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Studying Anthropause effects on marine ecology in New Zealand: a statistical assessment

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Studying Anthropause effects on marine ecology in New Zealand: a statistical assessment

Olivia Johnston, Paula Casanovas

Prepared for Environment Southland, Canterbury Regional Council and

Otago Regional Council

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Contents

Executive summary

The Cawthron Institute has been contracted by Environment Southland, Otago Regional Council and Canterbury Regional Council through an Envirolink advice grant (2418-ESRC508) to provide a desktop statistical investigation of the relationship between marine tourism activities and existing marine ecological time-series data. This project focused on five key marine tourism locations or 'areas of interest' (AOI) over the COVID-19 pandemic border lockdown period in Aotearoa New Zealand (the Anthropause).

For this project, we analysed ecological response variables under three lines of evidence (water quality, litter and biological) to understand the possible ecological impacts of marine tourism on the five AOI: Milford Sound / Piopiotahi, Stewart Island / Rakiura, Otago Harbour / Otakou, Akaroa Harbour and Kaikōura Peninsula. Our main hypothesis was that the reduction in marine tourism activity, as a result of the Anthropause, led to measurable differences to our indicator ecological proxies. First, this investigation tested if there were differences for multiple ecological variables, as well as the marine tourism variable (passenger vessel density), between the three time periods we defined for studying Anthropause effects: 2 years before lockdown, during the lockdown period, and 2 years after the lockdown period. Despite there being more variables and models where no significant differences were found, the study period analyses showed some evidence for an Anthropause effect. We found that several variables within each of the three different lines of evidence were significantly different between periods.

Many of the ecological variables investigated showed an improvement during and / or after the Anthropause, e.g. litter decreased, species abundance and richness increased and waterborne faecal indicator bacteria (FIB) decreased. In contrast, other ecological responses during and / or after the Anthropause showed degradation, e.g. FIB in wastewater discharges increased and waterborne chlorophyll-*a* concentrations increased. These results suggest:

- An improved ecological benchmark appears to have been achieved during the lockdown period. This benchmark was not achieved under pre- and / or post-Anthropause marine tourism passenger vessel operating conditions.
- Ecological improvements sometimes persisted following recommencement of marine tourism activities in the 2 years after the Anthropause.

Second, we used generalised linear models (GLMs) to relate the ecological variables with marine tourism impact (passenger vessel density) and sea surface temperature (SST; as an alternative predictor of change on the ecological variables) both at individual AOI and collectively. These results suggest:

- There were interacting explanatory drivers to the ecological responses observed (SST and passenger vessel density), suggesting that climate might influence the effect of tourism.
- There could be other potential drivers of the ecological responses observed that should be investigated (e.g. charter flights, shore-based activities).

We analysed the data in two levels: common data to all AOI, and site-specific data. When considering common and site-specific data results together, we found that:

- Marine tourism may contribute to increased concentrations of waterborne FIB, and possibly other contaminants that can affect human health. The suitability of FIB as indicators for

detecting marine tourism effects should be investigated.
- The evidence for an impact of the Anthropause (e.g. lack of tourism effects) on ecological variables varied between AOI, highlighting the importance for accurate local data to inform management responses for each area.

The next course of action is to develop site-specific marine tourism management response plans (MRP), specifically these should:

- Relate to the marine tourism activities that are unique to that AOI.
- Include a focused, finer scale assessment on the direct and interacting drivers identified in this assessment.
- Recommend approaches for monitoring the potential ecological responses identified here (biodiversity, water quality and litter) as future effect indicators.
- Identify possible management tools that could be used to manage potential effects.
- Provide recommendations for each council to ensure there is an accumulation of robust long-term ecological data to help future and ongoing marine tourism assessments.

1. Introduction

During the COVID-19 pandemic border lockdown, Aotearoa New Zealand's international borders remained shut for tourism from 19 March 2020 to 31 July 2022, limiting movement in and out of the country. This period of reduced activity is referred to as the 'Anthropause'. The term Anthropause was introduced by Rutz et al. (2020) and is now used globally to describe the substantial reduction in human mobility observed during early COVID-19 lockdowns (Bates et al. 2021; Callejas et al. 2021; Seelanki and Pant 2021; Armstrong et al. 2022; Gaiser et al. 2022; Mallik et al. 2022; Mosbahi et al. 2022; Muche et al. 2022; Pine et al. 2021; Rutz 2022). The Cawthron Institute (Cawthron) was contracted by Environment Southland (ES), Otago Regional Council (ORC) and Canterbury Regional Council (CRC) through an Envirolink advice grant (2418-ESRC508) to provide an analysis of the relationship between existing tourism activities and marine ecological time-series data before, during and after the Anthropause period. For this work, we focused on five key marine tourism locations or 'areas of interest' (AOI): Milford Sound / Piopiotahi, Stewart Island / Rakiura, Otago Harbour / Otakou, Akaroa Harbour and Kaikōura Peninsula (Figure 1).

The overall aim of this project was to improve councils' understanding of the ecological impacts of marine tourism on each AOI to enable informed management of tourism. Cawthron undertook preliminary investigations into potential marine tourism effects, the suitability of data sources, and the development of data analyses approaches in 'Stage one' of this investigation (Envirolink advice grant 2306-ESRC507; Johnston and Casanovas 2023). As part of Stage one, we presented preliminary recommendations for a methodological approach to analyse the datasets deemed 'suitable' for assessing marine tourism-related impacts during the Anthropause period at the five AOI. The Stage one report also summarised the available ecological and marine tourism-related data for each region and encouraged collaborative working interactions between the participating regional councils. The ecological data identified as being suitable included those data that were: across the Anthropause period; an appropriate time series (and / or had potential for ongoing data collection); in close proximity to marine tourism activities; robust (high levels of sampling replication and scientifically sound); and readily available for use in 'Stage two' of the assessment.

This report focuses on Stage two of the investigation. The working hypothesis of Stage two is that the reduction in marine tourism activities, as a result of the COVID-19 travel restrictions, led to measurable improvements to marine ecology. The following steps were addressed to obtain the required knowledge and deliver the outcomes of Stage two:

- Obtain data use approval in writing.
- Develop the conceptual research model (methods section of this report) to define the data specific research questions on the potential effects (from the response data) and how the effects will be measured.
- Provide a detailed methodological description for data analysis.
- Provide a summary of any potential marine tourism / Anthropause-related impacts at the AOI and any significant results over all the locations.

The Stage two reporting was designed and interpreted with a focus on improving the councils' environmental management of marine tourism operators at the AOI. The key questions that were discussed in this assessment are listed below, and each question is presented in the final report discussion (see Section 4):

- **Anthropogenic effects**: Are there detectable effects from marine tourism at the case study locations, pre- and post-Anthropause? If so, what are they?
- **Recovery**: Does halting marine tourism ventures of concern result in measurable improvements to marine ecology?
- **Management / monitoring**: What are appropriate indicator variables for determining effects from marine tourism ventures of concern, and what level of tourism intensity is (ecologically[1]) sustainable?
- **Mitigation of effects**: What tourism control / adaptation / mitigation measures should be implemented to reduce risk associated with marine tourism ventures of concern?

The final section of this report summarises the next recommended management steps for councils.

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[1] The ability to sustain a full range of ecological systems, indefinitely.

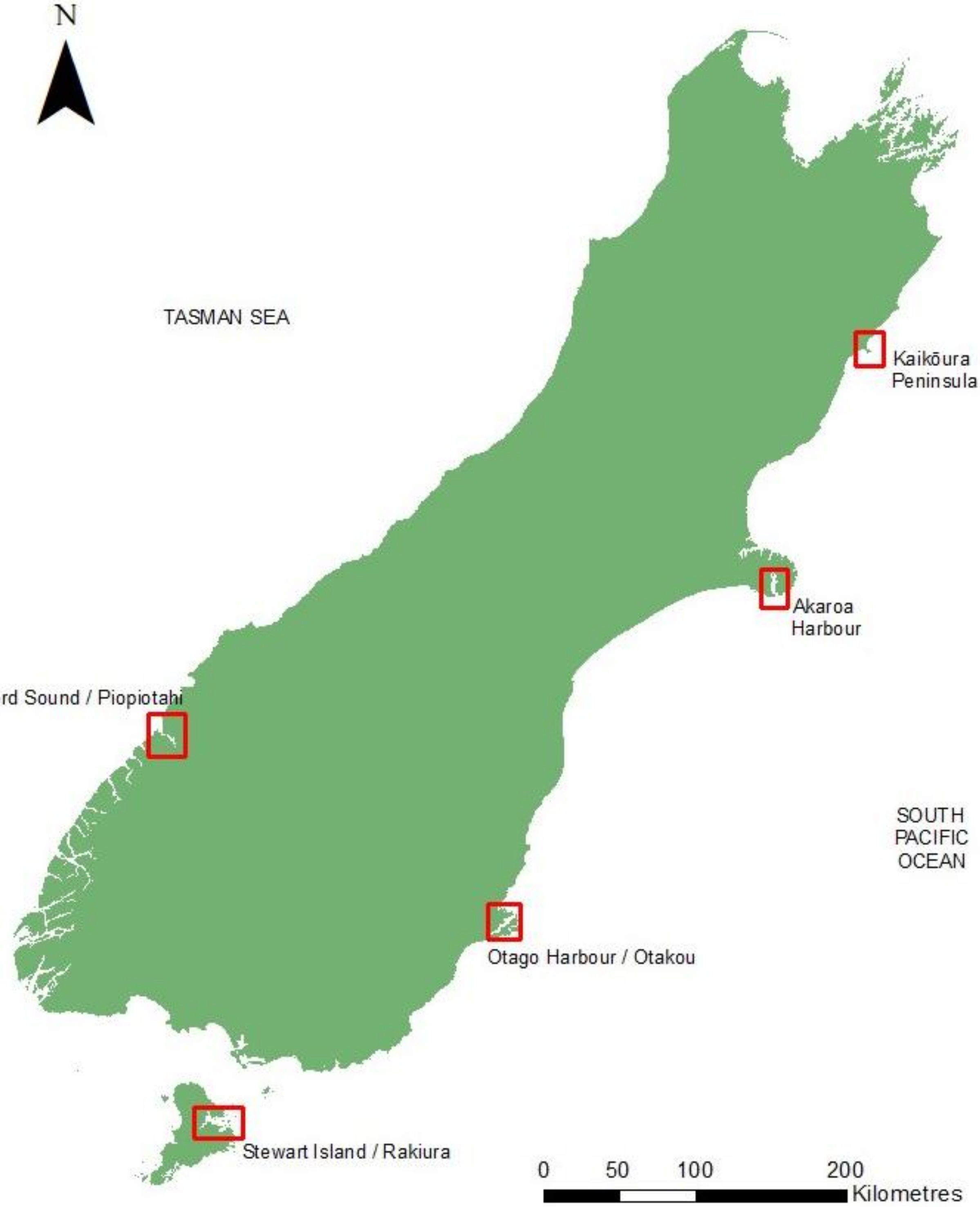

Figure 1. Marine tourism areas of interest investigated in the South Island of Aotearoa New Zealand (red boxes): Milford Sound / Piopiotahi, Stewart Island / Rakiura (Environment Southland jurisdiction); Otago Harbour / Otakou (Otago Regional Council jurisdiction); Akaroa Harbour and Kaikōura Peninsula (Canterbury Regional Council jurisdiction).

2. Methods

2.1 Data approval and collation

There was a wide range of possible data sources identified in Stage one of this project, but only a limited number were identified as potentially suitable. Those that could be accessed or supplied were either available from web-based platforms for public use or directly supplied (and approved for use) from the data custodian. Records of data use permissions are available on request.

2.2 Conceptual model development

The development of the data analysis model needed to consider the following caveats:

1. Individual dataset issues (e.g. data errors)
2. Varying data collection frequency (e.g. daily, weekly, monthly or opportunistically)
3. Varying data types, not directly comparable (e.g. different units of measure)
4. Covariates (climate, seasonality, drought, southern oscillation, sea surface temperature [SST], etc.)
5. Repeatability (methods of collection clearly defined and repeatable).

To address the above, the data analysis concept used a multiple lines of evidence (MLE) approach (Norris et al. 2005; Sherwood et al. 2020; Chancay et al. 2021), whereby each potentially suitable response data type (e.g. species abundance or species richness) is a potential 'line of evidence' to infer a relationship from an explanatory variable (e.g. passenger vessel traffic density). Individual data types were pooled into three temporal groups (using the dates specified for each dataset):

- **Before:** 1 January 2018 to 18 March 2020
- **Lockdown:** 19 March 2020 to 31 July 2022
- **After:** 1 August 2022 to 31 December 2023.

2.3 Data analysis

Tourism activities (explanatory variables)

The potential explanatory variable for determining marine tourism effects on ecological variables over the Anthropause was passenger[2] vessel density data (hours per km^2; GMT 2024).

