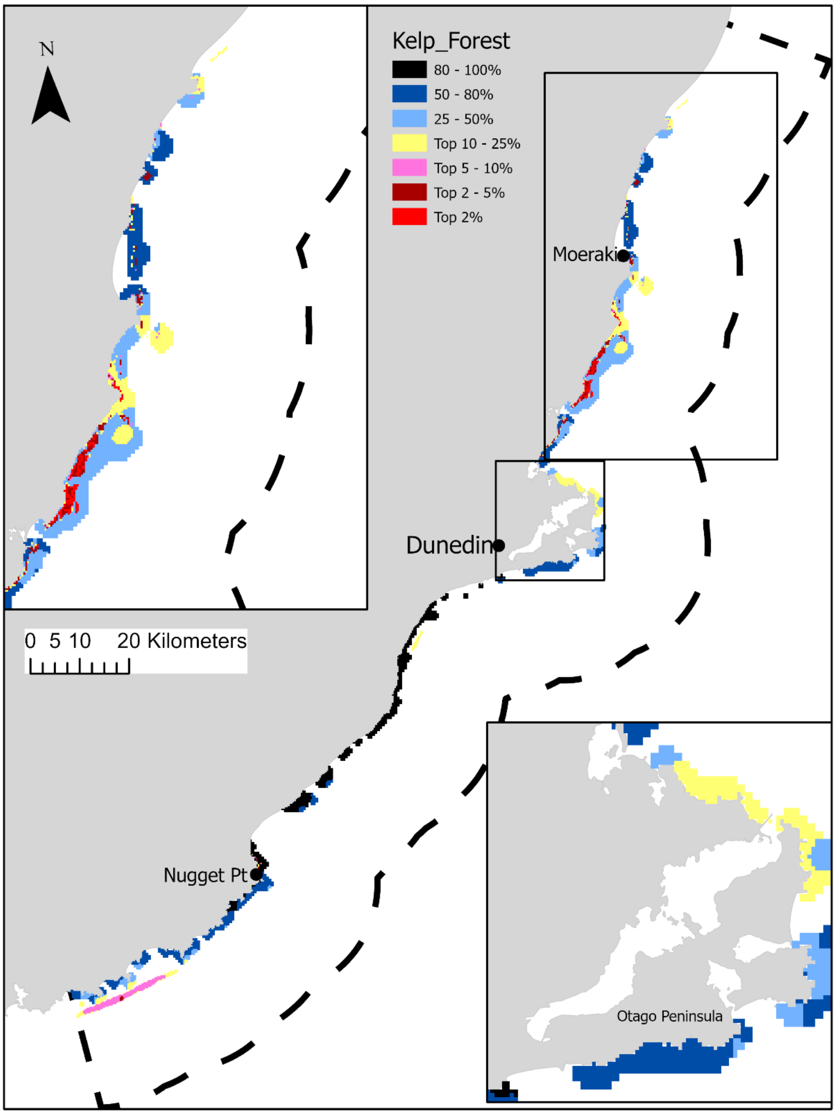
Demersal Fish



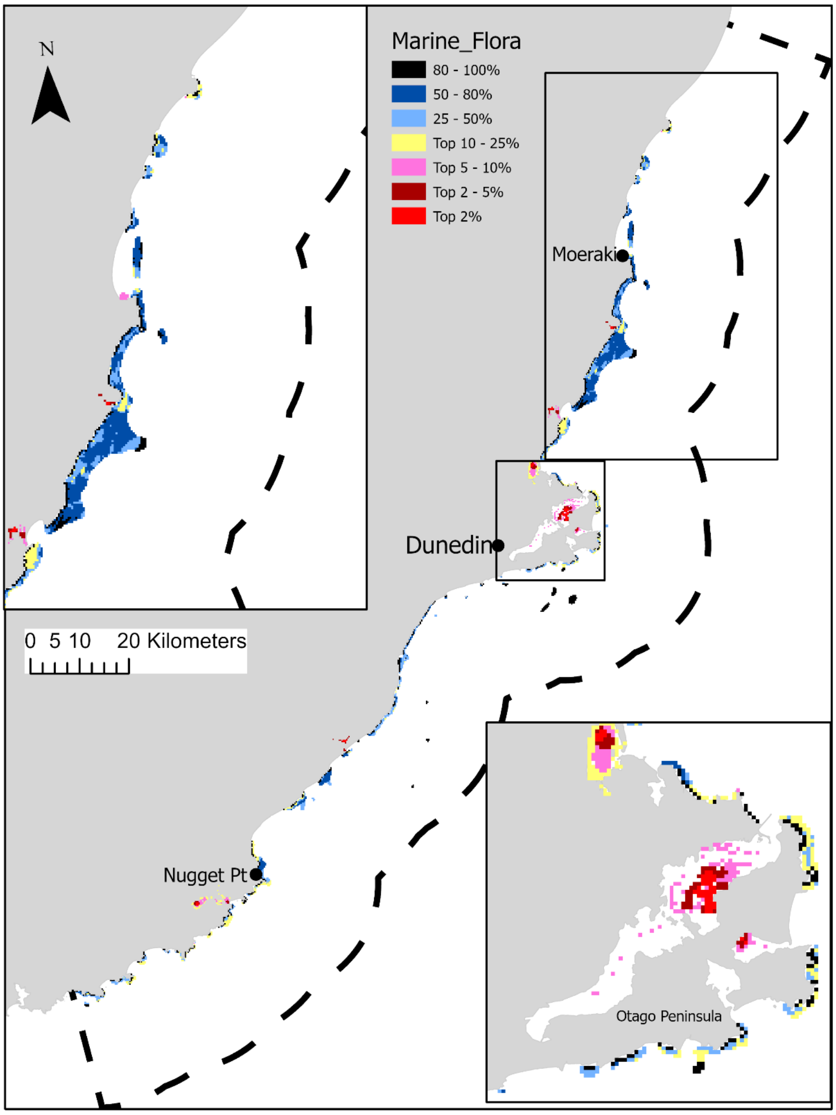
Reef Fish


N
Reef Fish
80 - 100%
50 - 80%
25 - 50%
Top 10 - 25%
Top 5 - 10%
Top 2 - 5%
Top 2%
Moeraki
Dunedin
0 5 10 20 Kilometers
Nugget Pt
Otago Peninsula

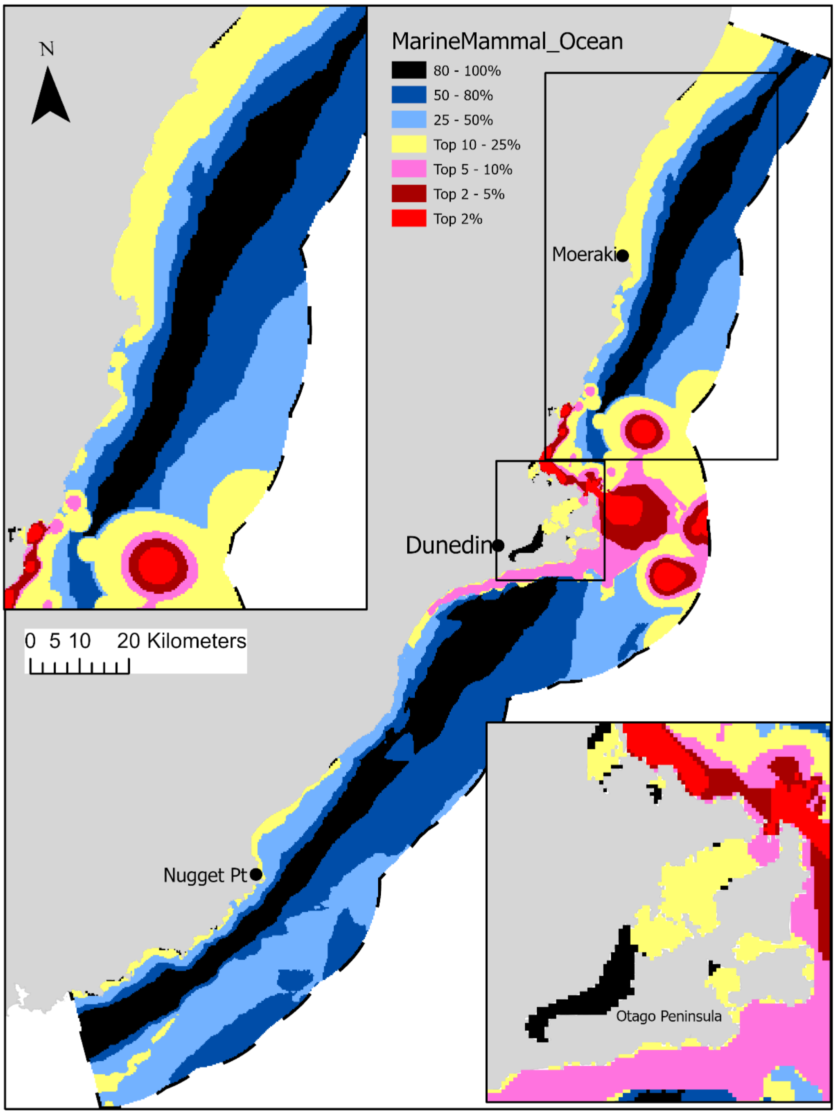
Kelp Forest


N
Kelp_Forest
80 - 100%
50 - 80%
25 - 50%
Top 10 - 25%
Top 5 - 10%
Top 2 - 5%
Top 2%
Moeraki
Dunedin
0 5 10 20 Kilometers
Nugget Pt
Otago Peninsula