Other vessel types and large-scale environmental variables were also investigated as alternative explanatory variables:

- The vessel density data (hours per km^2; GMT 2024) of other vessel types (such as fishing, cargo, etc.) that were not tourism-related (passenger type vessels) were included in the investigation as alternative explanatory variables.
- Changes in SST over the study period also likely had a potential effect on the ecological variables analysed. We sourced SST from remote sensing data (Sea Surface Temperature product; MODIS 2024), as well as from the New Zealand Ocean Acidification Observing Network (NZODN 2024b) and the New Zealand Ocean Data Network (Fisheries conductivity, temperature, and depth [CTD] data; NZODN 2024a).

Ecological data (response variables)

Ecological data that were used in the data analysis are referred to in this document as either 'common' (data available for all AOI) or 'site-specific' (only available for specific AOI). Both types of data are discussed below and summarised in Table 1 and Table 2; these tables also include the data abbreviation definitions.

Common data (Table 1) were those data that were available for all AOI, allowing for between and within site comparisons. The available data included:

1. Sighting / observation / incidents data (e.g. marine mammals, seabirds and the wider marine community)
2. Commercial fisheries bycatch data (of protected marine taxa)
3. Litter[3] surveys (undertaken by public)
4. Microbiological concentrations (e.g. enterococci (MPN/100 ml))
5. Satellite ocean colour data (Moderate Resolution Imaging Spectroradiometer [MODIS])
6. Water quality measures (e.g. New Zealand Ocean Data Network [NZODN])
7. Biological taxa records (e.g. benthic sampling).

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[2] The standard 'Passenger Ships' category filter from the GMT (2024) online map portal was used to download passenger vessel density data. This category is described as including both 'sailing' (AIS code: 36) and 'pleasure craft' (AIS code: 36), and also AIS codes: 60-69, which include passenger vessels under the 'hazardous A-D' categories, or where 'no additional information' was available. Note that cruise ships fall under the category of pleasure craft.

[3] Human-derived litter is not technically considered a natural 'ecological' variable; however, it has been included here under the same umbrella term.

Site-specific data (Table 2) were those data that were available for individual AOI, allowing for within site comparisons only. The available data included:

8. Water quality measures
9. Wastewater composition
10. Benthic community measures (community composition, abundance, richness).

All data were either directly supplied (and approved for use) from the data custodian (e.g. Department of Conservation [DOC] or Fisheries New Zealand [FNZ] / Ministry for Primary Industries [MPI], ES, Christchurch City Council [CCC]) or were available from web-based platforms for public use (e.g. Litter Intelligence, LAWA, MODIS, NZODN, Ocean Biodiversity Information System [OBIS], iNaturalist, eBirds).

Note that Sanford's monthly consent-based water quality sampling data (ES 2024b) were supplied through official information request. However, the data were supplied in report format and required extensive transposing; therefore, Sanford's data could not be used in this assessment.

Table 1. Common environmental response data used in this study.

Lines of evidence	Common response data
Water quality: Differences over the Anthropause potentially caused by: Passenger vessel turbulence Run-off from passenger vessels and coastal discharges	**Chlorophyll-*a*** (mg/m^3), **particulate organic carbon** (mg/m^3; POC) – MODIS Aqua monthly product (MODIS 2024) **Salinity** (psu) – Fisheries conductivity, SST, and depth (CTD) data (NZODN 2024a) **Dissolved inorganic carbon** (µm/kg), **salinity** (psu), **pH** and **carbonate ion states** (µm/kg) – New Zealand Ocean Acidification Observing Network records (NZODN 2024b) **Coastal enterococci (MPN/100 ml)** concentrations (LAWA 2024)
Litter: Differences over the Anthropause potentially caused by: Passenger vessel littering	**Type of litter** (plastic, textiles, wood, paper, cardboard, metal), **number of items** (count)**, weight of litter** (g) – Litter Intelligence survey data (LI 2024)
Biological (abundance and richness): Differences over the Anthropause potentially caused by: Direct physical disturbance from passenger vessels Indirect effects from reduced water quality and litter stressors (attributable to passenger vessel presence, density)	**Sector, colony, fresh, decomposed** Department of Conservation fur seal dead counts (incidents) (DOC 2023a) **Sighting location, name of species, number of individuals, circumstances, distance from shore, number of juveniles** NZ marine mammal incidents database (DOC 2023b) NZ marine mammal sightings database (DOC 2023c) **Species, family, abundance, gender, age, fishing method** Fisheries New Zealand marine mammal bycatch records (FNZ 2022) **Species, family, abundance, fishing method, target fishery** Protected species bycatch in New Zealand commercial fisheries, commercial bycatch (FNZ 2021) **Species, family, abundance** Ocean Biodiversity Information taxa records (OBIS 2024) Biological observation/sighting records (iNaturalist 2024) International bird sighting database, NZ shorebirds (eBird 2023)

Table 2. Site-specific ecological response data used in analysis along with the associated marine tourism potential effect. Note that the web-based data sources identified in Stage one of the investigation (Johnston and Casanovas 2023) for Otago Harbour were not available at the time of this investigation; subsequent requests made to the University of Otago for data supply were unsuccessful.

Lines of evidence	Milford Sound / Piopiotahi data	Akaroa data	Kaikōura data
Water quality: Passenger vessel turbulence Run-off from passenger vessels and coastal discharges Compositional changes in wastewater discharge from tourism onshore	Enterococci (MPN/100 ml) [a] *E. coli* (CFU/100 ml) [a] Conductivity (EC) [a, b] Dissolved oxygen (g/m^3) [a] Temperature (°C) [a, b] Salinity (psu) [b] [a] Environment Southland Wastewater Treatment Plant receiving water monitoring dataset (ES 2024a) [b] Meridian Energy physical monitoring (Meridian 2024b)	Enterococci (MPN/100 ml) [c, d] Faecal coliforms (CFU/100 ml) [c, d] Ammoniacal nitrogen (mg/L) [c] Ammonia (g/m^3) (g/m^3) [d] Chlorophyll-*a* (ug/L) [c] Dissolved oxygen (mg/L) [c] Dissolved reactive phosphorus (mg/L) [c, d] Total nitrogen (g/m^3) [c, d] Total phosphorus (g/m^3) [c] pH (field) [c] Total suspended solids (mg/L) [c, d] Temperature (°C) [c] [c] Akaroa water quality (WQ) monitoring data – French Bay and Wainui sites (CRC 2024a) [d] Akaroa wastewater treatment plant discharge monitoring database (CCC 2024)	Enterococci (MPN/100 ml) [e, f] Faecal coliforms (CFU/100 ml) [f] Ammoniacal nitrogen (mg/L) [f] Chlorophyll-*a* (ug/L) [f] Dissolved oxygen (mg/L) [f] Dissolved reactive phosphorus (mg/L) [f] Total nitrogen (g/m^3) [f] pH (field) [f] Total suspended solids (mg/L) [f] Temperature (°C) [e, f] [e] WQ monitoring data, Armers Beach bathing area, South Bay bathing area, and Peketa Beach at Peketa (CRC 2024b) [f] WQ monitoring site data, Ingles Bay at Gooches Beach and South Bay in Marina (CRC 2024b)
Biological: Due to presence of marine tourism activities, e.g. passenger vessel presence (density)	**Intertidal and subtidal communities.** Meridian Energy biological monitoring (Meridian 2024a)		

2.4 Data summarisation and analysis

To enable comparisons of available data, datasets were delimited by AOI using the same rectangular polygons corresponding to a set area that included the coast around each port (see Figure 1). For some datasets, we also analysed the data for the whole of the South Island of Aotearoa New Zealand (Appendix 1). For other datasets, we were able to analyse the data collectively for the whole South Island – this also included some datasets that represented coastal data from around the whole South Island that were not available for each AOI. Final AOI and South Island datasets were summarised by month and year for the periods of interest between 1 January 2018 and 31 December 2023. For each ecological (response) variable, we calculated the mean or biodiversity relevant metrics such as species richness or abundance.

We performed two sets of analyses to evaluate the changes among the three periods of interest (i.e. before lockdown, lockdown, and after lockdown). The first set of analyses investigated the differences between the study periods for all the variables individually, for each AOI, or for the whole of the South Island. For these analyses, we performed generalised linear models (GLMs[4]) with family error distributions appropriate for each variable. For datasets with assigned AOI, we added the AOI as a factor on the model. We estimated the marginal means[5] for the comparisons among the periods, and adjusted[6] p-values for the differences were calculated using the Tukey method (Tukey 1949).

For the second set of analyses, we also performed GLMs to relate the ecological variables with passenger vessel density (as a proxy of tourism impact) and SST (an alternative predictor of change on the ecological variables). In the models, we included the interaction effect[7] between vessel density and SST for all variables, except for the variables associated with litter because SST is not expected to influence the abundance of litter. For these models, we used family error distributions appropriate for each response variable, and for the analyses, we used SST derived from remote sensing (MODIS 2024), as it was available for all AOI.

All response variables available for each AOI are shown in Appendix 1 (Tables A.1.1 and A1.2) for each set of analyses described above. Note that not all variables were available for all AOI or for the whole of the South Island. All statistical analyses were performed within the ‘R’ statistical and programming environment (R Core Team 2024). We used the package ‘emmeans’ (Lenth 2024) to estimate the marginal means (least-squares means) for testing the differences (contrasts for all pairwise comparisons among estimated marginal means with a p-value Tukey adjustment for multiplicity) between factor combinations from the GLMs.

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[4] Generalised linear models (GLMs) are a class of linear-based regression models for data with varying types of error distributions.

[5] Marginal means are means extracted from a statistical model and represent an average of the response variable for each level of predictor variable.

[6] Where p-values are computed with consideration for the number of estimates to be calculated.

[7] The interaction effect is where the behaviour of the response to one factor depends on the levels of the other factor.

3. Results

3.1 Common data

Comparison of study periods

For the first set of analyses, we tested if there were differences between the study periods for vessel density (three different ship types: passenger, fishing and all vessels), and the three different sources of SST for the three lines of evidence variables (water quality, litter and biological variables) across all AOI (see Table 1 for all data references). We performed a total of 343 contrasts for the different GLMs, of which 76 showed significant differences ($p < 0.05$) between the study periods. Figure 2 shows the proportion of significant and non-significant contrasts for the different AOI and lines of evidence. Table 3 identifies those variables and the number of contrasts that demonstrated significant differences between the study periods.

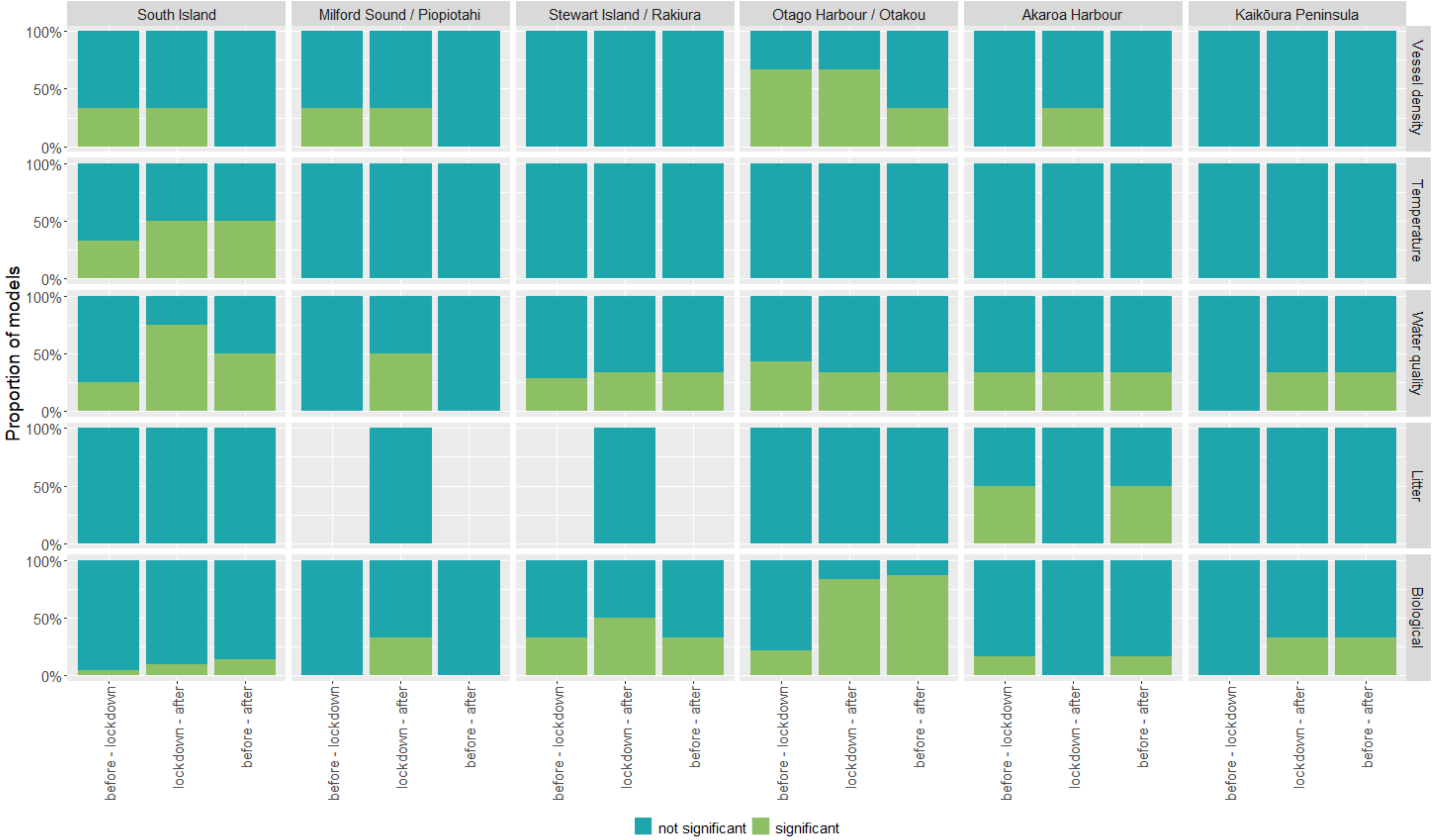

Figure 2. The proportion of generalised linear models for which we found a significant difference or no significant difference among the different study periods for vessel density, temperature and the three different lines of evidence (water quality, litter and biological variables) across all areas of interest.

Table 3. Variables that were significantly different between the study periods and the number of generalised linear models for which they were significant. psu = practical salinity unit, µm/kg = micromoles per kilogram, DIC = dissolved inorganic carbon, POC = particulate organic carbon, species richness = total number of species, species abundance = total number of individuals. Means represent monthly means for the study areas (AOI and the whole of the South Island).

Green shading and (*) represent types of explanatory variables. The remaining rows are response variables.

Line of evidence	Variable (units)	Number of significant contrasts	Total number of contrasts
Tourism activity*	Passenger vessels density, hrs/km^2 (GMT 2024)	7	18
Fishing *	Fishing vessels density, hrs/km^2 (GMT 2024)	3	18
Temperature*	Sea surface temperature, °C (NZODN 2024a)	3	3
Water quality	Mean enterococci count, MPN/100 ml (LAWA 2024)	14	15
Water quality	Salinity, psu (NZODN 2024a)	3	3
Water quality	Salinity, psu (NZODN 2024b)	1	3
Water quality	Mean carbonate/alkalinity, µm/kg (NZODN 2024b)	1	3
Water quality	Mean DIC, µm/kg (NZODN 2024b)	1	3
Water quality	Mean chlorophyll-*a*, mg/m^3 (MODIS 2024)	1	18
Water quality	Mean POC, mg/m^3 (MODIS 2024)	1	18
Litter	Litter, total count per survey/effort (LI 2024)	2	11
Biological	General species richness (iNaturalist 2024)	10	18
Biological	General species abundance (iNaturalist 2024)	7	18
Biological	General species richness (OBIS 2024)	1	4
Biological	General species abundance (OBIS 2024)	1	1
Biological	Seabird species richness (eBird 2023)	5	18
Biological	Seabird species abundance (eBird 2023)	4	15
Biological	Shorebird species abundance (eBird 2023)	5	15
Biological	Shorebird species richness (eBird 2023)	1	18
Biological	Pinniped species abundance (DOC 2023a, 2023b, 2023c; FNZ 2021, 2022)	1	1
Biological	Toothed whale and dolphin species richness. Sightings and incidents (DOC 2023b, 2023c)	1	5
Biological	Toothed whale and dolphin species abundance. Sightings and incidents (DOC 2023b, 2023c)	1	3

Explanatory variables

Of the potential explanatory variables that were significantly different between study periods (Table 3), only passenger vessel density (representing tourism activity) was prevalent across all AOI (Figure 3). Interestingly, fishing vessel density (hrs/km^2) during this period was also significantly different for Otago Harbour / Otakou (this trend was not identified at other AOI). Sea surface temperature was only significantly different between study periods for the Fisheries CTD dataset (NZODN 2024a), which was available for the South Island of Aotearoa New Zealand as a whole, but not for the individual AOI (Table 3).

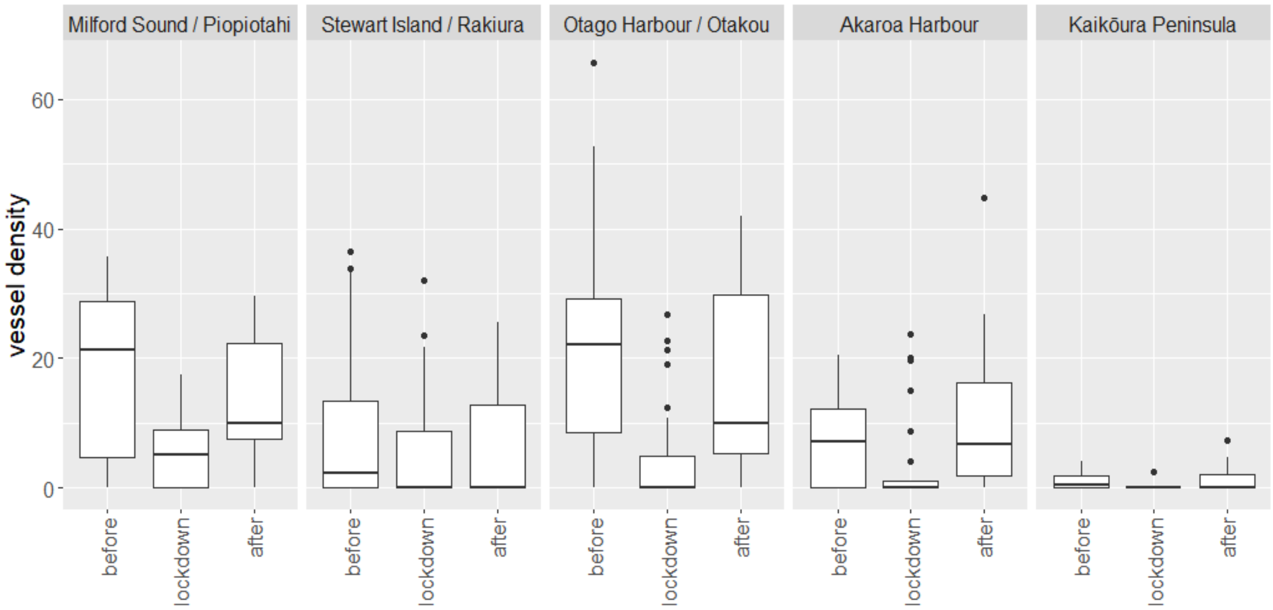

Figure 3. Passenger vessel density (hrs/km^2) data (GMT 2024) distribution for the different areas of interest analysed in the generalised linear models. The interquartile range of each box is the middle 50%. Dots represent outliers. Horizontal lines in bold represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

Response variables

The response variables that were identified in the various GLMs as significantly different between study periods (Table 3) are described further below. Results of all other GLM contrast combinations are provided in Appendix 1.

Water quality

Among the water quality variables tested, mean count of enterococci (MPN/100 ml) (LAWA 2024) appeared to be significantly different for all the AOI tested (Akaroa Harbour, Kaikōura Peninsula, Otago Harbour / Otakou, Stewart Island / Rakiura), between most of the study periods (Table 3). Salinity from two different sources (NZODN 2024a, 2024b), chlorophyll-*a* (MODIS 2024), mean dissolved inorganic carbon (NZODN 2024b) and mean particulate organic carbon (MODIS 2024) all appeared significant for one study period comparison and in one AOI alone (Table 3; see Table A.1.1 in Appendix 1 for the specific AOI and periods significantly different for each variable).

Litter

Litter per survey (normalised by effort;[8] LI 2024) appeared to be significantly different only within Akaroa Harbour (with a reduction of litter count between before / lockdown, and before / after lockdown; Figure 2; Figure 4). However, there was also some evidence of a reduction of litter (although not significant) at both Stewart Island / Rakiura and Kaikōura Peninsula (Figure 4).

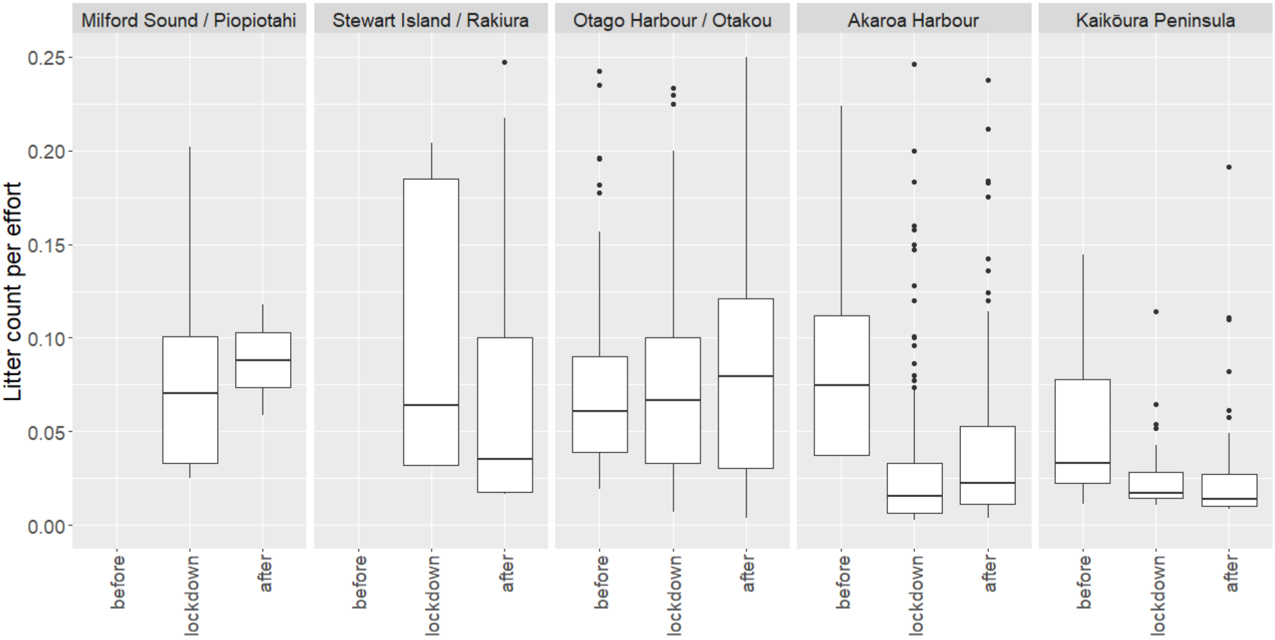

Figure 4. Litter count per unit of effort for the different areas of interest analysed in the generalised linear models. Note that the data is omitting counts of zeros, which skew the distribution. However, zeros are included in the statistical analyses. The interquartile range of each box is the middle 50%. Dots represent outliers. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

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[8] We normalised effort by survey width in metres, survey hours and number of citizen scientists participating in a given survey.

Biological

Biological variables showed significant differences in biodiversity when analysing data from eBird (both seabirds and shorebirds; eBird 2023), iNaturalist (2024) and OBIS (2024) across the study periods (Table 3). Species richness values from iNaturalist (Figure 5) showed the greatest increases in richness values across the different study periods in most of the individual AOI. This relationship was also noted for the whole of the South Island between the periods 'before' and 'lockdown', and between 'lockdown' and 'after' lockdown).