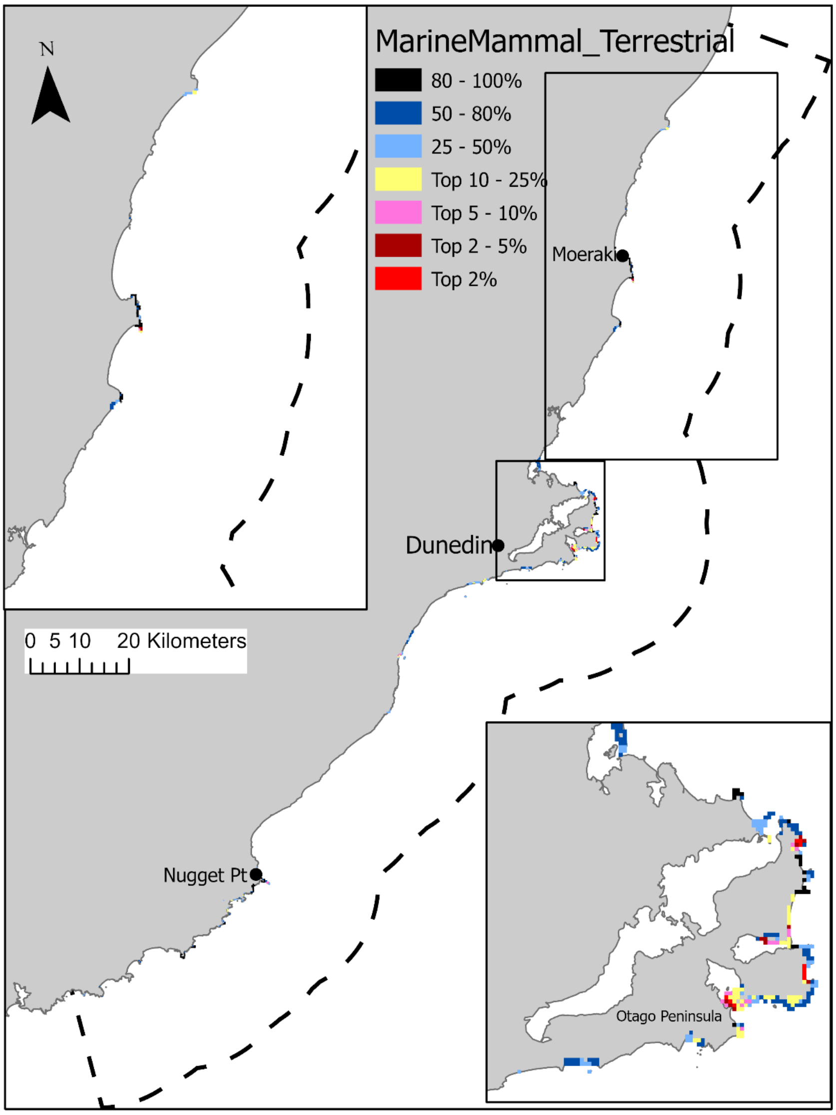
Marine Flora



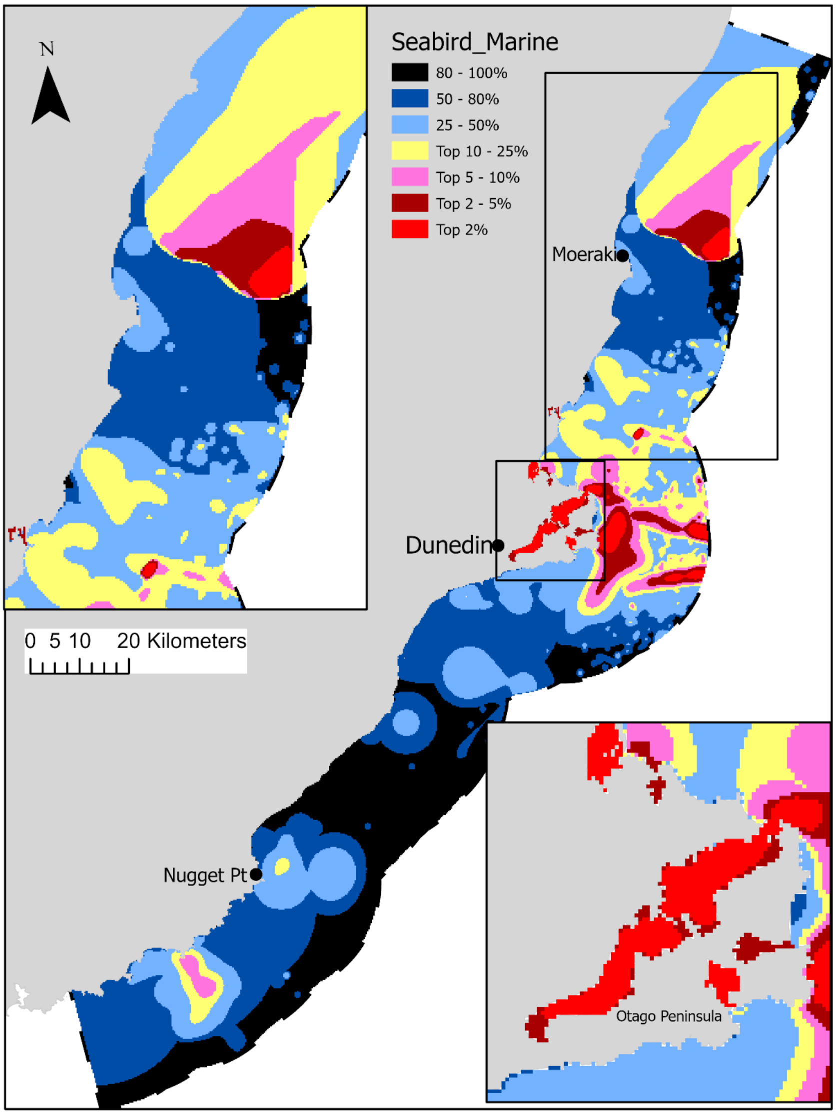
Marine Mammal – Ocean



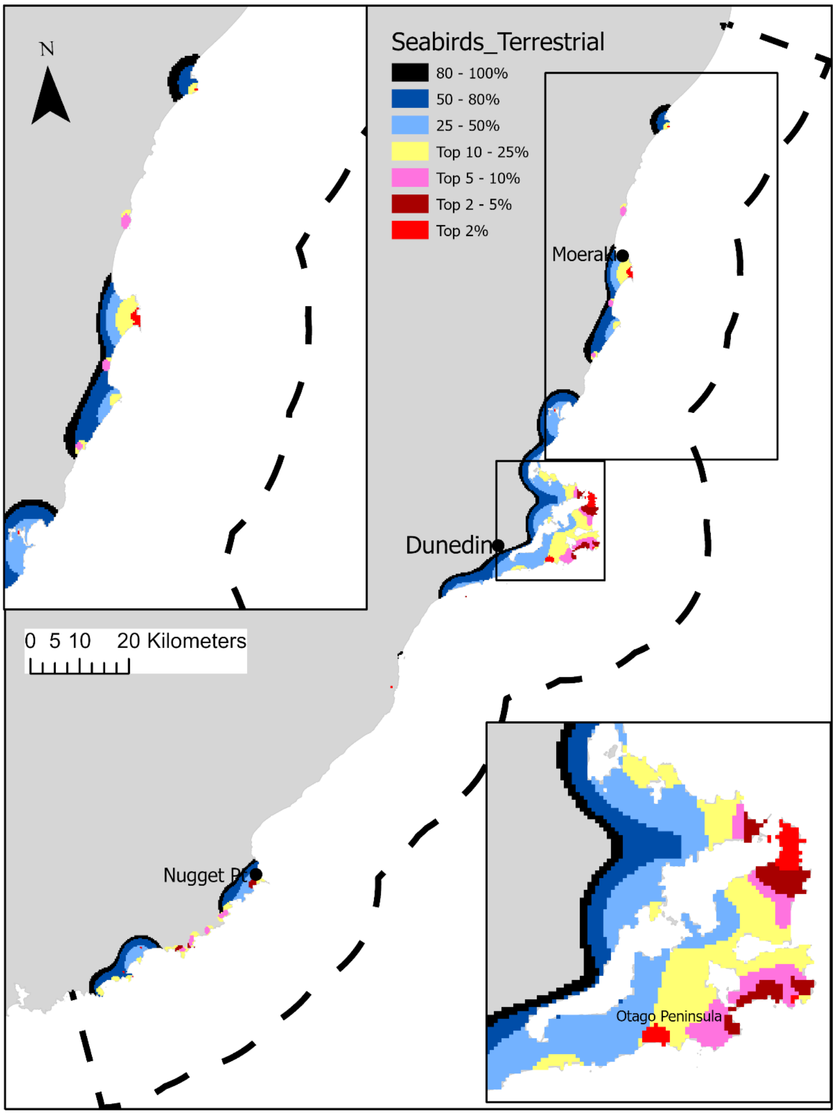
Marine Mammal – Terrestrial



Shore/seabird – Marine



Shore/seabirds – Terrestrial



6.7. Key messages from the Ministry for the Environment and Stats NZ report Our Freshwater 2023 released on 12 April 2023

Prepared for:	Environmental Science and Policy Comm
Report No.	POL2304
Activity:	Environmental: Water
Author:	Peter Constantine, Acting Principal Planner
Endorsed by:	Anita Dawe, General Manager Policy and Science Pim Borren, Interim Chief Executive
Date:	15 April 2023

PURPOSE

[1] The purposes of this report are:

a. to draw to the Otago Regional Council's (ORC or Council) attention the publication of the report *Our freshwater 2023* and
b. to set out the key findings of that report, and
c. to make some observations regarding the implications of those findings for the Council.

EXECUTIVE SUMMARY

[2] On 12 April 2023, the Ministry for the Environment and Stats NZ released the report *Our Freshwater 2023*. This report 2023 examines the most pressing issues in Aotearoa New Zealand's lakes, rivers, streams, wetlands and aquifers, which connect to each other, ki uta ki tai (from mountains to sea).

[3] *Our freshwater 2023* is the third report in the series dedicated to the freshwater environment, following the 2017 and 2020 reports, and is part of the third cycle of reports released under the Environmental Reporting Act 2015. The report brings together peer reviewed published studies, mātauranga Māori and data from environmental indicators.

[4] Indicators presented in *Our freshwater 2023* and the research literature are based on the best available science and highlight the issues facing the freshwater environment. Ongoing monitoring and advancing research have improved understanding of these issues, but the report acknowledges there are still gaps in our knowledge. These gaps are primarily the result of the challenge presented by the scale and diversity of the freshwater environment, and by the complexity of interactions between land-based pressures and their impacts on freshwater.

[5] The report discusses issues at a national level, drawing on a limited number of region-specific examples, but only to illustrate the point being made. With a few exceptions, the report does not contain any information that is specific and unique to the Otago region.

[6] Overall, the findings in *Our freshwater 2023* are a salutary reminder to the reader that while there is ongoing good work being done to improve the quality and management of Aotearoa New Zealand's freshwater resources, there is much work still to do. Additionally, this report reminds us that the task is complex, because of the many different moving parts, and reinforces that gaps in our knowledge are not sufficient reasons to do nothing.

RECOMMENDATION

That the Council:

1) ***Notes** this report.*
2) ***Notes** the key findings from* 0ur freshwater 2023*.*
3) ***Notes** the observations regarding the implications of the key findings for the ongoing work of the Otago Regional Council.*

BACKGROUND

[7] *Our freshwater 2023* is the third in a series of environmental reports (following the 2017 and 2020 reports) produced by the Ministry for the Environment and Stats NZ. It was released on 12 April 2023. It is prepared and released under the Environmental Reporting Act 2015.

[8] *Our freshwater 2023* continues the scaled-back format for environmental reports first signalled in Our air 2021, making information available while further progress is made with necessary and fundamental changes required to improve the reporting system to align with recommendations from the Parliamentary Commissioner for the Environment (Focusing Aotearoa New Zealand's environmental reporting system, PCE, 2019). This is an information-oriented release, with the primary focus on recent information about the freshwater environment. This report brings current freshwater indicators together with what is known from past reports and insights from the research literature.

[9] The report uses pressure, state, and impact to report on the environment and this forms the basis for the report's structure. The logic of the framework is that pressures cause changes to the state of the environment and these changes may have impacts on freshwater values.

DISCUSSION

Overview of key findings

[10] Aotearoa New Zealand's freshwater environment supports all aspects of our lives, and we share an intimate and innate connection with it. It is central to wellbeing, supporting our economy, recreation, and gathering food. For many Māori, the freshwater environment is central to tikanga Māori (customs/protocols), mātauranga Māori (Māori knowledge), and mahinga kai (traditional food gathering practices).

[11] Despite this, our freshwater environment is under pressure from activities on the land and in the water, and from a changing climate. While some freshwater bodies are in a

reasonably healthy state, many have been degraded by the effects of excess nutrients, pathogens, and other contaminants from land.

[12] *Our freshwater 2023* describes impacts on freshwater species and ecosystems, infrastructure, culture, economy, public health, and recreation.

[13] In determining the state of Aotearoa New Zealand' freshwater, the report notes the importance of acknowledging the whole catchment – ki uta ki tai - and explores connections to the freshwater environment to the extent that is possible with the available information and identifies information gaps.

[14] It recognises that the freshwater ecosystem health framework is a concept that recognises the holistic nature of the freshwater environment, connecting landscapes, ecosystems, and people. The framework incorporates factors like biodiversity, the quality of habitats, and how well essential ecosystem processes are working. Understanding the overall health of freshwater ecosystems requires measures of five core components: aquatic life and biodiversity, habitats, water quantity and flows, ecological processes, and water quality.

[15] Importantly, the report also acknowledges that measuring all parts of an ecosystem is challenging, and data are not widely available for some components of ecosystem health like aquatic life and ecological processes. As a result, any ability to comprehensively assess the health of most of our ecosystems, and the health of our freshwater environment as a whole is limited.

[16] Following the introduction, which includes a section on Te ao Māori, mauri, and our connection to freshwater, the research findings are presented under four headings. Set out below, under each of those four headings, are the key findings. Each of the key findings is substantiated in the report through text and links to the original research upon which they are founded.

[17] The research findings outlined in the report generally apply at a national level, drawing on a limited number of region-specific examples, but only to illustrate the point being made. With a few exceptions, the report does not discuss any pressures, issues or findings that are specific and unique to the Otago region.[1]

1. Pressures on our freshwater environment

[18] Our freshwater environment continues to be affected by a variety of pressures. Key pressures include the following:

- Land-use intensification and other changes to how we use the land have increased pressures on water quality.
- Land-based human activities contribute to excess nutrients and sediment in our waterways.
- Wastewater, stormwater, and livestock waste are sources of freshwater contaminants, such as pathogens and heavy metals.

[1] The report notes that introduced fish species are more prevalent in Otago and in the central North Island than in any other part of the country. (Ministry for the Environment, Our Freshwater 2023, p14)

- Plastics and chemicals that have been produced and used for decades contaminate our freshwater environment.
- Introduced freshwater species are widespread, with some degrading freshwater bodies and threatening native species.

- Structures for diverting or controlling water place pressure on freshwater flows and fish and kōura migrations.
- Hydropower and irrigation are the largest consented uses of freshwater, and place pressure on the timing and volume of freshwater flows.
- Our climate is changing, and more frequent and intense rainfall and droughts are putting increasing pressure on our freshwater environment.

2. State of our freshwater environment

[19] Key findings with respect to the state of our freshwater are:

- Indigenous indicators and mātauranga Māori (Māori knowledge) can help us understand the state of the freshwater environment.
- The freshwater ecosystem health framework measures multiple components of freshwater to understand the overall health of freshwater ecosystems.
- The water quality of some of our rivers and lakes could be harmful to ecosystems and human health.
- Our freshwater quality is mixed, with some excess nutrient levels that can harm ecosystems.
- The quality of some of our freshwater is unsuitable for recreational activities.
- The quality of some of our groundwater is unsafe for drinking.
- Many of our indigenous taonga freshwater fish, invertebrate species and indigenous freshwater bird species are threatened with extinction or at risk of becoming threatened.
- Much of our historic wetland extent has been converted to other land uses, and wetland loss has continued, reducing habitat for dependent native species.
- Aotearoa has a lot of freshwater and we also use a lot of freshwater

3. Impacts on culture, species, wellbeing, and people

[20] Key findings with respect to the impacts of changes to the health of our freshwater on culture, species, wellbeing, and people are:

- Mātauranga Māori of te taiao is connected with the health of freshwater ecosystems and the abundance of taonga species.
- The lifegiving and healing properties that are essential for tikanga can be impacted by the health of freshwater systems.
- The ability to practice and access mahinga kai is impacted by the abundance and health of freshwater species and access to mahinga kai sites.
- Wāhi tapu, such as wetlands, have many benefits, though these benefits have been reduced by reductions in their extent and condition.
- Freshwater ecosystems are impacted by the excessive algal growth caused by increased nutrients. At high concentrations some nutrients become toxic to freshwater species.

- The effects of climate change on water temperatures, flows, and coastal environments are likely to impact our freshwater species and ecosystems.
- Fish migration is impacted by human changes to river flows and habitats.
- Public health has been impacted by contaminants and water-borne diseases in water used for recreation and drinking water.
- Our economy relies on our freshwater environment. Changes driven by climate change have impacts on both freshwater and our economy.

4. Data and research gaps

[21] Under this heading, the following key findings are noteworthy:

- The issues facing the freshwater domain are often complex and strongly linked to pressures occurring on the land. The time it takes for pressures, especially those on land, to be felt in the environment adds another layer of complexity.
- There are still critical gaps in our knowledge and further improvement is needed in terms of how well we collect and analyse data.
- There continues to be gaps in data, inconsistencies in methods and monitoring, lack of accessibility, and a gap in elevating mātauranga Māori. Also, there is not a fit-for-purpose environmental monitoring and reporting system that is adaptable to future challenges.

Implications of the key findings for the ORC

[22] The release of *Our freshwater 2023* is timely for the work currently being undertaken on the proposed Land and Water Regional Plan (pLWRP) for Otago in three separate but related respects.

1. While there are some knowledge gaps, there is sufficient knowledge held by Council and available elsewhere to underpin some of the necessary actions required to improve the quality and management of Otago's freshwater resources.
2. The management of freshwater resources in Otago involves a comprehensive consideration of many different moving parts and is therefore complex, but such management is necessary to achieve freshwater outcomes
3. ORC is on a journey and the direction of travel, the destination, and the time it will take to get there are not always clearly defined. There will be a need to be adaptable in respect of each of these elements as more data comes available and our collective knowledge improves, but halting the journey is not an option.

OPTIONS

[23] There are no options to be considered in relation to this paper.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[24] National planning instruments and the Proposed Otago Regional Policy Statement set the framework for managing Otago's natural and physical resources and these will be further implemented through the pLWRP. This report provides some useful insight into some of the complexities involved in the preparation of that plan.

Financial Considerations

[25] There are no financial considerations in relation to this paper

Significance and Engagement

[26] This paper or the upcoming report to the Minister do not trigger any requirements of *He Mahi Rau Rika: Significance, Engagement and Māori Participation Policy 2021*.

Legislative and Risk Considerations

[27] The report draws together recent research findings and is useful contextual material for the development of the pLWRP, but Council is not bound to give effect to or implement any of its findings.

Climate Change Considerations

[28] There are no climate change considerations from this paper.

Communications Considerations

[29] There are no specific communications considerations as a result of this paper.

NEXT STEPS

[30] As part of the development of the LWRP, staff will consider and discuss the findings set out in Our freshwater 2023 and, as appropriate and/or applicable will use them to inform plan drafting.

ATTACHMENTS

1. our-freshwater-2023 [**6.7.1** - 52 pages]

Our freshwater 2023

New Zealand's Environmental Reporting Series

Ministry for the Environment
Manatū Mō Te Taiao

Stats NZ
Tatauranga Aotearoa

Citation

Ministry for the Environment & Stats NZ (2023). *New Zealand's Environmental Reporting Series: Our freshwater 2023.* Retrieved from environment.govt.nz.

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Cover: Lake Tarawera.
Photo: Fraser Tebbutt, *truestock*

Contents

Introduction

Aotearoa New Zealand’s freshwater environment

Aotearoa New Zealand’s freshwater environment supports all aspects of our lives, and we share an intimate and innate connection with it. It is central to wellbeing, supporting our economy, recreation, and gathering food. For many Māori, the freshwater environment is central to tikanga Māori (customs/protocols), mātauranga Māori (Māori knowledge), and mahinga kai (traditional food gathering practices).

Despite this, our freshwater environment is under pressure from our activities on the land and in the water, and from a changing climate. While some of our freshwater bodies are in a reasonably healthy state, many have been degraded by the effects of excess nutrients, pathogens, and other contaminants from land.

Most of our indigenous freshwater fish and freshwater bird species, including some taonga (treasured) species, are either threatened with extinction or at risk of becoming threatened. The effects of our historic and contemporary activities on our freshwater environment have impacts on many of the things we value as individuals, communities, and as a nation, such as our iconic and taonga species and being able to swim and practice mahinga kai without risk of illness.

This report has been produced at a particularly poignant time, in the immediate aftermath and initial recovery from a number of severe weather events, notably, Cyclone Gabrielle. The effects of these events have made the combined pressures of climate change, land use, and human modifications to waterways more evident than ever before.

While this report covers these pressures and impacts, it does not discuss them in the context of recent severe weather events. Reporting on topics requires an understanding that is grounded in robust data and validated research, and scientific evidence is only beginning to emerge for these events. As new evidence and research about these events is published, it will be available to inform future reports.

Indicators presented in this report alongside the research literature are based on the best available science and highlight the issues facing the freshwater environment. Ongoing monitoring and advancing research have improved our understanding of these issues, but there are still gaps in our knowledge. This is primarily owing to the challenge presented by the scale and diversity of the freshwater environment, and by the complexity of interactions between land-based pressures and their impacts on freshwater. These and other issues are discussed in the Data and research gaps section.

About Our freshwater 2023

Our freshwater 2023 is the latest in a series of environmental reports produced by the Ministry for the Environment and Stats NZ. It is the third report in the series dedicated to the freshwater environment, following the 2017 and 2020 reports, and is part of the third cycle of reports released under the Environmental Reporting Act 2015.

In 2019 the Parliamentary Commissioner for the Environment (PCE) released his report, *Focusing Aotearoa New Zealand's environmental reporting system* (PCE, 2019). The report identified how the environmental reporting system can be improved, and recommended changes to the system and amendments to the Environmental Reporting Act. Implementation of these changes is in progress and will provide a stronger foundation to ensure we better understand te taiao (the environment) and the impacts people are having on it.

Our freshwater 2023 continues the scaled-back format for environmental reports first signalled in *Our air 2021*, making information available while we progress the fundamental changes needed to improve the reporting system to align with recommendations from the PCE (PCE, 2019). This is an information-oriented release, with the primary focus on recent information about the freshwater environment. This report brings current freshwater indicators together with what we know from past reports and insights from the research literature. Interactive graphs and maps can be found on the Stats NZ website (see links to indicator web pages throughout this report).

Our freshwater environment: everything is connected

Our freshwater environment is under pressure. These pressures lead to changes in the state of the environment – and these changes have impacts on ecosystems, our lives, and things that are important to us.

There are many pressures, changes in state, and impacts, and the relationships between them are complex. Here are two simplified examples.

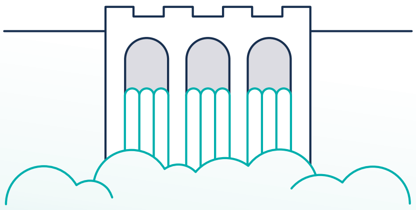
Pressure

LAND USE

Agriculture, forestry, and urban expansion can increase contaminants like harmful amounts of nutrients, such as nitrogen and phosphorus.

STRUCTURES AND MODIFICATIONS

Dams and other structures have changed the natural flow of our waterways and water bodies, and the connections between them.



State

LAND USE

An important way we gauge the health of freshwater ecosystems is the trophic level index (TLI). It gives a score based on nutrient and algae levels.

46% of all our lakes larger than 1 hectare have poor or very poor health, according to computer model estimates of TLI scores between 2016 and 2020. Only 2% of those lakes rated good or very good.

STRUCTURES AND MODIFICATIONS

Native freshwater fish play an essential role in freshwater ecosystems, and many need to migrate to and from different areas and habitats to breed and feed.

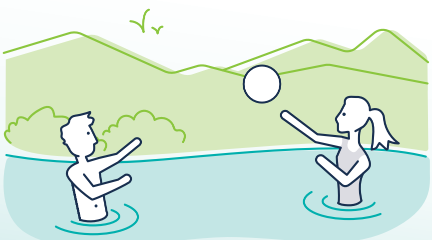
But some migratory species are threatened with extinction or at risk of becoming threatened – including taonga (treasured) species like tuna (longfin eels) and īnanga (whitebait).

Impact

LAND USE

Algal blooms and other effects of excess nutrients can harm freshwater species and ecosystems.

They can also restrict people's use of lakes and rivers for recreational activities like swimming.



STRUCTURES AND MODIFICATIONS

Mātauranga (Māori knowledge), tikanga (customs and protocols), mahinga kai (traditional food gathering practices), and other aspects of te ao Māori are impacted when fish are threatened, and habitats are degraded.

Report structure

As required by the Act, we use pressure, state, and impact to report on the environment and this forms the basis for the report's structure. The logic of the framework is that pressures cause changes to the state of the environment and these changes may have impacts on our values.

The report describes impacts on freshwater species and ecosystems, infrastructure, culture, economy, public health, and recreation. In addition, it explores our connections to the freshwater environment to the extent that is possible with the available information and identifies information gaps. Note that evaluation of specific policy is out of scope for environmental reporting releases under the Environmental Reporting Act 2015, so are not discussed here.

This report also continues discussions of wellbeing that were the focus of the last synthesis report, *Environment Aotearoa 2022*. The concepts of wellbeing that support this report include, among others, the Treasury's Living Standards Framework, the He Ara Waiora framework, and the view that our economic and non-economic wellbeing are inherently connected to te taiao (McMeeking et al, 2019; New Zealand Treasury –Te Tai Ōhanga, 2021; PCE, 2021). For further discussion connecting wellbeing with te taiao, see *Environment Aotearoa 2022*.

The data used in this report came from many sources including Crown research institutes and central and local government. Further supporting information was provided using a 'body of evidence' approach. This body of evidence includes peer reviewed, published literature, as well as mātauranga Māori and observational tools used to identify changes in the freshwater environment.

All data used in this report, including references to scientific literature, were corroborated, and checked for consistency with the original source. The report was produced by a team of analysts and scientists from within and outside of the Ministry for the Environment and Stats NZ, and was reviewed by a panel of independent scientists. The indicators related to the freshwater environment and the date they were last updated are available on the Stats NZ indicators web pages.

Te ao Māori, mauri, and our connection to freshwater

Wai (water) is essential for life. It sustains, cleanses, and refreshes our bodies and provides opportunities for recreation. Wai supports how we live. Freshwater appears in many forms, from tiny alpine streams and puna (springs) to large roto (lakes), repo (wetlands), and the widest awa (rivers). It is also present but unseen in underground rivers and aquifers.

In te ao Māori (Māori world view), the human and non-human worlds are indivisible. Different water bodies have different associated taonga species, and kaitiaki (guardians), that protect the mauri of the wai (Stewart-Harawira, 2020).

Mauri is a te ao Māori concept that describes the spark of life and active component of that life (Mead, 2003), and the binding force that holds together the physical and spiritual components of a being or thing (Durie, 1998; Morgan, 2006).

There is an intrinsic link between the health and wellbeing of wai and the health and wellbeing of communities (Harmsworth & Awatere, 2013; Stewart-Harawira, 2020). When the mauri of the freshwater environment is negatively affected this can affect the cultural, spiritual, and physical wellbeing of communities. Mauri has been used by many scientists to describe state and sustainability of a particular environment and indicators have been created to assist this (Morgan, 2006) (see: *Environment Aotearoa 2022*).

In te ao Māori there are many pūrākau (stories) about the origins of our freshwater systems, each with its own whakapapa (genealogy) to describe their relationships to these important waterways. Wainui-ātea is personified as the mighty waters and through her the other bodies of water are connected (Whaanga & Roa, 2021). After their separation, the soft mists of Papatūānuku (Earth mother) rise to greet Ranginui (sky father), and Ranginui's tears took the visible form of rain and dew that fall from the sky to give life to the land (Salmond et al, 2019; Reed, 2021). This highlights the holistic connection of water in the atmosphere, in groundwater, and on land. Our previous synthesis report, *Environment Aotearoa 2022*, framed the freshwater domain with Waitī. She is the whetū (star) in Te Kāhui o Matariki (the Matariki cluster) who is connected to the freshwater environment (see *Environment Aotearoa 2022*).

Taonga species are endemic to Aotearoa New Zealand (found nowhere else in the world) and significant to Māori, being unquestionably treasured. Taonga species vary among whānau, hapū, and iwi: this can be due to whakapapa connection and identified kaitiaki responsibilities. They are also connected to traditional Māori practices and knowledge (Waitangi Tribunal, 2011). Taonga species names can also vary according to their life-cycle stage, iwi and hapū dialect, and within different regions. Taonga species represent symbols of status, association with death, tohu (signs), predictions of weather, metaphors, and stories (Keane-Tuala, 2015).

Pressures on our freshwater environment

Photo: Kiwi Droneography – truestock

Our freshwater environment is an interconnected system and is affected by many pressures from human activities.

Land-based activities in catchments have detrimental effects on freshwater through excess sediment, nutrient, and contaminant pollution, and these pressures have been amplified by the intensification and expansion of agriculture and urbanisation.

Diverting, controlling, and abstracting water from our waterways alters the natural flow and resilience of waterways ki uta ki tai – from mountains to the sea – and places pressure on species.

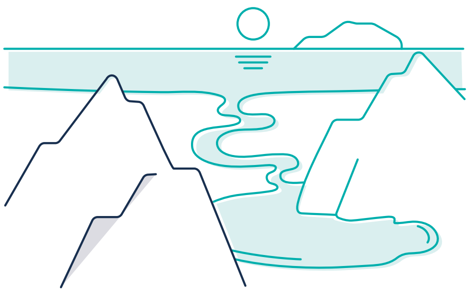
Increases in greenhouse gas emissions are raising sea levels at our coasts and increasing the magnitude and frequency of extreme rainfall and drought, which puts further pressure on the freshwater environment.

Pressures on our freshwater environment

Water is essential for life. But our freshwater environment continues to be affected by a variety of pressures – mostly due to the way we're using land and water, and the changing climate.

KI UTA KI TAI (MOUNTAINS TO THE SEA)

Freshwater comes in many forms, such as lakes, rivers, streams, wetlands, springs, and aquifers. They connect to each other, ki uta ki tai.



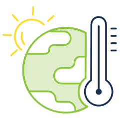
So, if one part of a catchment comes under pressure, there are flow-on effects.

STRUCTURES AND MODIFICATIONS

We've changed the natural flow of waterways and water bodies with dams, channels, stop banks, and culverts. This puts pressure on fish and other freshwater species.

Data suggests 48% of the country's river network is at least partially inaccessible to migratory fish – and the figure may be higher.