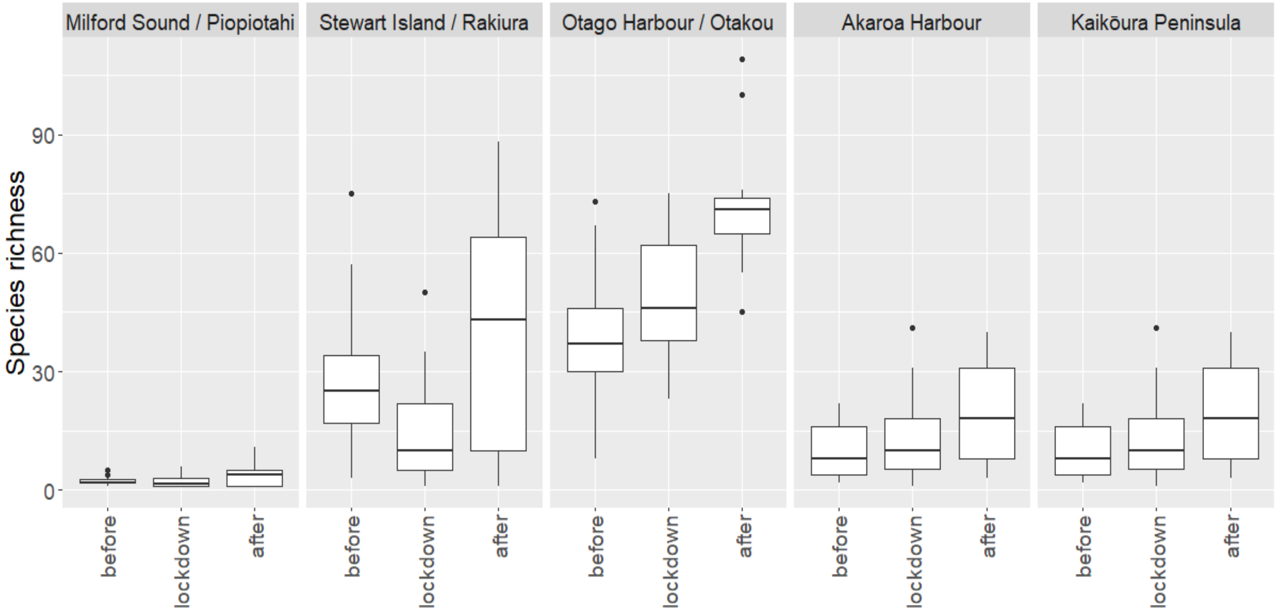

Figure 5. Species richness calculated from the iNaturalist (2024) dataset for the different areas of interest analysed in the generalised linear models. Dots represent outliers. The interquartile range of each box is the middle 50%. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

Relationship between sea surface temperature and vessel density with the ecological variables

Model results found that trends in several of the ecological variables examined showed significant relationships with one or both of the presumed explanatory variables (SST and vessel density). In many cases, when there was a significant relationship ($p < 0.05$), there was also a significant interaction between SST and vessel density (Figure 6; Table 4). The nature of the interactions (how temperature moderated, increased or reduced the effect of vessel density) was different for each ecological variable, and more research is needed to fully understand the complexity of these interactions. In general, temperature increased slightly through the time frame analysed, while tourist vessel density was high before and after the lockdown period, with very low density during the lockdown period.

The water quality variables had the highest proportion of significant relationships to vessel density, SST or both (two-way interaction) (Figure 6). Significant relationships were found with mean enterococci (MPN/100 ml) (LAWA 2024), chlorophyll-*a* (MODIS 2024) or mean particulate organic carbon (MODIS 2024) and either the two-way interaction between SST and vessel density (in six cases), SST alone (in five cases) or vessel density alone (in only one case: chlorophyll-*a* concentration at Milford Sound / Piopiotahi). These results (Table 4) coincide with the response variables that showed significant differences between study periods (before, during and after lockdown) in these AOI in the first part of the analysis (Table 3).

All of the Stewart Island / Rakiura models and half of the Otago Harbour / Otakou models found that litter per effort (LI 2024) was significantly related to vessel density (Figure 6). However, there were no significant relationships at other AOI with litter variables.

Only three of the five AOI demonstrated significant relationships with the biological variables (Figure 6). Several species richness and abundance models were significantly related to the two-way interaction between SST and vessel density for: the iNaturalist (2024) dataset, seabirds from eBird (2023) and seals from the DOC marine mammal sightings dataset (DOC 2023c) off Otago Harbour / Otakou and Kaikōura Peninsula. While for Stewart Island / Rakiura, a significant relationship with biological variables was only found with SST (Figure 6; Table 4).

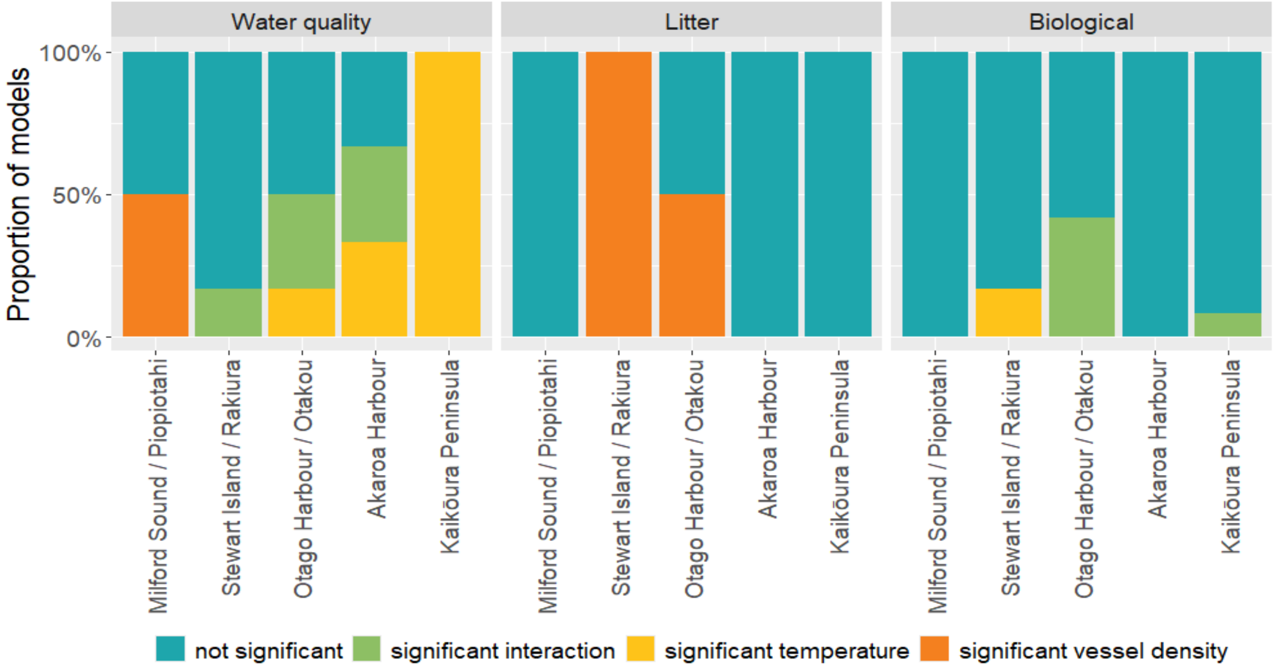

Figure 6. Proportion of generalised linear models (%) in which there were: **1)** no significant relationships effect (p > 0.05, teal colouring); **2)** a significant interaction effect between sea surface temperature (SST) and vessel density (p < 0.05, green colouring); **3)** a significant effect of SST (p < 0.05, yellow colouring); and / or **4)** a significant effect of vessel density (p < 0.05, orange colouring) was present for the different variables within each line of evidence and at the various areas of interest.

Table 4. Model variables that showed significant relationships ($p < 0.05$) with vessel density, temperature and / or their interaction at all areas of interest (AOI). Note that New Zealand = South Island only.

Line of evidence	Variable	AOI	Relationship
Water quality	Chlorophyll-*a* concentration (MODIS 2024)	Akaroa Harbour	Significant temperature
		Kaikōura Peninsula	Significant temperature
		Milford Sound / Piopiotahi	Significant vessel density
		New Zealand	Significant interaction
		Otago Harbour / Otakou	Significant interaction
	Mean count of enterococci (MPN/100 ml) (LAWA 2024)	Akaroa Harbour	Significant interaction
		Kaikōura Peninsula	Significant temperature
		Otago Harbour / Otakou	Significant interaction
		Stewart Island / Rakiura	Significant interaction
	Particulate organic carbon (MODIS 2024)	Kaikōura Peninsula	Significant temperature
		New Zealand	Significant interaction
		Otago Harbour / Otakou	Significant temperature
Litter	Litter count per effort / survey (LI 2024)	Stewart Island / Rakiura	Significant vessel density
		Stewart Island / Rakiura	Significant vessel density
		Otago Harbour / Otakou	Significant vessel density
Biological	Species abundance (iNaturalist 2024)	Otago Harbour / Otakou	Significant interaction
		Stewart Island / Rakiura	Significant temperature
	Species richness (iNaturalist 2024)	Otago Harbour / Otakou	Significant interaction
		Stewart Island / Rakiura	Significant temperature
	Seabird abundance (eBird 2023)	Otago Harbour / Otakou	Significant interaction
	Seals – abundance (DOC 2023c)	Otago Harbour / Otakou	Significant interaction
		Kaikōura Peninsula	Significant interaction

3.2 Site-specific data

Only water quality data were sufficient for site-specific analyses within Milford Sound, Akaroa Harbour and Kaikōura Peninsula, hence Otago was excluded from these analyses.

Milford Sound / Piopiotahi

From the Environment Southland Wastewater Treatment Plant (WWTP) receiving water monitoring dataset (ES 2024a), we analysed the data of five response variables (pH, conductivity, dissolved oxygen and counts of *E. coli* and enterococci (MPN/100 ml) and temperature data (potential explanatory and / or response variable) across the study periods. Figure 7 and Figure 8 show the distribution of the data for each variable at the control, north and south sites; noting that the north and south sites are near the Milford Sound discharge site, and the control site is more distant. Our results suggested the following:

- Dissolved oxygen at the south site was significantly lower before the lockdown period in comparison to during the lockdown period (Figure 7).
- pH was significantly higher during the lockdown period in comparison to after the lockdown period, but only for the sewage discharge itself (Figure 8).
- Enterococci (MPN/100 ml) and *E. coli* counts were significantly different between most periods and most sites (Table 5; Figure 7; Figure 8), with higher concentrations evident during lockdown.
- Temperature (from the WWTP) was significantly different (decreased) between the 'before' and 'lockdown' periods for the control, south and north sites, and was different (increased) between the 'lockdown' and 'after' periods only for the control site.
- Conductivity was not significantly different between periods for any site.

Similar to the common data results (Section 3.1), the GLMs between the water quality response variables and the explanatory variables (SST and vessel density) showed that the two-way interaction[9] between temperature and passenger vessel density (see Figure 3 for the changes in vessel density through the study time frame) was significant for some response variables – in this case, *E. coli* and enterococci (MPN/100 ml) counts (p-values < 0.001, with the response variable decreasing with vessel density at lower SST, but increasing with SST across vessel density values; Table 5). However, the other three variables (pH, dissolved oxygen and conductivity) did not appear significantly related to either temperature or vessel density. These models were performed by aggregating the data for all sites.

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[9] See Section 3.1 for a trend description of the interaction relationship between temperature and vessel density.

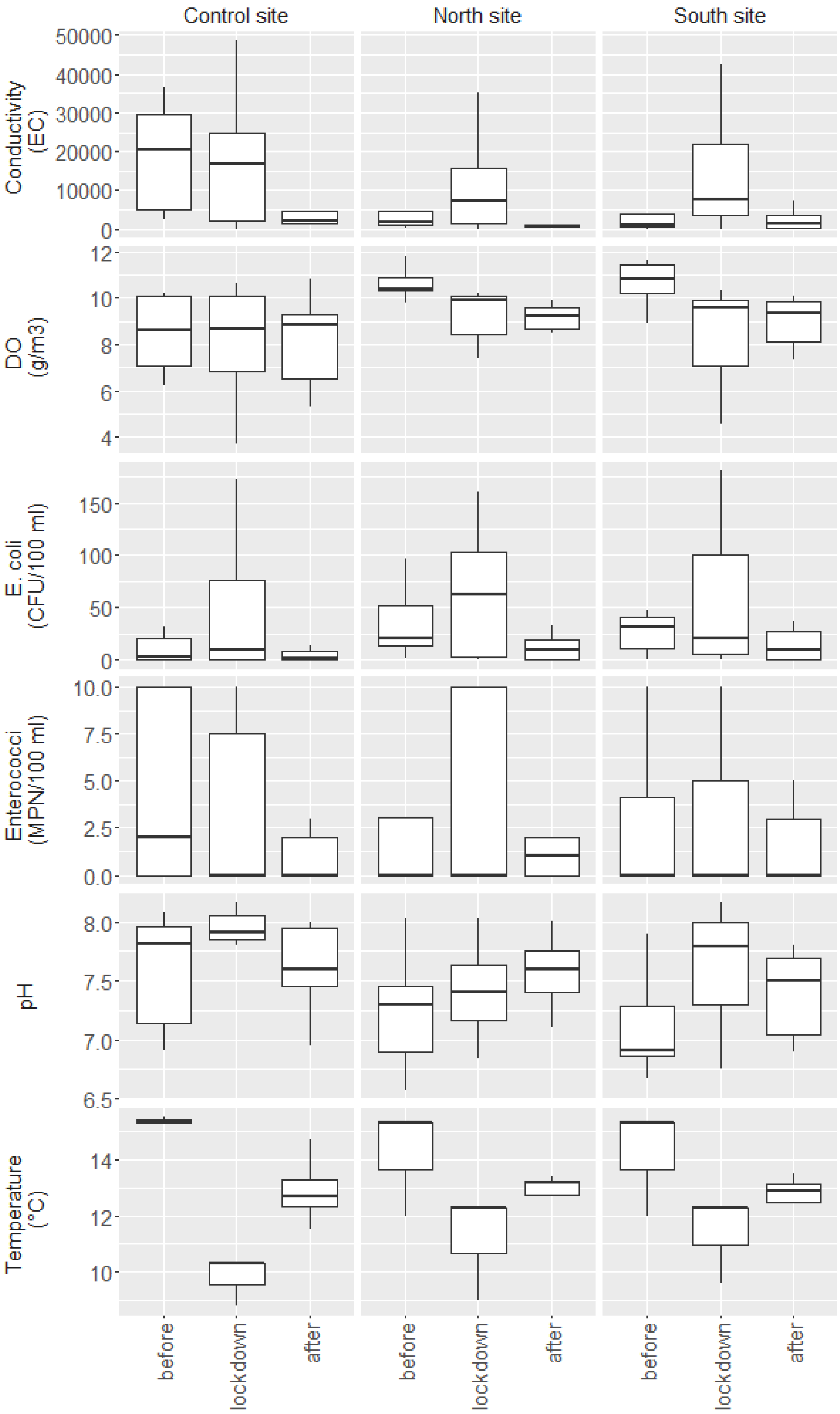

Figure 7. Environment Southland Wastewater Treatment Plant receiving water monitoring dataset comparison between study periods for the control, north and south sites in Milford Sound / Piopiotahi, as analysed in generalised linear models. The interquartile range of each box is the middle 50%. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