CLIMATE CHANGE



Freshwater species and ecosystems are under pressure due to our changing climate.

It is playing a role in:

- increasing droughts and floods
- raising sea levels
- heightening the risk posed by exotic pests.

LAND USE

High intensity agriculture – such as dairy farming – uses more fertiliser and irrigation than other types of farming.

Almost 60,000 hectares of exotic grassland was converted from low to high producing land between 1996 and 2018 – that's 2.5 times the size of Abel Tasman National Park.

Wastewater service suppliers reported more than 4,200 overflows due to wet weather events, or blockages and failures during dry weather in the year ending 30 June 2021.

Agriculture, forestry, and urban expansion can increase contaminants like bacteria, sediment, and harmful amounts of nutrients.

The freshwater environment is a holistic system that connects landscapes, ecosystems, and people.

- The kinship relationship between Māori and the natural world, through whakapapa (genealogy), views all people as part of the natural system including all forms of wai (water), flora, fauna, and natural resources (Harmsworth & Awatere, 2013; Stewart-Harawira, 2020).
- Ki uta ki tai acknowledges the journey that wai makes from the atmosphere to the mountains and across the land. As small and large streams connect and grow bigger, connect with lakes, reach into wetlands and estuaries, and eventually meet with the sea. It highlights how resources and ecosystems throughout catchments and the landscape are interconnected with cumulative pressures and the pressure of human activities affecting the mauri of freshwater (Harmsworth & Awatere, 2013; Hopkins, 2018). (See the Te ao Māori, mauri, and our connection to freshwater section for the definition of mauri used in this report.)
- Ki uta ki tai approaches are intrinsically connected to particular places, wai, whenua (land), and the values of the people that live there (Crow et al, 2018; Rainforth & Harmsworth, 2019) (see *Environment Aotearoa 2022* for more information).

Land-use intensification and other changes to how we use the land have increased pressures on water quality.

- Intensification involves increasing the use of inputs such as fertiliser and irrigation, with the aim of increasing production – for example, having more animals per hectare of land or increasing the number or volume of harvests from crops (see *Our land 2021*). This includes converting land that is used for less intensive agricultural land uses like sheep farming to more intensive uses like dairy farming.
- Analyses of national river water quality monitoring data for 2016 to 2020 show that water quality is more degraded when there is more high-intensity pasture and horticultural land upstream (Whitehead et al, 2022).
- Aotearoa has experienced one of the highest rates of agricultural land intensification over recent decades internationally (OECD/FAO, 2015 within Mouton et al, 2022). Between 1996 and 2018, almost 60,000 hectares of exotic grassland was converted from low producing to high producing, compared with only 3,500 hectares of exotic grassland converted from high to low producing (see indicator: Exotic land cover).
- Urban area increased 14.6 percent (30,264 hectares) between 1996 and 2018, with 24,396 hectares of this increase (81 percent) due to conversion of high producing exotic grassland and 2,602 hectares (9 percent) due to conversion of horticultural land (see indicator: Urban land cover). This loss of highly productive agricultural land means the agricultural land that remains must be farmed more intensely to sustain the same level of production (see *Our land 2021* for more information on urbanisation and highly productive land).
- The intensity of agriculture has increased since the 1980s particularly due to a switch from sheep to dairy farming (Wynyard, 2016). Dairy cattle numbers increased by 61 percent between 1996 and 2014, before falling 5 percent by 2018 (see indicator: Livestock numbers).

- The amount of irrigated land almost doubled between 2002 and 2019 from 384,000 hectares to 735,000 hectares (a 91 percent increase). Over the same period 73 percent of increases in irrigated land area were related to farms with dairy farming as their dominant farm type; 18 percent to grain, fruit and berry, and vegetable growing; and 9 percent to sheep and beef (see indicator: Irrigated land). Modelling indicates that the long-term changes in river water quality measured nationwide between 1990 and 2017 were closely associated with the proportion of upstream land dedicated to pastoral agriculture and plantation forestry, the type and intensity of the pastoral agriculture upstream, and how these changed over time (see Attribution of river water-quality trends to agricultural land use and climate variability in New Zealand, Snelder et al, 2021, for detailed information on this model).
- Models estimate that on-farm mitigations like fertiliser management and protecting waterways from livestock reduced the amount of phosphorus and sediment that reached our rivers between 1995 and 2015, but not nitrogen. While the mitigations were estimated to reduce nitrogen losses from individual farms, this was not enough to offset the effects of the expansion of dairy and intensification of pastoral agriculture, which resulted in an increase in the nitrogen that reached our rivers during this period (see Quantifying contaminant losses to water from pastoral landuses in New Zealand II. The effects of some farm mitigation actions over the past two decades, Monaghan et al, 2021, for detailed information on this model).
- Pressures from existing and intensifying land uses, and a changing climate, are contributing to spatial shifts in biodiversity and ecosystem function in New Zealand rivers (Mouton et al, 2022).

Land-based human activities contribute to excess nutrients and sediment in our fresh waterways.

- Livestock urine is the dominant source of nitrate-nitrogen leaching. Leaching occurs because some of the additional nitrogen that can't be used by plants and microorganisms may leach (drain) from the soil (see indicator: Nitrate leaching from livestock).
- Leached nitrate-nitrogen can enter groundwater and waterways, potentially causing ecological harm. The amount of nutrients leaching from the soil varies around the country because of differing land uses, climates, and soils (see indicator: Nitrate leaching from livestock).
- Fertilisers are added to soil to improve soil fertility. Surplus nutrients that aren't absorbed by plants, such as phosphorus, can run-off into freshwater bodies such as streams, rivers, and lakes (see indicator: Fertilisers – nitrogen and phosphorus).
- Research into soil physical properties suggests pasture irrigation can lead to soil compaction and less readily available water capacity, leading to increased nutrient leaching and run-off to waterways (Drewry et al, 2022).
- Erosion rates in Aotearoa are naturally high by international standards (Basher, 2013).
- Human activities on land such as urban expansion, forestry, and agriculture, can further increase the amount of sediment entering freshwater environments (Larned, 2020; Basher, 2013). When excess sediment exceeds the natural erosion rate it can cause greater ecological, cultural, socio-economic and recreational harm (Larned, 2020; Basher et al, 2011).
- In Aotearoa, most phosphorus enters rivers attached to eroded sediment (Elliot et al, 2005).

- Clear felling (the method used to harvest exotic forests in Aotearoa) exposes and disturbs soil, including from the construction of roads used for vehicle access during harvesting, which can increase erosion and the sediment loads to rivers and lakes (MfE & Stats NZ, 2019; Larned, 2020).
- Agriculture can accelerate soil degradation, erosion, and soil loss rates due to stock grazing on the land and treading on the soil, which can affect our waterways (Donovan, 2022).

Wastewater, stormwater, and livestock waste are sources of freshwater contaminants, such as pathogens and heavy metals.

- Wastewater discharge, including sewage, often from houses, businesses, and industrial processes, must be treated to reduce levels of pathogens and other contaminants before it can be released into freshwater. Wastewater that is discharged is not free of contaminants, and can contain high levels when treatment is incomplete, or the systems fail (see *Our freshwater 2020*).
- Almost half (47 percent) of publicly owned wastewater treatment plants discharge treated wastewater to rivers and lakes, while the remainder discharge it into the sea or onto land (DIA, 2018). Many industrial facilities, like meat and dairy processing plants, also operate wastewater plants that discharge into freshwater.
- In the national performance review by Water New Zealand, participating wastewater service suppliers reported that between 2020 and 2021 there were 4,268 reported overflows of wastewater due to wet weather events, or blockages and mechanical failures that occurred during dry weather. However, it is likely that this number is under reported (Water NZ, 2021).
- Stormwater is rainwater that comes off solid surfaces like roofs, roads, and asphalt and is piped into waterways or the sea. It is almost always collected separately from wastewater and is not generally treated.
- Stormwater can be polluted with pathogens from animal faeces, and from wastewater systems that leak or overflow to stormwater systems (LAWA, 2022; Leonard & Eaton, 2021). It can also be polluted with contaminants like hydrocarbons from leaking vehicles and industrial yards (Kennedy et al, 2016), and heavy metals from vehicles (copper from brake pads and zinc from tyres), metal roofing, and industrial yards (Gluckman et al, 2017; Kennedy & Sutherland, 2008).
- Heavy metals in high concentrations can be toxic to aquatic life. They can accumulate in sediments and living organisms (Boehler et al, 2017).
- Dung from sheep and cows contains pathogenic species of *Campylobacter*, *Cryptosporidium*, *E. coli*, and *Giardia*, which can contaminate waterways where livestock congregate. These pathogens can also be carried from farms into waterways by storm run-off, and contaminated surface water can infiltrate into groundwater (Devane et al, 2018; Leonard & Eaton, 2021).

Plastics and chemicals that have been produced and used for decades contaminate our freshwater environment.

- Plastic waste is a major problem: some plastics take centuries to break down, and large quantities continue to be produced (PMCSA, 2019).

- In 2021 and 2022 there were 807 items counted in Aotearoa freshwater ways in the Litter Intelligence programme, with most items (68 percent) being plastic. More information can be found at Litter Intelligence – Data (Litter Intelligence, nd).
- Microplastics are generally defined as plastic particles that are less than 5 millimetres in diameter (De Bhowmick et al, 2021). Microplastics have been found in urban streams in Aotearoa and are often transported via smaller urban streams (Mora-Teddy & Matthaei, 2020). A survey across 52 urban streams in Aotearoa found microplastics in samples from all sites (Mora-Teddy & Matthaei, 2020).
- Emerging contaminants are non-natural chemicals in the environment that have not been extensively monitored, and whose potential effects on human health and the environment are not well understood. Over 700 different compounds are classified as potential emerging contaminants including pharmaceuticals, pesticides, and personal care product additives (like shampoo preservatives), and industrial compounds such as flame retardants (NORMAN Network, 2016).
- Pesticides have been used in Aotearoa for many decades over large areas of land (Manktelow et al, 2005; Chapman, 2010; Rolando et al, 2016). Many pesticides (which include insecticides, herbicides, and fungicides) stay in the environment for long periods and can enter waterways.
- Emerging organic contaminants, such as biocides and pharmaceuticals, have been internationally shown to interact with microbial communities in freshwater environments and potentially increase the spread and development of antimicrobial resistance. Antimicrobial resistance is the development of resistance to antibiotics, mainly due to significant antibiotic use in humans and animals, threatening human and ecological health worldwide (Alderton et al, 2021).

Introduced freshwater species are widespread, with some degrading freshwater bodies and threatening native species.

- Some freshwater fish, invertebrate, plant, and algal species introduced to Aotearoa by humans, place pressures on our unique native species, ecosystems, and local economy (MPI, nd; DOC, ndm).
- Historically, over 200 species of freshwater animals and plants have been introduced to Aotearoa, mostly deliberately. Illegal and accidental introductions still occur (NIWA, 2020).
- In 2020, 9 fish species, 1 reptile species, 11 invertebrate species, and 35 plant species were identified as non-indigenous species of greatest concern for freshwater environments in Aotearoa (NIWA, 2020).
- Introduced fish account for more than 80 percent of fish species recorded at 925 river sites from 1999 to 2018. These were most prevalent in parts of Otago and the central North Island (MfE, 2020).
- Koi carp is an introduced freshwater fish species that puts pressure on our freshwater ecosystems. With a preference for still and slow-moving water, they destroy native habitat through stirring up mud when they feed, and also eat invertebrates and compete with native species (Tiaki Tāmaki Makaurau – Conservation Auckland, 2023).

- Some introduced species, such as morihana (common goldfish), trout, and brown bull-headed catfish, can be considered culturally important. For example, when īnanga (whitebait) was harder to source, brown bullhead catfish was considered an important food source (Taura et al, 2017; Tadaki et al, 2022).
- Didymo (*Didymosphenia geminata*) is an introduced algae species that can form thick, dense mats – sometimes over entire streambeds. Since its discovery in 2004 didymo has spread to more than 150 waterways in the South Island, but has not yet been detected in the North Island (Jellyman & Harding, 2016; MPI, 2020).

Structures for diverting or controlling water place pressure on freshwater flows and fish and kōura migrations.

- Structures for diverting or controlling water such as dams, weirs, culverts, fords, stop banks, and floodgates can affect the water flow and the connections between waterways in a catchment and put pressure on ecosystems (Franklin et al, 2018; Brierley et al, 2022).
- Blocking waterways and altering flow patterns alters the natural adaptability and resilience of rivers. The mauri of a river is adversely impacted through not being able to flow unobstructed from the mountains to the sea (PCE, 2012; Young et al, 2004). Confining waterways to well-defined channels has consequences for the volume of water in a river, how fast it flows, how the flows vary, and the connections between waterways (MfE & Stats NZ, 2020; Watene-Rawiri, 2022).
- Combined, these barriers and changing flows place pressure on the migration and spawning of taonga species such as īnanga, tuna (eels), kanakana/piharau (lamprey), and kōura (freshwater crayfish) (McDowall, 2000).
- The first national assessment of river barriers in Aotearoa found that we have approximately one barrier per 6.25 kilometres of river length on average. This is high compared to international reporting (eg Belletti et al, 2020), though this may be due to inclusion of smaller barriers other studies often exclude. Data suggests a minimum of 48 percent of Aotearoa New Zealand's river network is at least partially inaccessible to migratory fish, though a further 36 percent have not yet been assessed for barriers and could be potentially inaccessible (Franklin et al, 2022).
- Channelling rivers alters their natural character and can also erode riverbanks and increase the amount of sediment deposited downstream (Maddock, 1999; Fuller et al, 2011).

Hydropower and irrigation are the largest consented uses of freshwater, and place pressure on the timing and volume of freshwater flows.

- Models have predicted that irrigation greatly alters river flows in some parts of Aotearoa (see *National water allocation statistics for environmental reporting: 2018*, Booker & Henderson, 2019 for detailed information on this model). Of all consumptive water uses nationally, except for hydropower, irrigation had the largest consented allocation by total volume (58 percent) in the 2017/18 water reporting year. Hydropower consents are based on rates rather than volume, so this comparison excludes use for hydroelectric generation (Booker & Henderson, 2019) (see indicator: Consented freshwater takes).

- Most hydroelectric generation does not consume water, but some hydro schemes divert flows from one river system to another (like the Tongariro Power Scheme), or to the ocean (like the Manapōuri hydro station), and are considered consumptive (Genesis Energy, 2023; Engineering New Zealand, 2023).
- For the 2017/18 water reporting year, the consented maximum abstraction rates for consumptive hydro schemes were higher than all other water uses in three of the four regions where these schemes operate, meaning they could be the largest consumers of water at any given time (see *Our freshwater 2020*).
- Even where it does not consume water, hydroelectric generation can still affect the timing and volume of flows downstream of dams and diversions. No large hydroelectricity infrastructure has been built in the past two decades, but several schemes have been proposed (see *Our freshwater 2020*).

Our climate is changing, and more frequent and intense rainfall and droughts are putting increasing pressure on our freshwater environment.

- Human-driven increases in global atmospheric carbon dioxide continue to drive climate change, with Aotearoa New Zealand's average annual temperature rising by 1.13 (+/-0.27) degrees Celsius from 1909 to 2019 (see *Our atmosphere and climate 2020* and indicator: Temperature).
- A warmer atmosphere can hold more water vapour, which then comes back to Earth's surface as precipitation. As Earth warms, scientists expect more frequent extreme rainfall. In Aotearoa, extreme rainfall is variable from year to year and from location to location (Bodeker et al, 2022) (see indicator: Extreme rainfall).
- The frequency of extreme weather events due to climate change is expected to increase (see *Our atmosphere and climate 2020*). Droughts are predicted to increase in frequency in northern Aotearoa and heavy rainfall intensity is expected to increase over most regions of Aotearoa (IPCC, 2022). This will change the amount of water in our soils, and the storage, flows, mixing, and temperature of water in lakes, rivers, groundwater, and glaciers (see *Our freshwater 2020*).
- Increasing floods due to climate change may put pressure on freshwater ecosystems and the habitat ranges of species that are culturally important for many Māori (Awatere et al, 2021; IPCC, 2022; Foley and Carbines, 2019).
- Sea levels are rising, with annual average coastal sea levels having risen (relative to land) at all six monitoring sites around Aotearoa based on available data to 2020 (see indicator: Coastal sea-level rise). Sea level rise moves saltwater farther into coastal freshwater environments, which puts pressure on these ecosystems (IPCC, 2022).
- Ecosystem fragmentation and pest species are likely to increase with climate change; however, it is hard to predict exactly how biodiversity will react as Aotearoa New Zealand's climate is highly variable (McGlone et al, 2010 in DOC, 2020a).

State of our freshwater environment

Photo: *Greater Wellington Regional Council*

To understand the health of our freshwater ecosystems we need to understand how they connect to each other and to the land: ki uta ki tai (mountains to the sea). There is an intrinsic link between the health and wellbeing of wai (water) and the health and wellbeing of communities. When wai is healthy and flowing, and ecosystem health is intact, mauri is enhanced and it can better provide for our interaction with freshwater, such as mahinga kai (traditional food gathering practices), swimming, and drinking water.

Mātauranga Māori (Māori knowledge) and the freshwater ecosystem health framework help us understand what different freshwater indicators tell us about the overall health of freshwater bodies and the environment.

These indicators show that the health of our freshwater ecosystems is variable around Aotearoa. High levels of organic pollution and nutrient enrichment in many of our rivers and lakes has degraded habitats and can be harmful to freshwater species. Some of our freshwater is unsuitable for swimming and drinking.

Aotearoa has a lot of freshwater, though we also use a lot for activities such as irrigation and hydroelectricity.

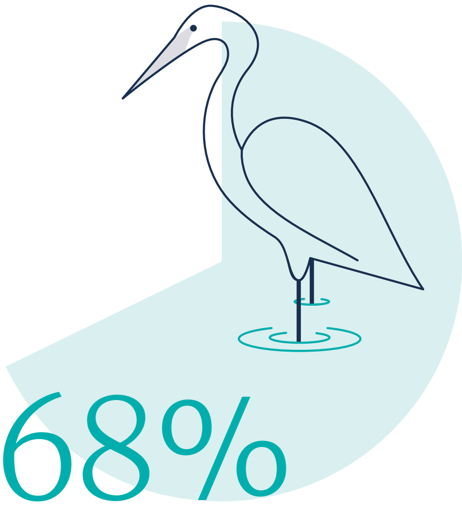
Modifications to our freshwater environment have caused the ongoing loss of wetlands, and this reduces the habitat available for our freshwater-dependent native species. Altering flows diminishes the mauri of our awa (river).

Some of our indigenous taonga (treasured) freshwater species, such as kanakana/piharau (lamprey) and kākahi (freshwater mussel), are threatened with extinction and many others are at risk of becoming threatened.

State of our freshwater environment

Evidence shows the health of freshwater ecosystems around Aotearoa is variable. Some places and measures got better, but others got worse.

INDIGENOUS AND TAONGA (TREASURED) SPECIES



68%

of indigenous freshwater birds were threatened with extinction or at risk of becoming threatened in 2021.

Of these 19 birds, it's estimated that the populations of seven species are increasing, seven are decreasing, and five are stable.

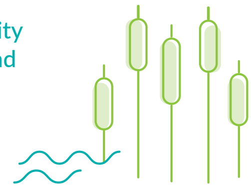
76% of indigenous freshwater fish species were threatened with extinction or at risk of becoming threatened in 2017.

Ten of 18 taonga freshwater fish and invertebrate species were too.

Abundance of food supplies such as īnanga (whitebait) and kōura (freshwater crayfish) is an important sign of mauri (health and vitality of living systems).

REPO (WETLANDS)

We've lost the majority of our historic wetland area, with estimates that only around 10 percent remains.



Wetlands provide a habitat for many of our taonga bird species, including kotuku (white heron), tētē whero (brown teal), and mātātā (New Zealand fernbird).

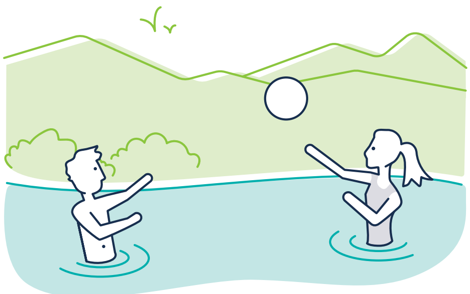
POLLUTION AND EXCESS NUTRIENTS

36% of lake monitoring sites improved and 45% worsened between 2011 and 2020 (according to trophic level index (TLI) scores, a measure of ecosystem health based on nutrient and algae levels).

Models of TLI scores for all lakes larger than 1 hectare suggest 46% had poor or very poor health between 2016 and 2020.

Only 2% rated good or very good.

Models of *Campylobacter* infection risk estimate 45% of our country's total river length was not suitable for activities like swimming between 2016 and 2020.



Indigenous indicators and mātauranga Māori can help us understand the state of the freshwater environment.

- Mauri is an indigenous concept of the state of te taiao (the environment) often characterised/reflected by 'local tribal areas', so it is not possible to understand the state of freshwater without also understanding the core values of the people who engage with it (Crow et al, 2018; Harmsworth et al, 2016; Tipa, 2009). (See the Te ao Māori, mauri, and our connection to freshwater section for the definition of mauri used in this report.)
- Decline in the mauri of wai can also include reduced habitat extent and species population, reduced river/stream flow, and poor condition of ecosystems and resources, such as mahinga kai and taonga species (Harmsworth et al, 2016).
- Mahinga kai is a cultural indicator of a healthy freshwater system (Hikuroa et al, 2018; Tipa, 2009). Sustaining and accessing mahinga kai is closely linked to the state of freshwater and is an important indicator of the mauri of the waters, whenua (land), and people. These are all important for Māori in understanding the health of an ecosystem (Tipa, 2009; Rainforth & Harmsworth, 2019).
- Some iwi and hapū monitor freshwater health using cultural indicators to observe and record changes. The cultural health index (CHI) is a tool for water quality that measures factors of cultural importance to Māori in the freshwater environment. The CHI is made up of three components: site status, mahinga kai status, and cultural stream health status (Tipa & Teirney, 2006; Stewart-Harawira, 2020). Each component is assessed separately by the iwi/hapū and then all three are combined to provide a cultural health measure.
- Following from, and in many cases adapting from, the CHI, other methods and tools used by iwi, hapū, and whānau include the Mauri Model/Mauri-o-meter, the Mauri Compass, Wai Ora Wai Māori, and Cultural Flow Preference Study (Rainforth & Harmsworth, 2019).
- In determining the state of our freshwater, it is important to acknowledge the whole catchment – ki uta ki tai. The whole catchment that is drained by a river must be examined, as an intact mauri depends on the status of all the interrelated components in the catchment. For example, the mauri of the wai diminishes as it moves downstream and increasingly comes into contact with human activities (Tipa, 2009).

The freshwater ecosystem health framework measures multiple components of freshwater to understand the overall health of freshwater ecosystems.

- The freshwater ecosystem health framework is a concept that recognises the holistic nature of freshwater ecosystems. It incorporates factors like biodiversity, the quality of habitats, and how well essential ecosystem processes are working. Understanding the overall health of freshwater ecosystems requires measures of five core components: aquatic life and biodiversity, habitats, water quantity and flows, ecological processes, and water quality (Clapcott et al, 2018).
- Measuring all parts of an ecosystem is challenging, and data are not widely available for some components of ecosystem health like aquatic life and ecological processes. This limits our ability to comprehensively assess the health of most of our ecosystems, and the health of our freshwater environment as a whole (see *Our freshwater 2020*). However, considering individual measures in the context of ecosystem health is useful for understanding the state of the freshwater environment more holistically.

The water quality of some of our rivers and lakes could be harmful to ecosystems and human health.

- Water quality is the most widely measured component of ecosystem health and is assessed by measuring physical and chemical components of water that are important to support life (Clapcott et al, 2018).
- Both measured and modelled data were used to estimate the water quality of our rivers and our lakes. Computer models were used to estimate water quality for all river segments and all 3,813 lakes larger than 1 hectare, including those that do not have monitoring sites. For example, water quality is only monitored in a very small proportion of our lakes (approximately 5 percent of the lakes larger than 1 hectare). Model estimates are informed by measured water quality data, as well as by variables describing aspects of climate, geology, topography, hydrology, and land cover.
- Ecosystem health can be assessed by comparing water quality measures to the National Objectives Framework (NOF) bands, which consider the suitability of a water body to sustain the indigenous aquatic life expected in the absence of human disturbance or alteration (MfE, 2023). Similarly, the ability of a water body to support human connection with the water through a range of activities, including swimming, can be assessed.
- Trends were assessed for monitoring sites, but it would not be appropriate to assess trends for modelled data. For monitoring sites where trends could be determined, trends were classified as improving or worsening if the trend certainty was above 66 percent (‘likely’) or above 90 percent (‘very likely’). We use the term ‘indeterminate’ when there was either no trend direction or not enough statistical certainty to determine trend direction (less than 66 percent certainty).
- We present 20-year trends for rivers because of the strong influence of natural climate variation on shorter trend periods (Snelder et al, 2021). For lakes and groundwater we present 10-year trends because there was limited data to determine longer trends across the monitoring networks.
- Visual clarity is a water quality measure of underwater visibility in rivers and streams, with low clarity indicating poor visibility. Clarity can be used as an indicator of cultural health, as well as ecosystem health. Seventy-seven percent of Aotearoa New Zealand’s river length had modelled visual clarity values indicative of minimal to moderate impact of suspended sediment on instream biota (NOF bands A and B) between 2016 and 2020, whilst 23 percent indicated moderate to high impact (NOF bands C and D). Measured data showed that median visual clarity was greatest at river monitoring sites with lower proportions of human modified land cover in the upstream catchment area.
- For visual clarity, trends at 52 percent of river monitoring sites were improving, and 33 percent were worsening, between 2001 and 2020 (see indicator: River water quality: clarity and turbidity for more information on measured and modelled state and trends).
- Elevated nutrient levels can lead to excessive algal growth, degrading river and lake habitats, including where groundwater enters the surface water environment. Nutrients have flow-on effects for ecosystem health, which we have assessed through high level indicators of river and lake water quality (see following sections). For further discussion of nutrients in water, see indicators: River water quality: nitrogen, River water quality: phosphorus, Lake water quality, and Groundwater quality.

- We have focused on water quality indicators which provide the best high-level understanding of ecosystem health: macroinvertebrate community index for rivers and trophic level index for lakes (see following sections). For further discussion of river and lake water quality, see the Freshwater indicators.

Our freshwater quality is mixed, with some excess nutrient levels that can harm ecosystems.