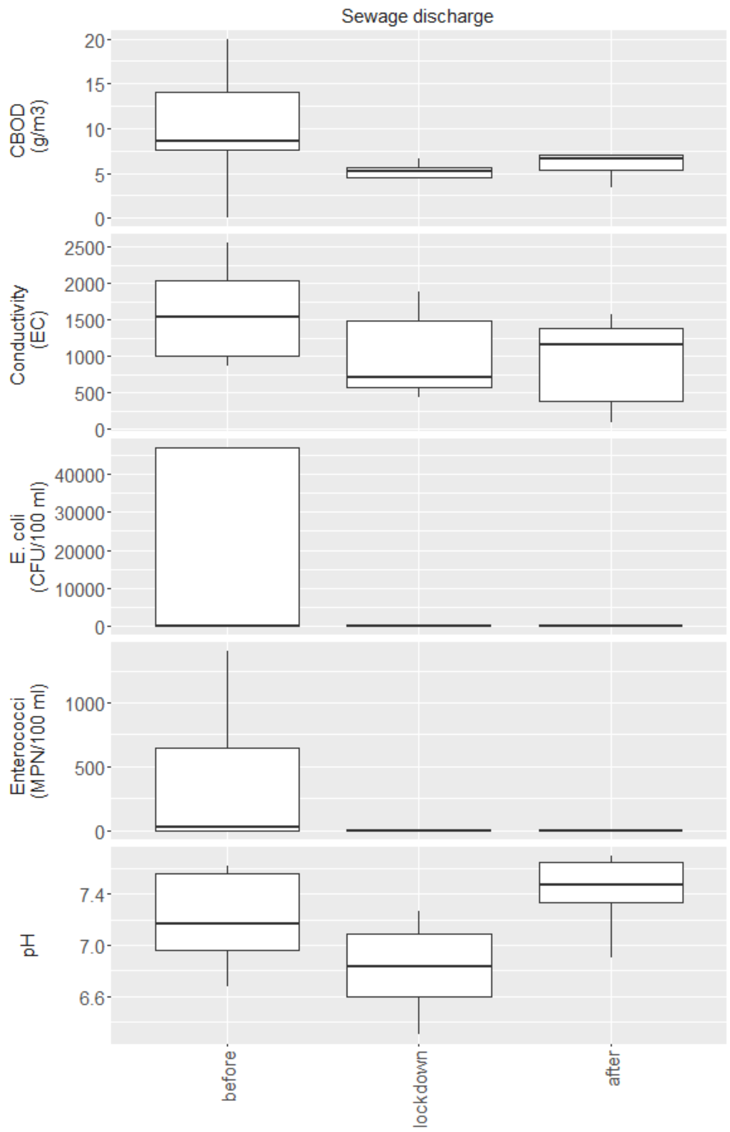

Figure 8. Environment Southland Wastewater Treatment Plant receiving water monitoring dataset comparison between study periods for the sewage discharge site in Milford Sound / Piopiotahi, as analysed in the generalised linear models. The interquartile range of each box is the middle 50%. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

Table 5. Variables that were significantly different ($p < 0.05$) between study periods for each site in Milford Sound / Piopiotahi.

Variable	Site	Period	p-value
E. coli **(CFU/100 ml)**	**Control site**	before – lockdown	< 0.0001
		before – after	< 0.0001
	North site	before – lockdown	< 0.0001
		before – after	< 0.0001
		lockdown – after	< 0.0001
	Sewage discharge	before – lockdown	< 0.0001
		before – after	< 0.0001
	South site	before – lockdown	< 0.0001
		before – after	< 0.0001
	Control site	before – lockdown	< 0.0001
		before – after	< 0.0001
	North site	before – lockdown	< 0.0001
Enterococci (MPN/100 ml)	**Control site**	before – after	< 0.0001
		lockdown – after	< 0.0001
	North site	before – lockdown	0.037
		before – after	< 0.0001
		lockdown – after	< 0.0001
	Sewage discharge	before – lockdown	< 0.0001
		before – after	< 0.0001
	South site	before – lockdown	0.011
		before – after	< 0.0001
		lockdown – after	0.005

From the Meridian Energy biological monitoring datasets (Meridian 2024a) on intertidal and subtidal communities (collected before and after lockdown, but not during the lockdown period), we found that there were no significant differences between the periods in taxa richness, but there was a significant difference (increasing) between the periods for taxa abundance (p-value = 0.02; Figure 9). The apparent increase in taxa abundance between periods could be due to the presence of multiple outliers (not removed for this analysis). From the Meridian physical monitoring dataset (Meridian 2024b), we found that there were significant differences in near surface water temperature between the study periods (with increasing temperature during and after lockdown periods; p-values < 0.05), which likely reflected wider catchment influences.

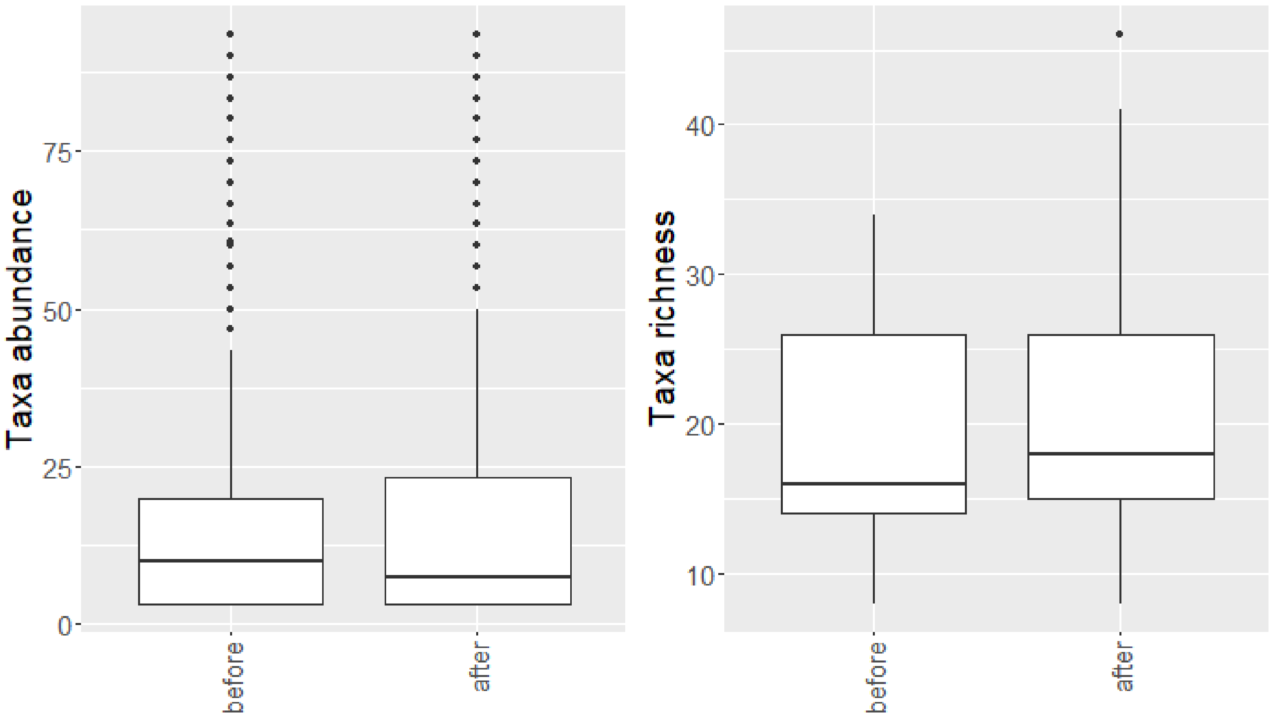

Figure 9. Differences in taxa abundance and taxa richness for the Meridian underwater biodiversity surveys dataset.

Akaroa

From the Akaroa water quality monitoring data (French Bay and Wainui sites in Akaroa Harbour; CRC 2024a), we analysed the following response variables: pH, total nitrogen (g/m^3), dissolved oxygen, total suspended solids (mg/L), dissolved reactive phosphorus (mg/L), chlorophyll-*a*, and counts of faecal coliforms (CFU/100 ml) and enterococci (MPN/100 ml), along with the site-specific temperature data. From the council's receiving environment sampling data (CRC 2024a), we also analysed faecal coliforms (CFU/100 ml) and counts of enterococci (MPN/100 ml) for three sites (shoreline nearest outfall, 400m S on shoreline, 400m N on shoreline) and enterococci (MPN/100 ml) and total nitrogen (g/m^3) for the discharge site. Enterococci (MPN/100 ml) and faecal coliforms (CFU/100 ml) counts were significantly different between most study periods and all sites (see Table 6; Figure 10; Figure 11). Temperature did not vary significantly between any of the study periods for the sites with data available. Total nitrogen (g/m^3), total suspended solids (mg/L), ammonia (g/m^3) and dissolved reactive phosphorus (mg/L) were significantly different between study periods for the discharge site (Table 6; Figure 11).

The GLMs between the water quality response variables and the explanatory variables (SST and vessel density) were performed by aggregating the data for all sites. These models showed that the interaction[10] between temperature and vessel density had a significant relationship with faecal coliforms (CFU/100 ml) and enterococci (MPN/100 ml) counts (with p-value < 0.001), dissolved oxygen (p-value = 0.002), and total suspended solids (mg/L) (p-value = 0.029). The nature of this interaction (how SST and vessel density affect the results simultaneously) was different for the different variables and needs further investigation. Total nitrogen (g/m^3) had a significant positive relationship with SST only (p-value < 0.001). The other variables (pH and chlorophyll-*a*) did not appear to be significantly related to either temperature or vessel density.

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[10] See Section 3.1 for a trend description of the interaction relationship between temperature and vessel density.

Table 6. Model variables that were significantly different ($p < 0.05$) between study periods for each monitoring site within Akaroa Harbour.