- Macroinvertebrates play a central role in stream ecosystems by feeding on periphyton (algae), dead leaves, and wood, or on each other. In turn, they are an important food source for fish and birds. The macroinvertebrate community index (MCI) is a measure of the abundance and diversity of macroinvertebrates and is an indicator of overall river health. A high MCI score indicates a high level of river health, with more impacted rivers having low MCI scores.
- Forty-five percent of Aotearoa New Zealand's river length had modelled MCI scores indicative of conditions with almost none or mild organic pollution or nutrient enrichment (NOF bands A and B) between 2016 and 2020, whilst 55 percent indicated moderate or severe impairment (NOF bands C and D). The average proportion of human modified land cover in the upstream catchment area of monitored sites increased with decreasing MCI scores.
- For MCI, trends at 56 percent of river monitoring sites were worsening, and 25 percent were improving, between 2001 and 2020 (see indicator: River water quality: macroinvertebrate community index for more information on measured and modelled state and trends).
- Of 459 river and stream monitoring sites, 79 percent had good or excellent habitat condition based on 10 measured parameters including habitat diversity, streambed sedimentation, bank erosion, bank vegetation, and shade (see indicator: Freshwater physical habitat).
- Trophic level index (TLI) is a lake water quality measure that is an indicator of ecosystem health, and is a combined measure of chlorophyll-a (algae), and the nutrients nitrogen and phosphorus. Forty-six percent of Aotearoa New Zealand's 3,813 lakes larger than 1 hectare had modelled TLI scores indicating poor or very poor health in terms of nutrient enrichment between 2016 and 2020, whilst only 2 percent rated good or very good. Lake monitoring sites with lower trophic levels (linked to better ecosystem health) had significantly lower proportions of human modified land cover in the upstream catchment area compared to sites with higher trophic levels.
- For TLI, trends at 36 percent of lake monitoring sites were improving, and 45 percent were worsening between 2011 and 2020 (see indicator: Lake water quality for more information on measured and modelled state and trends).
- The submerged plant index (SPI) is one measure of a lake's ecological health, that reflects the diversity and extent of native and invasive plant species that provide habitats and support ecosystem processes. Between 1991 and 2019, 34 percent of monitored lakes were in excellent or high ecological condition, 31 percent were in moderate condition, and 36 percent were in poor ecological condition or were entirely without submerged plants. Most monitored lakes (90 percent) with vegetation had some non-indigenous plant species present (see indicator: Lake submerged plant index).

- Aotearoa New Zealand's groundwater ecosystems are poorly understood, though over 100 aquifer-dwelling species have been named, with approximately 700 invertebrate species awaiting analysis (Fenwick et al, 2018).
- Nitrate is present in groundwater across Aotearoa, but the concentration that is harmful to groundwater species is unknown (Fenwick et al, 2018).
- Further research is needed to better understand groundwater ecosystem extent and function, species present, and the cumulative impacts of human activities on these environments.

The quality of some of our freshwater is unsuitable for recreational activities like swimming.

- *E. coli* is used as an indicator for the presence of other pathogens associated with animal or human faeces, especially *Campylobacter*.
- The suitability of rivers and lakes for recreational activities like swimming, paddling, and water sports can be assessed by using measured *E. coli* concentrations to calculate the risk of infection from *Campylobacter* bacteria. Higher *E. coli* concentrations indicate higher infection risk. Suitability for lakes also considers the risk they pose from exposure to cyanobacteria, but we have limited our assessment to *E. coli* (MfE, 2023).
- Models estimate that 45 percent of Aotearoa New Zealand's total river length was not suitable for activities like swimming between 2016 and 2020, based on having an average *Campylobacter* infection risk greater than 3 percent (corresponding to NOF bands D and E for *E. coli*, see MfE, 2023). *E. coli* concentrations tended to be higher at river monitoring sites with higher proportions of human modified land cover in the upstream catchment area.
- For *E. coli*, trends at 37 percent of river monitoring sites were improving (declining concentrations), and 41 percent were worsening (increasing concentrations) between 2001 and 2020 (see indicator: River water quality: Escherichia coli for more information on measured and modelled state and trends).
- For the period 2016 to 2020, 7 of 40 monitored lake sites had an average *Campylobacter* infection risk of greater than 3 percent, corresponding to NOF bands D and E for *E. coli* (see indicator: Lake water quality), making them unsuitable for activities like swimming (MfE, 2023). There were insufficient monitoring data to perform a national assessment of lakes based on *E. coli*, or to assess trends for *E. coli* in lakes (see indicator: Lake water quality).

The quality of some of our groundwater is unsafe for drinking.

- Sixty-eight percent of 364 groundwater monitoring sites failed to meet the Ministry of Health *E. coli* drinking water standard on at least one occasion between 2014 and 2018 (see indicator: Groundwater quality), indicating a risk to people if they consume water from these aquifers that has not been adequately treated. For *E. coli*, trends at 18 percent of groundwater monitoring sites were improving, and 50 percent of trends were worsening between 2009 and 2018 (see indicator: Groundwater quality)[1].

- Nineteen percent of 433 groundwater monitoring sites failed to meet the nitrate-nitrogen drinking water standards on at least one occasion between 2014 and 2018, based on having concentrations above the maximum acceptable value of 11.3 g/m^3 set by the Ministry of Health (Ministry of Health, 2018). Groundwater with concentrations above this standard must undergo specific treatment for nitrate before it is safe to drink (Ministry of Health, 2022). For nitrate-nitrogen, trends at 49 percent of groundwater monitoring sites were improving, and 35 percent of trends were worsening between 2009 and 2018 (see indicator: Groundwater quality).
- In 2018, a national groundwater survey was conducted for pesticides and emerging organic contaminants. For pesticides, none of the 121 surveyed groundwater wells exceeded the maximum acceptable value for drinking water in Aotearoa. Emerging organic contaminants were found in 70 percent of surveyed groundwater wells (85 of 121) but at low levels (Close et al, 2021).

Many of our indigenous taonga freshwater fish and invertebrate species are threatened with extinction or at risk of becoming threatened.

- In 2017, 76 percent of known indigenous freshwater fish species (39 of 51) were threatened with extinction or at risk of becoming threatened. Estimated population trends show 63 percent of freshwater fish species have a decreasing population trend (see indicator: Extinction threat to indigenous species).
- Over half (10 of 18) of taonga freshwater fish assessed in 2017 and invertebrate taonga species assessed in 2018 were threatened with extinction or at risk of becoming threatened, including kākahi, kanakana/piharau, īnanga (whitebait), and tuna (eels) (see indicator: Extinction threat to indigenous species).
- Some freshwater taonga species such as kākahi, īnanga, and tuna are important for mahinga kai (Collier et al, 2017; Williams et al, 2017) and abundance of food supplies such as īnanga, tuna, and kōura (freshwater crayfish) is an indication of mauri ora (health).
- Kākahi include three species. Two are classified as threated with extinction or at risk of becoming threatened and have declining population trends (*Echyridella aucklandica* and *E. menziesii*), and one is data deficient *(E. onekaka*) (Grainger et al, 2018). Kākahi are widespread throughout Aotearoa, with habitats including small, fast-flowing streams, rivers, and lakes (Williams et al, 2017).
- Īnanga are classified as at risk of becoming threatened with extinction and have a declining population trend (Dunn et al, 2018). Īnanga are predominantly observed near the coast. They are often found in gently flowing and still water, such as lowland streams, but also spend part of their life cycle in the marine environment (Williams et al, 2017).

[1] The Groundwater quality indicator is scheduled to be updated pending the outcome of an independent methodological review, which is in progress.

- Kanakana/piharau are classified as threatened with extinction and have a declining population trend (Dunn et al, 2018). They spend different stages of their life in freshwater and marine environments. In freshwater fish surveys, kanakana/piharau are typically underrepresented, with low observations likely due to detection difficulties (Williams et al, 2017).
- The longfin tuna is classified as at risk of becoming threatened with extinction and have a declining population trend (Dunn et al, 2018). Longfin tuna are widespread throughout Aotearoa (Williams et al, 2017). Shortfin tuna are classified as not threatened with extinction and have an increasing population trend (Dunn et al, 2018). Shortfin tuna are not as widespread, but generally outnumber longfin tuna in the most densely populated tuna habitats (Williams et al, 2017).

Many of our indigenous freshwater bird species are threatened with extinction or at risk of becoming threatened.

- Of 28 indigenous freshwater dependent bird species in 2021, 35.7 percent (10 of 28) are threatened with extinction and a further 32.1 percent (9 of 28) are at risk of becoming threatened.
- Of the 19 bird species threatened with extinction or at risk of becoming threatened, the population trend for seven species is increasing, and the population trend for seven species is decreasing. The population trend for the remaining five bird species in these categories is stable (see indicator: Extinction threat to indigenous species).
- Of these 19 bird species, 12 are river, lake, or wetland birds, and seven occupy both freshwater and marine habitats including coastal streams and seashores (DOC, nda – ndk; New Zealand Birds Online, nda – ndh).
- Six of 19 bird species threatened with extinction or at risk of becoming threatened have declining population trends and are also identified as taonga species (see indicator: Extinction threat to indigenous species). These species are koitareke (marsh crake), tarāpuka (black-billed gull), tūturiwhatu (banded dotterel), matuku hūrepo (Australasian bittern), pārera (grey duck), and whio (blue duck) (Keane-Tuala, 2015; Taura et al, 2017; Te Manahuna Aoraki Project, 2022).
- The list of indigenous freshwater birds identified as taonga is not exhaustive. Some of the freshwater bird species included in the Extinction threat to indigenous species indicator are recognised as marine taonga species because of their connection to a marine environment. This indicator uses a definition of taonga species that may differ from that used throughout *Our freshwater 2023*, which is based on taonga species identified in published literature (Keane-Tuala, 2015; Taura et al, 2017; Te Manahuna Aoraki Project, 2022) (see Extinction threat to indigenous species and Extinction threat to indigenous marine species: Approach used to highlight taonga species).

Much of our historic repo extent has been converted to other land uses, and repo loss has continued, reducing habitat for dependent native species.

- Repo (wetlands) cover less than one percent of the land area of Aotearoa, yet they support a disproportionately large number of threatened plants and animals (Clarkson et al, 2013).
- Repo are vital for the survival of many of our taonga bird species, including the matuku hūrepo, tētē whero (brown teal), mātātā (New Zealand fernbird), koitareke (marsh crake), and kotuku (white heron), who rely entirely on remnant wetlands (Clarkson et al, 2013; DOC, ndl; Keane-Tuala, 2015; Taura et al, 2017).
- We have lost the majority of our historic repo area, with estimates that only around 10 percent of this area remains (Dymond et al, 2021).
- Freshwater repo area decreased by 1,498 hectares (0.6 percent) between 2012 and 2018, and saline wetland area decreased by 69 hectares (0.1 percent) in the same period (see indicator: Wetland area).
- Southland has experienced the greatest losses, with a net loss of 2,665 hectares of freshwater repo between 1996 and 2018. Of the area of freshwater repo that were lost, 98 percent were because of conversion to land covers associated with farming and forestry (see indicator: Wetland area).

Aotearoa has a lot of freshwater and we also use a lot of freshwater.

- Rivers have naturally variable flows, but when water flows are also altered by human activities this can affect average flows, alongside the size and frequency of high and low flows. Due to the interconnected nature of the freshwater system, diverted or altered flows in one area can also affect or alter the state of flows in connected water bodies and affect the health of the wider ecosystem (see *Our freshwater 2020*).
- A healthy mauri, or life supporting capacity, is a sign that a river is expressing its mana (power, authority). The re-routing (severing) of the natural water flows has seen the diminishment of the mauri of the Tarawera River (Hikuroa et al, 2018).
- Approximately 440 million cubic metres flows in our rivers and streams every year (Collins et al, 2015). For the 2017/18 water reporting year, 9.83 billion cubic metres of surface water was allocated for consented consumptive use across Aotearoa. This figure excludes use for consumptive hydroelectric generation, which cannot be calculated because hydropower consents are based on rates rather than volume (see indicator: Consented freshwater takes). Consents (permits) to take water are managed by regional authorities that allocate water for hydroelectric generation, irrigation, drinking water, industrial, and other uses, and set limits on how much can be used, but do not tell us how much water is actually used.
- In 2014, 73.2 percent of our groundwater was located in Canterbury, amounting to 519 billion cubic metres (see indicator: Groundwater physical stocks). For the 2017/18 water reporting year, 3.1 billion cubic metres of groundwater was allocated for consented consumptive use across Aotearoa (see indicator: Consented freshwater takes).

- Glaciers are fed by snow and hold large amounts of freshwater. Glaciers in Aotearoa decreased in volume by 35 percent and the rate of annual loss increased between 1978 and 2020 (see indicator: Annual glacier ice volumes).

Impacts on culture, species, wellbeing, and people

Photo: *Fraser Tebbutt – truestock*

The state of the freshwater environment has impacts on freshwater species, habitats, ecosystems, and people. The health of freshwater environments and ecosystems directly support tikanga (customs/protocols), mahinga kai (traditional food gathering practices), and the transmission of mātauranga Māori (Māori knowledge). Our wellbeing and economy are linked to a healthy freshwater environment.

Excess nutrients can cause algal blooms that reduce visibility and the availability of oxygen, having ecosystem-wide impacts. Excess sediment degrades freshwater habitats, and other contaminants contaminate filter feeding organisms.

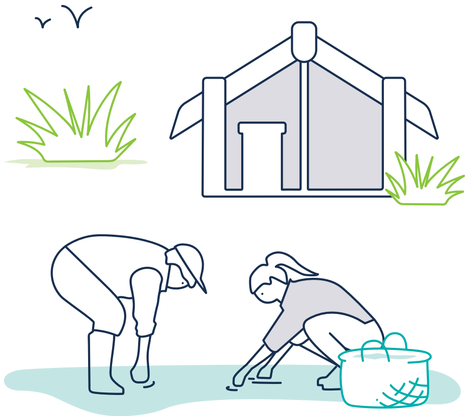
The forecasted effects of human-induced climate change, such as changes in water temperature, are likely to change the range and life cycles of some species. Contamination of swimming and water recreation areas and drinking water sources with waterborne diseases and other contaminants can pose a risk to public health.

Our primary production, tourism, and hydroelectricity sectors rely on a plentiful supply of freshwater, but we do not have a complete national picture of how much freshwater we use. This makes it difficult to assess the sustainability of our water use.

Impacts on aquatic life, people, and culture

Pressures on freshwater and changes to it are affecting the environment, our lives, and things that are important to us.

TE AO MĀORI



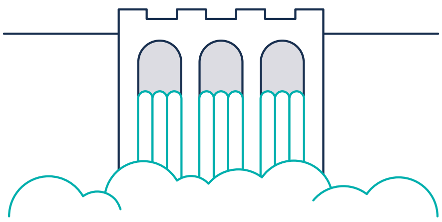
For many Māori, the freshwater environment is central to tikanga (customs and protocols), mātauranga (Māori knowledge), and mahinga kai (traditional food gathering practices).

For example, if rivers and lakes are contaminated, iwi and hapū can't gather kai and offer manaakitanga (helping people and hosting guests).

BIODIVERSITY

Fish and other aquatic life – including endangered species – can be affected by water temperature and weather pattern changes due to climate change.

Algal blooms and other effects of excess nutrient levels can harm freshwater species and ecosystems.



Fish can be affected by structures like dams, weirs, and flood pumps, which hamper their ability to migrate and breed.

LIVES AND LIVELIHOODS

All New Zealanders – and many sectors of the economy – need clean and reliable supplies of water.

Auckland's 2020 drought cost over

$200m

for emergency drinking water supplies.

People's health is put at risk by pollution from wastewater overflows and livestock run-off.

Algal blooms and other effects of excess nutrient levels can restrict people's recreational use of lakes and rivers.

Communities and infrastructure can be dramatically affected by extreme weather events that cause flooding.

Mātauranga Māori of te taiao is connected with the health of freshwater ecosystems and the abundance of taonga species.

- Some freshwaters in Aotearoa have been irreversibly degraded, impacting the connection and interaction with people (Stewart-Harawira, 2020) (see *Our freshwater 2020* for more information on irreversible degradation).
- Degraded ecosystems and the threatened loss of native species impacts the intrinsic connection and wellbeing many Māori have with te taiao (the environment) and associated mātauranga. This impacts mahinga kai practices and physical access to waterways (Mike, 2021; Parsons et al, 2021).
- The state of native taonga (treasured) species such as the longfin tuna (eels) and kōura (freshwater crayfish) impact the maintenance of values like mana (power, authority), mātauranga, and whakaheke korero (passing knowledge to the next generation) (Collier et al, 2017; Harmsworth & Awatere, 2013; Lyver et al, 2017a; Lyver et al 2017b; Lyver et al, 2021).
- The practice of gathering tuna is also connected to the observations of the maramataka, and the loss of our taonga species and mahinga kai areas can impact the ability to transmit mātauranga (Mauri Compass, 2022). Maramataka is the traditional Māori way by which time was marked by observing the phases of the moon.
- Pūrākau (stories) are often associated with taonga species – for example, the matuku hūrepo (Australasian bittern) whose call was thought to help people through grief; pārera is a metaphor for greediness by its way of eating; and the whio (blue duck) named accordingly to the male's call: a whistle sound. The bird calls of koitareke (marsh crake) and tarāpuka (black-billed gull) have been known to signal danger as warning signs of an oncoming attack, and the tūturiwhatu (banded dotterel) are written in songs as the only survivor of a cataclysmic disaster (Keane-Tuala, 2015).
- The deteriorating state of some taonga species can impact the ability of tohu (signs) and mātauranga to be maintained and transmitted (Taura, et al 2021).
- Kāinga (settlements) have existed near waterways for many reasons such as abundance of kai (food) and access. Healthy waterways are important for ahikāroa (connection with place), whanaungatanga (family ties and links), and kaitiakitanga (guardianship) (Morgan, 2006).
- The protection of taonga species that are important to the practice of mahinga kai therefore also contributes to protecting and maintaining te reo Māori (Māori language), tikanga, and mātauranga Māori (Harmsworth & Awatere 2013; Parsons et al, 2021; Rainforth & Harmsworth, 2019).
- The engagement and use of mātauranga Māori benefits the restoration of freshwater systems (Stewart-Harawira, 2020).

The lifegiving and healing properties that are essential for tikanga can be impacted by the health of freshwater systems.

- When wai (water) is healthy and strong it can be used for healing and life giving. But if the wai is depleted or absent it can negatively impact tikanga (Ngata, 2018).

- The pollution, degradation, and diversion of freshwater systems impacts the mauri of each water body (Hikuroa et al, 2018; Stewart-Harawira 2020). (See the Te ao Māori, mauri, and our connection to freshwater section for the definition of mauri used in this report.)
- The threatened status of taonga species and ecosystems, as well as the reduced quality and quantity of rongoā (healing) materials available, impacts important healing practices associated with rongoā (Mark et al, 2022).
- Many freshwater sites such as geothermal environments (eg pools and mud) are known for their healing properties (Hikuroa et al, 2011). Geothermal resources facilitate a spiritual connection between some Māori, their ancestors, and the gods (Taute et al, 2022).
- Wai tapu (sacred waters) are used for ceremonial practices. Traditional uses of wai include rituals, baptisms, drinking, and cleaning (Jefferies et al, 2011).
- Local communities are linked in with specific mahinga kai sites through knowledge and their place-based relationships, and frequently prioritise these areas in iwi and hapū environmental management plans (Awatere et al, 2018).
- Abstractions altering the flow of waterways can adversely impact the mauri of rivers by changing the connections from the mountains to the sea and disrupting the spiritual connection between iwi and the awa (rivers) (Young et al, 2004; Jones & Hickford, 2019).

The ability to practice and access mahinga kai is impacted by the abundance and health of freshwater species and access to mahinga kai sites.

- Mahinga kai can be described as traditional Māori food gathering practices and food gathering sites. Mahinga kai includes the ability to access food resources, food gathering sites, the gathering and use of food, and abundance and health of species (Panelli & Tipa, 2009).
- Mahinga kai is one of the main ways to protect and develop sustainable relationships with freshwater bodies (Awatere et al, 2018).
- Mahinga kai species are gathered from freshwater environments, including tuna, īnanga (whitebait), kākahi (freshwater mussels), kōura and wātakirihi (watercress). These are impacted by habitat loss and destruction which causes a loss of ability to collect kai and fish (Collier et al, 2017) and compromises the cultural use of species (Noble et al, 2016; McDowall, 2011).
- More than simply gathering kai, the ability to collect these resources affects the mana of an iwi or hapū, as they contribute to their capacity for manaakitanga – offering food from their whenua (land) and wai to invited guests, is an important part of hospitality (Rainforth & Harmsworth, 2019).
- When ecosystems and biodiversity have been degraded, there is a corresponding effect on the extent, quality, and access to customary resources. These impacts are felt catchment wide from the mountains to the sea – ki uta ki tai (Tipa, 2009).
- Decreased or altered flows can also affect the availability of traditional and customary resources and access to mahinga kai areas. The cultural health and wellbeing of a site can therefore be deeply affected by changed flows (Tipa, 2009).
- Sewage discharges can contaminate kai harvested from freshwater sources such as awa and roto (lakes). This impacts the health and wellbeing of those who harvest kai (Mika, 2021).

- Altered flows and accumulation of sediment alter the condition of the awa, putting pressure on mahinga kai species availability (Hikuroa et al, 2018).

Wāhi tapu, such as repo, have many benefits, though these benefits have been reduced by reductions in their extent and condition.

- Repo (wetlands) are wāhi tapu (sites of significance). If repo continue to be lost, cultural indicators that have been founded on generations of mātauranga Māori, such as those relating to kōwhitiwhiti (watercress), kuta (giant spike sedge), and harakeke (flax), will also be lost, along with the ability to interact with these places (Taura et al, 2021).
- Repo provide many benefits, such as storing carbon, regulating water flow during storms, and purifying water through filtering out nutrients and sediments (Clarkson et al, 2013; Schallenberg et al, 2013). The extent and condition of repo habitats and ecosystems, therefore, impact these important processes.
- Coastal wetlands are particularly sensitive to climate change, so may be exposed to change in freshwater flow and rising sea levels (Rodríguez et al, 2017).
- Human changes to wetlands and estuaries such as draining, ploughing, and burning impact how well the environment can adapt to flooding events, sedimentation, and pollutants before they reach the ocean (NIWA, 2007; Ausseil et al, 2011; Clarkson et al, 2013).
- Some lakes and waterways used for recreation and cultural practices are affected by high nutrient concentrations, frequent algal blooms, and decreased river flows. This can reduce the water quality for swimming and other activities. Such changes affect the mauri of waterways and how we relate to and use them.
- Many marae and urupā (burial grounds) located near rivers and flood prone areas are increasingly vulnerable to erosion caused by climate change induced extreme weather impacts (Awatere et al, 2021).

Freshwater ecosystems are impacted by the excessive algal growth caused by increased nutrients, which depletes dissolved oxygen levels and reduces clarity. At high concentrations some nutrients become toxic to freshwater species.

- Nutrients, such as nitrogen and phosphorus, occur naturally in the freshwater environment; however, elevated levels due to human activities can drive eutrophication: an overload of nutrients that can cause algal blooms, depleted oxygen levels, and subsequent harmful effects on freshwater ecosystems (Snelder et al, 2020).
- Algal blooms block out light and reduce the amount of native freshwater plants (that provide habitat for native species) (Collier & Grainger, 2015; Schallenberg et al, 2013; Rowe, 2007).
- Kākahi habitat decline has been attributed to river regulation, eutrophication, and other types of pollution (Phillips, 2007).
- High loads of nitrogen input into freshwater ecosystems can cause toxic levels of nitrate and ammonia which impair the survival, growth, and reproduction of some freshwater animals (Camargo & Alonso, 2006 in Snelder, 2020).

- Excess nutrients in waterways can lead to reduced oxygen levels and change the composition of plant and animal communities. This can negatively impact species associated with freshwater, including taonga species such as tuna, kākahi, kōura, and īnanga). These are important food sources in Aotearoa and valued taonga linked to mātauranga and cultural identity (Williams et al, 2017) (see indicator: Fertilisers – nitrogen and phosphorus).
- Some fish, particularly the young of species like īnanga, paraki/pōrohe (common smelt), and toitoi/tīpokopoko (common bullies) are more sensitive to low levels of dissolved oxygen than others (Franklin, 2014; Landman et al, 2005).

Freshwater habitats are degraded by contaminants from human activities on land, which can harm freshwater species.

- Soil washed from the land can degrade freshwaters both when it is suspended in the water and when it settles as sediment on a streambed (MfE & Stats NZ, 2020).
- Excess suspended sediment affects freshwater species by clogging their gills, affecting their oxygen exchange, feeding, and changing the visual clarity of the water which can affect fish feeding and their ability to migrate (Collier et al, 2017). It can also make the water cloudy, block out light, and reduce the amount of native freshwater plants (that provide habitat for native species) (NIWA, 2019; Rowe, 2007; Schallenberg et al, 2013).
- Excess deposited sediment smothers natural habitats on the bottom and banks of rivers and lakes, by filling in the spaces between rock and gravel that small fish and invertebrates use to hide and breed. It can also make their food harder to find (Clapcott et al, 2011; Burdon et al, 2013).
- Altering river channels and flows, increased erosion of riverbanks, and other changes to river habitats affect the range of species that rivers can support and can reduce or prevent the movement of some species (Harding et al, 2009; MfE & Stats NZ, 2020).
- Microplastics have been found to accumulate in freshwater organisms and can cause impacts depending on physical shape and size, age, density, and the chemicals the microplastics are made from (Zimmermann et al, 2020; Ockenden et al, 2022; Ockenden et al, 2021).
- A controlled study by Ockenden et al, 2022 found that dibutyl phthalate (DBP), a common chemical additive in plastic, can leach rapidly from microplastics into water and accumulated in the aquatic larvae of a common New Zealand caddisfly species (*olinga feredayi*) and its food source. DBP was found to have toxic effects on the macroinvertebrate's respiration and feeding rates when it accumulated to high concentrations (Ockenden et al, 2022).
- There is still limited research about the extent to which plastic will impact our freshwater species and ecosystems in Aotearoa (Mora-Teddy & Matthaei, 2020; PMCSA, 2019).

The effects of climate change on water temperatures, flows, and coastal environments are likely to impact our freshwater species and ecosystems.

- Climate change is predicted to have impacts on our freshwater ecosystems, including our taonga species (Egan et al, 2020). However, some of these impacts are not yet fully realised, as long-lived greenhouse gases build up in the atmosphere over decades, affecting long-term climate change outcomes (see *Our atmosphere and climate 2020*).

- Changes in water temperatures are predicted to influence the movement of some fish to higher elevations, impact spawning times, and change their migration timing and success (Awatere et al, 2021; Egan et al, 2020). Species that are already living close to their maximum temperature threshold are particularly sensitive to changes in temperature (Foley and Carbines, 2019).
- Reductions in glacier extent may impact species adapted to glacier-fed environments. As these environments become more similar to rain- and groundwater-fed systems, competition from downstream increases, and species highly adapted to glacier-fed flows are likely to decline. The effects on biofilm and microinvertebrates are less well known than the effects on macroinvertebrates (Fell et al, 2017).
- Due to climate and land-use driven pressures, macroinvertebrates were found to shift their ranges southward by an average of approximately 50 kilometres per decade between 1991 and 2016 (Mouton et al, 2022).
- Floods can wash out and destroy fish eggs that are laid in the vegetation in or beside a waterway (Goodman, 2018; Hayes et al, 2019). Floods also signal for many fish species to migrate so the change in height and variability of floods may also affect species' migration patterns (Goodman, 2018).
- Coastal erosion and rising sea levels can increase the amount of saltwater moving into freshwater environments (MfE, 2017). Even small changes in salinity (saltiness) can affect freshwater species and habitats (Schallenberg et al, 2003; Cañedo-Argüelles et al, 2013; Neubauer et al, 2013). Īnanga, for example, only spawn when the salinity is within a specific range (Goodman, 2018). Sea-level rise could also affect the success of īnanga spawning by forcing the fish into upstream areas that do not have appropriate vegetation for egg laying (Kettles & Bell, 2016).
- Some vulnerable and taonga species may lose parts of their habitats or become extinct due to changes in climate (Hennessy et al, 2007). Local kaitiaki, hapū, and whānau fishers are already noting seasonal shifts that affect their kaitiakitanga practices and harvest times, as well as the tohu that signal them (Deep South National Science Challenge, 2018).