Site	Period	Variable	p-value
400m N on shoreline	before – after	Enterococci (MPN/100 ml)	0.033
400m S on shoreline	before – lockdown	Enterococci (MPN/100 ml)	0.000
400m S on shoreline	before – after	Enterococci (MPN/100 ml)	0.000
400m S on shoreline	lockdown – after	Enterococci (MPN/100 ml)	< 0.0001
Akaroa Harbour in French Bay	lockdown – after	Enterococci (MPN/100 ml)	0.002
Akaroa Harbour off Wainui	lockdown – after	Enterococci (MPN/100 ml)	0.013
Discharge	before – lockdown	Enterococci (MPN/100 ml)	0.000
Discharge	before – after	Enterococci (MPN/100 ml)	0.000
Discharge	lockdown – after	Enterococci (MPN/100 ml)	0.000
Shoreline nearest outfall	before – lockdown	Enterococci (MPN/100 ml)	0.000
Shoreline nearest outfall	before – after	Enterococci (MPN/100 ml)	0.000
Shoreline nearest outfall	lockdown – after	Enterococci (MPN/100 ml)	0.000
400m N on shoreline	before – lockdown	Faecal coliforms (CFU/100 ml)	< 0.0001
400m N on shoreline	lockdown – after	Faecal coliforms (CFU/100 ml)	< 0.0001
400m S on shoreline	before – lockdown	Faecal coliforms (CFU/100 ml)	< 0.0001
400m S on shoreline	before – after	Faecal coliforms (CFU/100 ml)	< 0.0001
400m S on shoreline	lockdown – after	Faecal coliforms (CFU/100 ml)	< 0.0001
Akaroa Harbour in French Bay	before – lockdown	Faecal coliforms (CFU/100 ml)	< 0.0001
Akaroa Harbour in French Bay	before – after	Faecal coliforms (CFU/100 ml)	< 0.0001
Akaroa Harbour in French Bay	lockdown – after	Faecal coliforms (CFU/100 ml)	0.008
Akaroa Harbour off Wainui	before – lockdown	Faecal coliforms (CFU/100 ml)	< 0.0001
Akaroa Harbour off Wainui	before – after	Faecal coliforms (CFU/100 ml)	< 0.0001
Shoreline nearest outfall	before – lockdown	Faecal coliforms (CFU/100 ml)	< 0.0001
Shoreline nearest outfall	before – after	Faecal coliforms (CFU/100 ml)	< 0.0001
Shoreline nearest outfall	lockdown – after	Faecal coliforms (CFU/100 ml)	< 0.0001
Discharge	before – after	Total nitrogen (g/m^3)	< 0.0001
Discharge	lockdown – after	Total nitrogen (g/m^3)	0.002
Discharge	before – after	Total suspended solids (mg/L)	0.009
Discharge	before – lockdown	Dissolved reactive phosphorus (mg/L)	0.004
Discharge	before – after	Dissolved reactive phosphorus (mg/L)	< 0.0001
Discharge	before – lockdown	Ammonia (g/m^3)	0.010
Discharge	before – after	Ammonia (g/m^3)	0.007

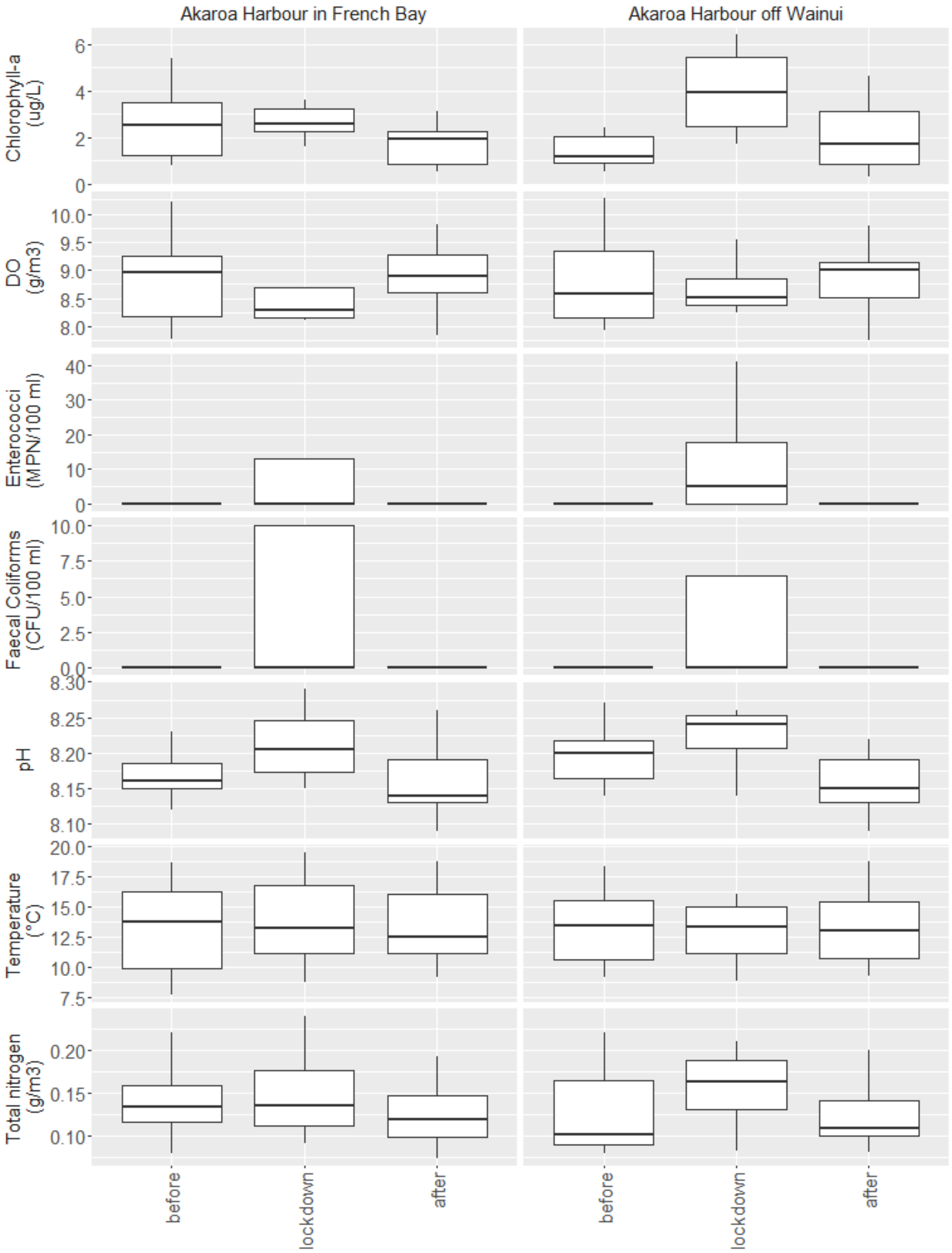

Figure 10. Akaroa water quality dataset (CRC 2024a) comparison between study periods, as analysed by the generalised linear models. The interquartile range of each box is the middle 50%. Dots represent outliers. Lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups. Note that faecal coliforms (CFU/100 ml) and enteroccoci showed significant differences, likely due to having zero values before and after lockdown, and an increase during lockdown.

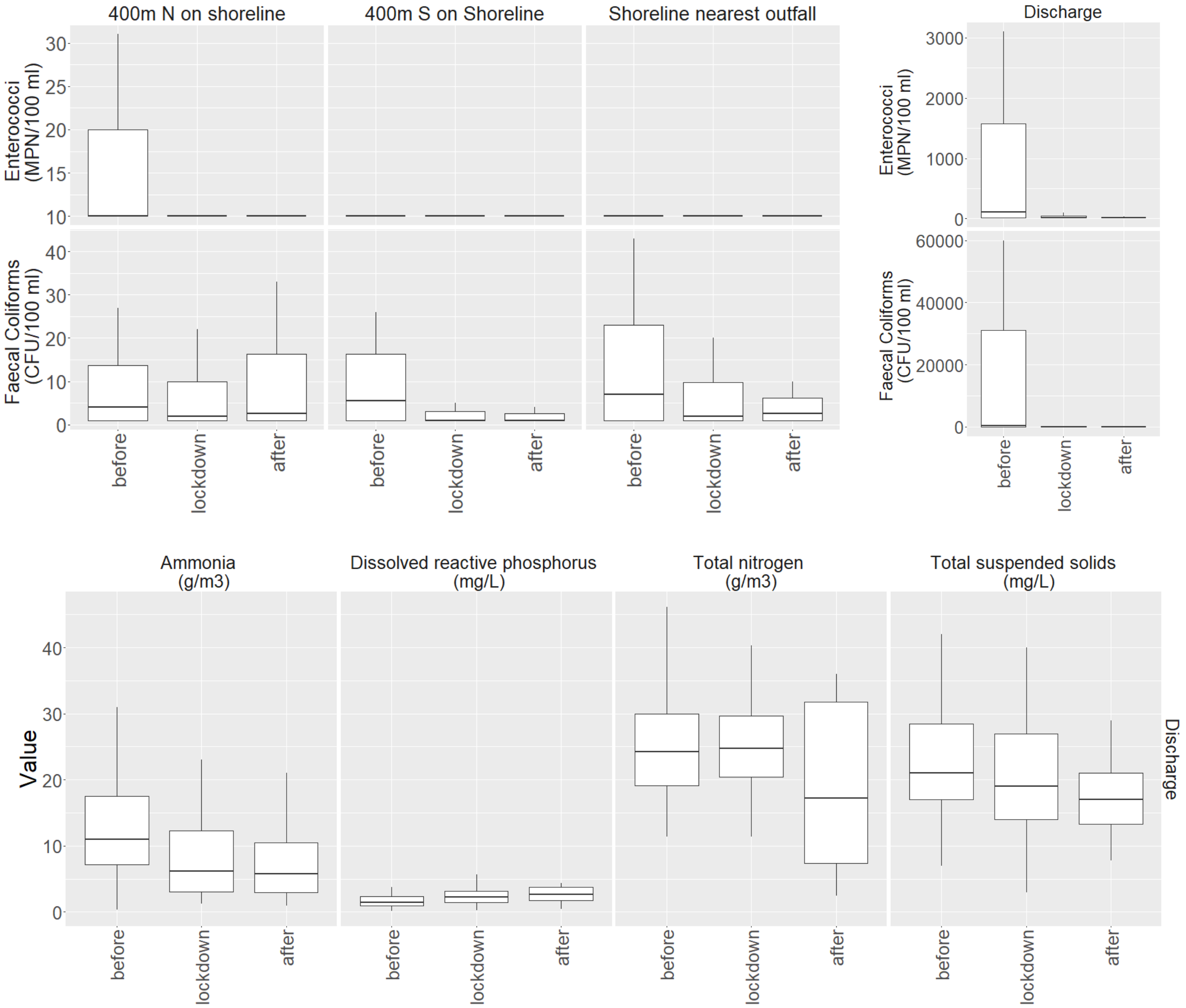

Figure 11. Akaroa receiving water and discharge quality dataset (CCC 2024) comparison between study periods, as analysed by the generalised linear models. The interquartile range of each box is the middle 50%. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.

Kaikōura Peninsula

From the CRC water quality monitoring dataset at two monitoring sites around Kaikōura Peninsula (Ingles Bay at Gooches Beach, South Bay in Marina; CRC 2024b), we analysed eight response variables: pH, total nitrogen (g/m^3) , dissolved oxygen, total suspended solids (mg/L), chlorophyll-*a*, and counts of faecal coliforms (CFU/100 ml) and enterococci (MPN/100 ml). Furthermore, we analysed counts of enterococci (MPN/100 ml) for three additional sites: Armers Beach bathing area, South Bay bathing area and Peketa Beach at Peketa. We also analysed the temperature data for all five sites. Enterococci (MPN/100 ml) and faecal coliform counts were significantly different between most study periods for all monitoring sites (see Table 7; Figure 12). Temperature was only significantly different between the 'before' and 'after' lockdown periods at Armers Beach bathing area, and pH was only significantly different between the 'before' and 'lockdown' periods at South Bay in Marina.

The GLMs between the water quality response variables and the explanatory variables (SST and vessel density) were performed by aggregating the data for all sites. These models showed that the temperature and vessel density interaction[11] was significant for faecal coliforms (CFU/100 ml) and enterococci (MPN/100 ml) counts (with p-values < 0.001). This interaction showed a decrease of these response variables with temperature (with increasing slope of the relationship as vessel density increases), and an increase of the response variable with vessel densities only at lower temperatures. Dissolved oxygen and pH showed a significant negative relationship with temperature. The other variables (total nitrogen, total suspended solids and chlorophyll-*a*) did not appear significantly related to either temperature or vessel density.

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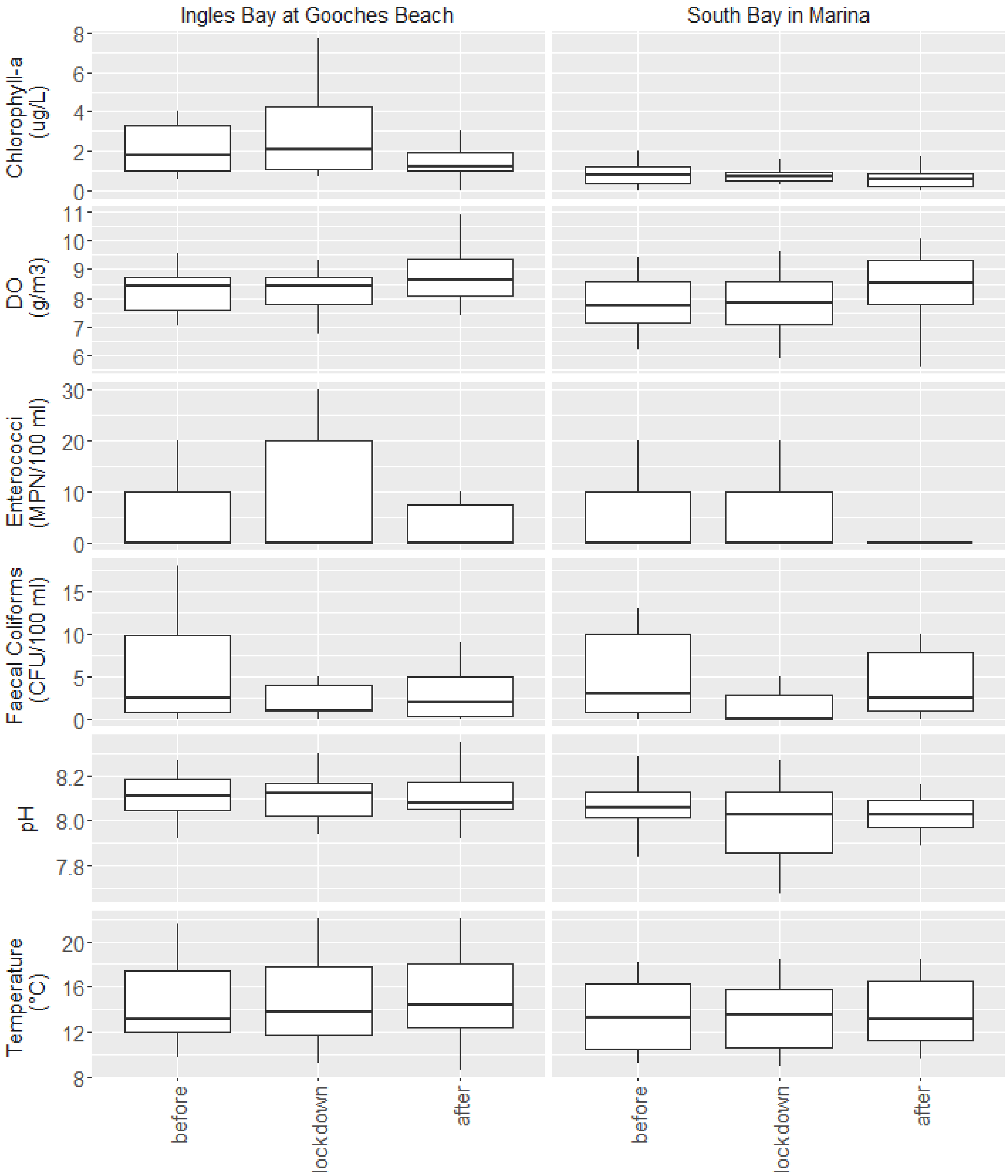
[11] See Section 3.1 for a trend description of the interaction relationship between temperature and vessel density.