Our native species and their habitats are impacted by introduced freshwater species.

- Climate change is predicted to enable invasive species to establish within higher elevations and move southwards in Aotearoa (IPCC, 2022).
- Impacts from invasions of non-native species can include the destabilisation of aquatic environments and loss of indigenous plant biodiversity (NIWA, 2020).
- Many introduced plants (like hornwort *Ceratophyllum demersum*) form tall, dense weed beds and spread quickly (Wells et al, 1997; de Winton et al, 2009). These plants can take the place of native freshwater species and make the habitat unsuitable for native fish and invertebrates (Champion et al, 2002; Clayton & Champion, 2006).
- Introduced freshwater fish species, such as perch, prey on our indigenous species (DOC, 2020a). Omnivorous species will also feed on aquatic plants, which can degrade water quality and clarity (DOC, 2020a).

- Trout and salmon fishing have recreational and economic benefits for Aotearoa but can have negative effects on rivers and streams (Mcintosh et al, 2010; Usio & Townsend, 2000). In many waterways, trout have replaced native galaxiids as the dominant fish species and affected the distribution of kōura (Mcintosh et al, 2010; Usio & Townsend, 2000).
- Didymo affects the populations of invertebrates in a stream and therefore reduces the number of native fish and trout because they prey on invertebrates (Jellyman & Harding, 2016; MPI, 2020).

Fish migration is impacted by human changes to river flows and habitats.

- Some human-made structures such as dams, weirs, and culverts can obstruct fish migrations, reduce fish populations, affect natural stream processes, and prevent fish reaching habitats critical to their survival (Franklin et al, 2018; Graynoth et al, 2008) (see indicator: Selected barriers to freshwater fish in Hawke's Bay, and *Our freshwater 2020*).
- Research in the Greater Wellington Region has identified that monitoring sites upstream of barriers such as weirs and culverts have reduced diversity of species (Davis, 2021).
- A study of four Canterbury streams found that streams downstream of abstraction points had significantly lower fish abundances per metre of stream length, likely due to low flow rates reducing habitat size, changing interactions with other species, and barriers to movement (Boddy et al, 2020).
- Cumulative effects of warming, drought, floods, and algal blooms are compounded by water abstraction and are predicted to impact the ecosystems and species in rivers (Macinnis-Ng et al, 2021; Puddick et al, 2022). Affected species may include stream invertebrates, native fish, trout, and salmon (Ryan & Ryan, 2006).

Public health has been impacted by contaminants and water-borne diseases in water used for recreation and drinking water.

- Regional councils monitor popular swimming sites, including rivers and lakes, to assess the health risk of swimming at that site (see LAWA website). Faecal contamination from humans and animals is the main reason that exposure to water during swimming can become unhealthy. When counts of faecal contamination are too high it can cause gastroenteritis and infections, such as skin infections (LAWA, 2022).
- In 2017, there were 427 notifiable illness cases of campylobacteriosis, 250 of giardiasis, 219 of cryptosporidiosis, 135 of salmonellosis, and 88 of *E. coli* infection for cases where people reported contact with recreational water (river, lake, or sea). About 100 cases of two other notifiable waterborne diseases were also reported (ESR, 2019).
- Most of the time toxic algae are only present at low levels in Aotearoa freshwater environments. However, during summer months when nutrients and temperatures increase and rainfall decreases, algal blooms are likely to become more frequent (Puddick et al, 2022; LAWA, 2021; BPAC, 2020).
- Ingesting freshwater with high levels of toxic algae can cause illnesses in humans, including nausea, diarrhoea, and in extreme cases, liver damage (LAWA, 2021). Additionally, more than 70 dog deaths have been reported since 2006 across Aotearoa because of consuming cyanobacteria from rivers (MfE & Stats NZ, 2017).

- Rivers, lakes, and groundwater are used for drinking water supplies. When these waters are contaminated and not properly treated, people can become ill. Being able to drink from waterways is an indicator of its mauri (Hikuroa et al, 2011).
- Nitrate-nitrogen contamination of drinking water poses a health risk to formula-fed infants less than six months old through the development of methemoglobinemia (blue-baby syndrome) (WHO, 2016). This is the basis of the maximum acceptable value for nitrate in drinking water set by the Ministry of Health (Ministry of Health, 2018).
- In August 2016, a large campylobacteriosis outbreak occurred in Havelock North due to faecal contamination of the town's drinking water supply. It was estimated that between 6,000 and 8,000 of the town's 14,000 residents became ill with the waterborne disease, leading to 42 hospitalisations and contributing to at least four deaths (Gilpin et al, 2020).
- An assessment of 16 Aotearoa waterways that supply public drinking water between 2009 and 2019 found that sites on rivers draining predominantly agricultural catchments had higher prevalence of *Campylobacter*, *E. coli*, *Cryptosporidium*, and *Giardia* than those predominantly covered by native vegetation (Phiri et al, 2020).
- There are health risks for rural communities and marae who rely on water from unfiltered systems such as tank water and groundwater wells in intensively farmed areas. This may impact the ability of marae to supply sufficient safe drinking water for attendees. The risk can increase with extreme rainfall events and higher temperatures (Awatere et al, 2021).

Our economy relies on our freshwater environment. Changes driven by climate change have impacts on both freshwater and our economy.

- Our primary production, tourism, and hydroelectricity sectors rely on a plentiful supply of freshwater.
- Maintaining water infrastructure has been commonly identified as an issue, due to difficulties with cost and access in isolated communities (Henwood et al, 2019). Many individual household systems need urgent repair or replacement of tanks, roofs, guttering and pipes, or additional water storage (Henwood et al, 2019).
- River flows are projected to change as rainfall increases in the west and south of the South Island and decreases in the east and north of the North Island (see Climate Change 2022: Impacts, Adaptation and Vulnerability, IPCC, 2022, for more information on these projections). Flooding due to extreme rainfall presents direct risks to life, transport, people, access, and property (Awatere et al, 2021).
- Flooding can damage housing and transport, energy, stormwater, and wastewater systems. In 2013 about 675,000 New Zealanders were estimated to live in areas prone to flooding from rainfall and overflowing rivers (Paulik et al, 2019; MfE & Stats NZ, 2020).
- Auckland's 2020 drought cost over $200m for emergency drinking water supply (Orsman, 2020).
- Climate change influences on the frequency and severity of extreme events and long-term weather impact the resilience of many farming practices (Cradock-Henry, 2021).
- Whilst the quantity of water taken from our rivers, lakes, and groundwater are a knowledge gap at a national level, it is hard to assess how sustainable our water use is: whether our freshwater resources are overexploited, and if they can continue to support us in the future (MfE, 2021).

- Our economic and non-economic wellbeing are linked to the environment, now and in the future (PCE, 2021).

A healthy freshwater environment is important for our wellbeing.

- Spending time in or near rivers and lakes can provide important wellbeing benefits, including reduced fatigue and stress, improved immune system function, and increased fitness (Gascon et al, 2017; Pasanen et al, 2019; White et al, 2020).
- Many New Zealanders engage in freshwater and marine recreation. A survey of almost 4,000 New Zealanders found that over 50 percent of adults participate in swimming outdoors at least once a year. Approximately a third of people engage in fishing at least once a year, and around 20 percent of people participate in kayaking or rafting at least once a year (DOC, 2020b). If we are unable to swim, fish, or kayak in our rivers and lakes, this can impair the mental, physical, and psychological benefits of connecting with the freshwater environment.
- Pressures on the freshwater environment, such as fine sedimentation, can increase flooding, causing waterways to be less suitable for recreation and mahinga kai (Collier et al, 2017; Rey, 2021). This impacts the ability for New Zealanders to interact with the freshwater environment.
- The natural beauty of our freshwater environment, including rivers and lakes, is central to our national identity. How we identify as New Zealanders may be affected if we cannot easily access freshwater spaces (see *Environment Aotearoa 2022*).

Data and research gaps

Our freshwater environment is expansive, diverse and part of a highly interconnected system. As a result, the issues facing the freshwater domain are often complex and strongly linked to pressures occurring on the land. The time it takes for pressures, especially those on land, to be felt in the environment adds another layer of complexity. Understanding these dynamics is necessary to ensure the decisions we make now give us the best possible chance for ensuring that future generations benefit from a thriving freshwater environment.

Aotearoa New Zealand's environmental monitoring and reporting system plays a key role in protecting te taiao (the environment), but our ability to report on the state of the environment depends on how well we collect and analyse data about it, and that needs improving.

Many of the issues identified by the Parliamentary Commissioner of the Environment in his 2019 system review still challenge current reporting. These issues are evident in the content of *Our freshwater 2023*: there continues to be gaps in data, inconsistencies in methods and monitoring, lack of accessibility, and a gap in elevating mātauranga Māori (Māori knowledge). Work is underway to establish a fit-for-purpose environmental monitoring and reporting system that is adaptable to future challenges.

The Ministry for the Environment in conjunction with sector partners, are embarking on a significant programme of work to reform the foundations of the system. This will include developing core indicators for monitoring our environment, designing the analytical architecture required to assess and interpret the data, and the blueprint design of a national monitoring network. Alongside this, our work on the Environment and Climate Research Strategy will provide future direction for prioritising investment in science and research as part of Te Ara Paerangi – Future Pathways.

While this report has highlighted new evidence and research into the state of our freshwater environments since *Our freshwater 2020*, there are still critical gaps in our knowledge that need to be filled. These include:

- Building and strengthening our mātauranga Māori evidence base to better understand effects on te ao Māori (Māori worldview). Mātauranga Māori represents a valuable record of our environment that is unique to Aotearoa and that complements our existing science and evidence base. This requires improving the resourcing of Māori research, access to, and integration of ngā tohu o te taiao (environmental indicators) drawing from mātauranga Māori.
- Improving our ability to access and share rohe-based and place-based knowledge and evidence, to enhance our understanding of localised pressures, state, and impacts and elevating the value of this knowledge in reporting.
- Building a more holistic understanding of the health of the freshwater environment and all its component ecosystems, habitats, and species. This requires more integrated analyses of the data we have (like water quality), and investing in wider monitoring of, and research into, lesser understood components of the environment (like groundwater ecosystems and puna (springs)).
- Improving our understanding of how mauri is impacted by pressures from resource use and management and other human activities. (See the Te ao Māori, mauri, and our connection to freshwater section for the definition of mauri used in this report.)

- Improving our understanding of the pressures on freshwater and their causes, including how they interact and intensify in places and over time. This requires more detailed information on spatially complex land-use pressures (particularly those additional to pastoral agriculture) and mitigations in catchments, how these change over time, and how this impacts freshwater.
- Quantifying the benefits of freshwater for multiple values, including social and economic wellbeing, so that trade-offs are better understood. This requires more comprehensive and purposeful measurement of the benefits of freshwater ecosystems, and how these are affected by competing social forces like housing and economic development.
- Understanding how pollutants and other effects of multiple pressures act on the whole freshwater environment over time, from mountains to sea, and where they are having cumulative and cascading impacts on ecosystems. This includes improving our understanding of how human activities from the past several decades (and longer) may continue to impact the freshwater environment, even after these pressures have reduced.
- Understanding how quickly our freshwater ecosystems are changing in response to pressures, and how resilient they are to the ongoing effects of our activities. Central to this is building our knowledge of ecosystem ‘tipping points’, so we know where interventions are most needed to protect the most vulnerable water bodies and freshwater environments. This includes drawing from mātauranga Māori methods for protecting the resilience of te taiao, such as rāhui (temporary restricted access).
- Strengthening our understanding of the long-term risks that freshwater contamination poses to human health in Aotearoa, such as nitrate-nitrogen in drinking water. There is evidence emerging from overseas that suggests long-term exposure to levels of nitrate found in groundwater in some parts of Aotearoa could increase the risk of pre-term births, congenital abnormalities, and bowel cancer, but more research is needed before the level of risk can be fully understood.

Environmental indicators

The data used in *Our freshwater 2023* is drawn from *Our freshwater 2020* and *Environment Aotearoa 2022* and the Stats NZ indicators that have featured in them. Listed below are the indicators that have been incorporated in this report, including one updated indicator in bold:

- Annual glacier ice volumes
- Coastal sea-level rise
- Consented freshwater takes
- Exotic land cover
- **Extinction threat to indigenous species**
- Extreme rainfall
- Fertilisers – nitrogen and phosphorus
- Freshwater physical habitat
- Groundwater physical stocks
- Groundwater quality
- Irrigated land
- Lake submerged plant index
- Lake water quality
- Livestock numbers
- Nitrate leaching from livestock
- River water quality: clarity and turbidity
- River water quality: Escherichia coli
- River water quality: macroinvertebrate community index
- River water quality: nitrogen
- River water quality: phosphorus
- Selected barriers to freshwater fish in Hawke’s Bay
- Temperature
- Urban land cover
- Wetland area

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