Table 7. Model variables that were significantly different ($p < 0.05$) between study periods for each monitoring site around Kaikōura Peninsula.

Variable	Site	Period	p-value
Enterococci (MPN/100 ml)	Armers Beach bathing area	before – after	< 0.0001
		lockdown – after	< 0.0001
	Ingles Bay at Gooches Beach	before – lockdown	< 0.0001
		before – after	< 0.0001
	Peketa Beach at Peketa	before – after	< 0.0001
		lockdown – after	< 0.0001
	South Bay bathing area	before – lockdown	< 0.0001
		before – after	< 0.0001
	South Bay in Marina	before – after	< 0.0001
		lockdown – after	< 0.0001
Faecal coliforms (CFU/100 ml)	Ingles Bay at Gooches Beach	before – lockdown	< 0.0001
		before – after	< 0.0001
		lockdown – after	< 0.0001
	South Bay in Marina	before – lockdown	< 0.0001
		lockdown – after	< 0.0001
Temperature (°C)	Armers Beach bathing area	before – after	0.016
pH	South Bay in Marina	before – lockdown	0.028

Figure 12. Kaikōura Peninsula water quality dataset (CRC 2024b) comparison between study periods for the two sites for which data for all variables were available, as analysed in the generalised linear models. The interquartile range of each box is the middle 50%. Horizontal lines represent median values. Note that if the median line of a box plot lies outside of the box of a comparison box plot, then there is likely to be a difference between the two groups.



4. Discussion

For this project, we analysed ecological response variables under multiple lines of evidence to understand the possible ecological impacts of marine tourism on five areas of interest: Milford Sound / Piopiotahi, Stewart Island / Rakiura, Otago Harbour / Otakou, Akaroa Harbour and Kaikōura Peninsula. Our main hypothesis was that the reduction in marine tourism activity as a result of the COVID-19 travel restrictions (the Anthropause) led to measurable differences to our indicator ecological proxies. This hypothesis was supported by a limited number of models in each line of evidence for both the common and site-specific datasets. Below, we discuss the results in the context of the key knowledge questions as defined in Section 1.

Were there detectable effects from marine tourism at the AOI, pre- and post-Anthropause?

This study shows that there is some evidence for an effect of the Anthropause within each of the three different lines of evidence investigated: water quality, litter and biological. Overall, we found that there were significant differences for multiple ecological response variables between the three study periods that we defined for studying the Anthropause (Figure 13).

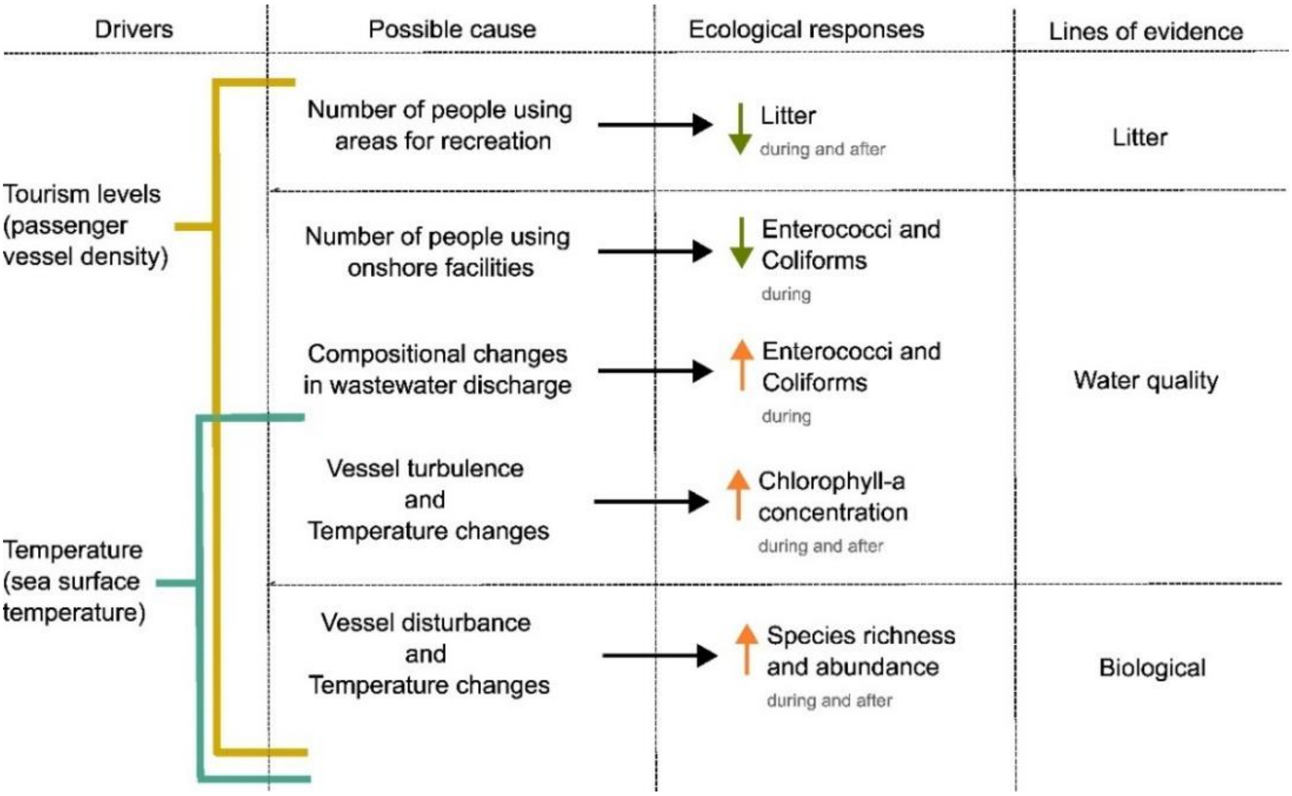


Figure 13. Summary of results for each line of evidence. Enterococci (MPN/100 ml) and coliforms = faecal indicator bacteria (FIB).

However, there was a greater number of ecological variables and models for which no differences were found. Where effects were detected, this study suggests:

1. There was an improved ecological benchmark[12] observed during the Anthropause lockdown period that was not being achieved during the pre- and / or post-Anthropause passenger vessel operating conditions that were investigated.
2. Some ecological improvements (ecological responses) persisted in the 2 years after the Anthropause lockdown period, even following the recommencement of passenger vessel activities.

Did halting marine tourism result in measurable improvements to marine ecology?

There were measurable changes to some of the ecological response variables investigated in this project following the Anthropause. While many of the ecological responses showed an improvement (litter decreased, species abundance and richness increased, and ocean-borne faecal indicator bacteria [FIB] decreased; Figure 13), this was not the case for FIB in wastewater discharges and ocean chlorophyll-*a* concentrations[13] during the lockdown (both increasing).

Although land-based wastewater FIB concentrations increased during the Anthropause, ocean-borne FIB concentrations significantly decreased (Figure 13). This decrease could suggest other compositional changes in the treatment plant's discharge quality (perhaps from the removal of passenger vessel waste contributions) and improved receiving water quality, which indirectly reduced FIB concentrations. It may also suggest that under regular operation, passenger vessels could be directly contributing to a significant proportion of FIB in marine waters (e.g. from vessel run-off or accidental discharges). While the effect could also relate to other contaminant contributors that were not identified in this investigation, this insight into a possible adverse effect of marine tourism should be investigated further, as it suggests there is potential for human and marine wildlife health-related risks, as well as the release of other potential contaminants.

Increasing chlorophyll-*a*[14] concentrations, and species richness and abundance (Figure 13) were significantly related to the interaction of water temperature and passenger vessel density. This significant two-way GLM interaction suggests that the two drivers of the ecological responses are either related (one influencing the other) or are occurring irrespective of each other (either as key drivers or coincidentally); more specifically:

- The interaction could represent the effect of direct to indirect drivers, whereby increased vessel density (as the direct driver) influences SST (indirect driver), which in turn influences chlorophyll-*a* concentrations (an ecological response). In the ocean, SST and chlorophyll-*a* can be inversely or positively correlated with trends varying globally depending on coastal nutrient concentrations,

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[12] A benchmark in this context is an ecological condition that is used to assess ecological change.

[13] Broadly speaking, high chlorophyll-*a* concentrations often indicate poor water quality, and low levels often suggest good conditions. However, chlorophyll-*a* naturally fluctuates over time, thus it is the long-term persistence of elevated levels that is typically of concern.

[14] Chlorophyll-*a* concentration is often used to reflect the abundance of phytoplankton in the sea (which forms the foundation of the marine food chain).

temperature and the carbon cycle (Ji et al. 2018). Given the results reported here, it may be that the vessel turbulence is directly mixing water and creating spatially extensive[15] thermal wakes, which influence chlorophyll-*a* concentrations (due to changes in nutrient supply). This phenomenon has been noted in other investigations, whereby ship-induced water turbulence (physical disturbance) impacts local hydrography, nutrient dynamics and plankton mortality (Guadayol et al. 2009; Nylund et al. 2021; Nylund et al. 2023). However, it is possible that other drivers not investigated in this study may also be at play. For example, Seelanki and Pant (2021) described the reduction of aerosol particles from industry (anthropogenic emissions and dust) and decreased SST as the drivers of decreased oceanic chlorophyll-*a* during the Anthropause (due to a lack of micronutrients in the upper ocean), illustrating the complex interactions of ocean productivity drivers.

- Species richness and abundance (biodiversity) are frequently used as numerical characteristics of an ecosystem. It is possible that the reduction in passenger vessels themselves (disturbance) and the variation in temperature could both be driving changes to species richness and abundance. This phenomenon has been noted in other investigations, whereby the reductions in water-based human activities resulted in increased coral reef fish biomass (Johnson et al. 2023).
- In both ecological response cases (biodiversity and chlorophyll-*a*), the interaction may also represent two independently acting drivers, occurring simultaneously but irrespective of each other, or alternatively, one 'driver' could be purely coincidental. For example, climate change may be the sole key ecological driver, with vessel density coincidentally increasing at the same time as temperature because of the preference for passenger vessel trips / movements on warmer, fine days.

Regardless of the mechanism of the interaction, it is clear that climate (represented by SST; Figure 13) plays a key role in driving ecological change in the marine environment. Further investigation into whether the influence of passenger vessel traffic exacerbates this effect should be investigated to better manage future climate change effects (e.g. water quality changes, die-off events, harmful algal blooms, etc.). As well as investigating the interacting drivers identified above in more detail, the investigation should incorporate any newly available ecological data (listed at the end of this section) and additional data on passenger vessel types (if obtainable). This more focused assessment could also address the feasibility of possible management tools, such as halting or having seasonal restrictions on specific passenger vessels (i.e. types / sizes of passenger vessels) when they may intensify any climate-related effects.

What are appropriate indicator variables for determining effects from marine tourism ventures of concern, and what level of tourism intensity is ecologically sustainable?

The evidence for an impact of the Anthropause (e.g. lack of tourism effects) on ecological variables varied between AOI. Such results highlight the importance and need for accurate local data and site-specific analyses to help determine specific management responses for each area. For example, biological response variables were more variable between all study periods at Otago Harbour / Otakou in comparison to most other sites. Interestingly, Otago Harbour / Otakou also showed the most

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[15] Nyland et al. (2021) found vessel thermal wakes as long as 60 km and as deep as 30.5 m, with effects lasting for approximately 10 minutes.

biological response variables related to the interaction between passenger vessel density and SST. Another example was litter, which was only significantly different between the study periods at Akaroa Harbour, but then significantly related to passenger vessel density at Otago Harbour / Otakou and Stewart Island / Rakiura. More work would be needed to assess if these results are related to the spatial distribution of the response variables within the AOI; for example, the biological response variables could have been recorded at different distances from the passenger vessel activity hotspots, and this could influence the results shown in this report.

Broadly speaking, the FIB variables (enterococci [MPN/100 ml], faecal coliforms [CFU/100 ml], etc.) modelled in this investigation appeared to be sensitive indicators for detecting marine tourism effects at all AOIs (i.e. decreasing FIB concentrations in the receiving water when passenger vessel density decreased). These microbiological indicators have the added benefit of being collected for many consent and council monitoring programmes, making them a useful existing tool to understand the human health-related effects of water-based marine tourism activities.

For this investigation, we focused on the lack of international marine tourism, using passenger vessel density as a proxy for this variable. However, the Anthropause period impacted many other activities that could influence water quality, littering and biological response variables. For example, aircraft flights are a source of tourism impact that were not included in this study. Data on this activity could be obtained from aircraft flight logs, but for the time frame of this study, it was not feasible to obtain these data sources. In addition, coastal land-based tourism, domestic tourism and recreational fisheries could affect the response variables studied, and collecting this type of information could be valuable in the future. Dupuis et al. (2023) found that a reduction of shore-based tourism activities (800,000+ visitors per year, reducing to zero during the Anthropause) had no effect on an Australian penguin colony, while an increase in marine traffic had a negative effect on penguin foraging efficiency. Such results suggest that using vessel density as a proxy for all types of marine tourism is overly simplistic and that shore-based activities should be assessed individually.

Overall, there were insufficient data to determine what level of tourism is ecologically sustainable at each AOI. To help establish these levels, the next step is to develop site-specific management response plans for each AOI; these plans should relate to the activities of concern in each location. Site-specific management response plans are discussed further below.

What tourism control / adaptation / mitigation measures should be implemented to reduce risk associated with marine tourism ventures of concern?

Based on this assessment, a common management measure that could identify and reduce risk associated with marine tourism is the continued monitoring of the potential ecological responses identified in this report (biodiversity, water quality and litter; Figure 13).

It is also important that councils implement changes to ensure they are improving data quality to advance the detection of ecological change associated with marine tourism, and to better understand potential management tools (e.g. restrictions). This could be achieved by:

- Retaining valuable consent monitoring data. Councils should ensure they have permission to use any data collected by consent or research holders as a condition of their consent; these data should also be supplied in a useable format. Additionally, with the exception of CRC, smaller councils have not established dedicated council data management and retrieval systems for council-owned monitoring data sources / records (e.g. wastewater treatment plants).
- Collecting long-term, time-series state of the environment data. Councils should make further efforts to collect ecological data: to better assess the state of the local environment; to understand the changing climate; to make informed predictions; to understand cumulative effects of activities over time; to detect effects from unpredicted changes (such as lockdowns); and to better understand ecological recovery following a disturbance.
- Investigating 'tourism fallowing' (closures, reductions / restrictions) as a marine tourism management tool. It is possible that councils could use 'fallowing' to reduce the risk associated with marine tourism ventures of concern, whereby the activity is halted for a period of time or particular spatial area, and affected waters have time to recover prior to the activity recommencing. Other international investigations over the Anthropause period found that reductions in human water-based activities had positive returns for marine ecosystems, and the studies recommended reductions of such activities as a consideration in future management strategies (Johnson et al. 2023). Marine farming (site fallowing; Fletcher et al. 2022) and commercial / recreational fisheries (reserves, restrictions and closures) in Aotearoa New Zealand already use this management method, and it is worth investigating further as a course of action for marine tourism effects management.

Applying the lessons learnt from this investigation to improve future investigations.

Many of the datasets used in this investigation could be studied in more detail, and further improvements could be made to the investigative model, for example:

- Bycatch by fishing vessels could be analysed by species or groups of taxa, rather than examining the total amount of bycatch. Time-series analysis could also be used to investigate the relationship between tourism, temperature changes and the different response variables.
- Multiple models could be developed to understand how a given relationship can result in spurious significant results, as some models may show a significant relationship or difference by chance. It is important to note that each model in this study represents a different specific hypothesis, and we consider this study to be exploratory with the aim of identifying potential variables that could be affected by a decrease in tourism; therefore, we did not correct the p-values of each model by the overall number of models performed (note that in the methods section a correction was applied within each model).
- Community composition and spatial distribution of species were not analysed in this study. However, the Anthropause may have affected these two aspects of biodiversity as much as or more than species richness and abundance.
- It was not possible to determine causality with the datasets analysed for this study. However, we found evidence of an impact of the Anthropause and marine tourism on multiple variables. More concurrent data would be needed to determine with confidence the effect of stopping or reducing tourism marine activities. Further investigation into the longer-term trends of these data

would help further the understanding of any potentially natural episodic features of these changes over time (Wetz et al. 2022).

- This study does not consider the potential for delayed ecological responses (lag time). Stressed environments may not respond immediately, but there may be lag period, where the impacts are detectable outside of the time frame investigated. Any future study should consider investigating a wider time frame of data.
- This study did not compare the relative ecological stress between each of the AOI. For example, the relative ecological stress for a commercial / industrial port (e.g. Otago) will likely be different in comparison to the other ports in AOI. The compounding effect of ecological impacts could mean that a response may not be detected when a stressor is removed. This potential should be considered in any future investigations and may explain why biological response variables were more variable between all study periods at Otago Harbour / Otakou in comparison to most other sites.
- Given the potential for compounding and interacting ecological effects, the response data collection point and its potential effect footprint may not spatially overlap with the explanatory variable data points. For this reason, any future mapping of the spatial overlap of the explanatory data points (e.g. vessel traffic) to the ecological response data points should include consideration of the potential response data effect footprints.

The results of this investigation were dependent on the accuracy of each dataset. However, the integrated multiple lines of evidence (MLE) approach used in this assessment addressed some of the potential effects of type 1 and 2 errors by:

- Ensuring ecologically relevant lines of evidence were used
- Identifying ecological responses
- Identifying response relationships with the stressor
- Identifying consistent spatial and temporal association of stressor and ecological responses.

Interestingly, although the data were not specifically collected for this investigation and were from multiple sources, significant relationships were still detected. It is also possible that stronger relationships may be identified if site- and project-specific long-term data are collected (e.g. water quality, litter and biological variables). Furthermore, additional existing data sources could be incorporated into this investigation. However, accessing some data sources within the project's time frame and / or from some online sources was challenging. If they become available, the following data resources should be incorporated into the model:

- Hydrophone data, wider Fiordland area (Evans 2022)
- Penguin tracking data, Milford, Fiordland (TTP 2024)
- The Marine Metre^2 project, Aotearoa New Zealand wide (MM^2 2024)
- The Healthy Harbour Watchers, Otago (HHW 2024)
- Munida Microbial Observatory Time-Series, Otago (MOTS 2024)
- Hector's dolphin sighting and monitoring data in Akaroa Harbour (Carome 2021)

- Sanford’s monthly consent-based water quality sampling data from 1999–2023 (ES 2024b) was supplied through official information request and was approved for use in this investigation. However, the data was supplied in report format (requiring extensive transposing).

4.1 Where to from here?

The next step in this investigation is to ensure the marine tourism intensity at each AOI is ecologically sustainable. To achieve this, each location needs to determine a reasonable ecological baseline or benchmark (to aim for) and develop a site-specific marine tourism management response plan (MRP). Each MRP should relate to the marine tourism activities that are unique to that location (AOI). To do this, the MRPs need to include a focused, fine-scale assessment on the direct and interacting drivers identified in this assessment for the specific AOI (as per Section 3.3). This work could be carried out using existing site-specific data, any newly available ecological data, additional passenger vessel type data, and / or any other types of water- or shore-based tourism-related datasets (if obtainable).

Each MRP should include recommended approaches for monitoring the potential ecological responses (potential effect indicators) identified (but not limited to those) in this report (biodiversity, water quality and litter; Figure 13). Future work could include a focus on the significant negative relationship of passenger vessel density (decreasing) and waterborne FIB concentrations (decreasing). Reduced passenger vessel density could also be used as an approach to improve bathing and contact recreation conditions (human health), as well as a potential proxy for other water quality measures.

The MRPs should also identify possible management tools (such as seasonal passenger vessel restrictions, areas protected from passenger vessels, etc.) that could be used to work towards the ‘reasonable ecological baseline’ for marine tourism at each AOI. Including specific recommendations for each council will help ensure the collection of robust long-term ecological data to better inform marine tourism management in the future; for example, the recommendation should address:

- Data use rights as a consent condition for all consent-based monitoring
- Dedicated council data management and retrieval systems
- Cost-effective methods of collecting long-term time-series ecological data (e.g. eDNA sampling, citizen science data collection, etc.).

5. Acknowledgements

We would like to thank Kathryn McLachlan and Ash Rabel from Environment Southland, Kate Schimanski from Canterbury Regional Council and Sam Thomas from Otago Regional Council for their unwavering support on this project. Without their cooperation we would not have been able to access much of the data used in this assessment.

6. Appendices

Appendix 1. Results for all common data analyses.

Table A1.1. A list of the significant variables (p-value < 0.05) from the comparison between study periods for each line of evidence and at each area of interest. Note that not all variables were available for all areas of interests, or for the whole of the South Island of Aotearoa New Zealand. DIC = dissolved inorganic carbon.

Line of evidence	Area of interest	Period	Variables
Vessel density	Akaroa	lockdown – after	Passenger vessels density (GMT 2024)
Vessel density	Milford	before – lockdown	Passenger vessels density (GMT 2024)
Vessel density	Milford	lockdown – after	Passenger vessels density (GMT 2024)
Vessel density	New Zealand	before – lockdown	Passenger vessels density (GMT 2024)
Vessel density	New Zealand	lockdown – after	Passenger vessels density (GMT 2024)
Vessel density	Otago	before – after	Fishing vessels density (GMT 2024)
Vessel density	Otago	before – lockdown	Fishing vessels density (GMT 2024)
Vessel density	Otago	before – lockdown	Passenger vessels density (GMT 2024)
Vessel density	Otago	lockdown – after	Fishing vessels density (GMT 2024)
Vessel density	Otago	lockdown – after	Passenger vessels density (GMT 2024)
Temperature	New Zealand	before – after	Temperature (NZODN 2024a)
Temperature	New Zealand	before – lockdown	Temperature (NZODN 2024a)
Temperature	New Zealand	lockdown – after	Temperature (NZODN 2024a)
Water quality	Akaroa	before – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Akaroa	before – lockdown	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Akaroa	lockdown – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Kaikōura	before – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Kaikōura	lockdown – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Milford	lockdown – after	Mean chl-*a* (MODIS 2024)
Water quality	New Zealand	before – after	Mean chl-*a* (MODIS 2024)
Water quality	New Zealand	before – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	New Zealand	before – after	Salinity (NZODN 2024a)
Water quality	New Zealand	before – lockdown	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	New Zealand	before – lockdown	Salinity (NZODN 2024a)
Water quality	New Zealand	lockdown – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	New Zealand	lockdown – after	Mean POC (MODIS 2024)

Line of evidence	Area of interest	Period	Variables
Water quality	New Zealand	lockdown – after	Salinity (NZODN 2024a)
Water quality	Otago	before – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Otago	before – lockdown	Carbonate (NZODN 2024b)
Water quality	Otago	before – lockdown	DIC (NZODN 2024b)
Water quality	Otago	before – lockdown	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Otago	lockdown – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Stewart	before – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Stewart	before – lockdown	Mean enterococci (MPN/100 ml) (LAWA 2024)
Water quality	Stewart	before – lockdown	Salinity (NZODN 2024a)
Water quality	Stewart	lockdown – after	Mean enterococci (MPN/100 ml) (LAWA 2024)
Litter	Akaroa	before – after	Litter count per effort (LI 2024)
Litter	Akaroa	before – lockdown	Litter count per effort (LI 2024)
Litter	Milford	lockdown – after	Litter weight per effort (LI 2024)
Biological	Akaroa	before – after	Biodiversity – richness (iNaturalist 2024)
Biological	Akaroa	before – lockdown	Seabird – richness (eBird 2023)
Biological	Kaikōura	before – after	Biodiversity – richness (iNaturalist 2024)
Biological	Kaikōura	before – after	Shorebird – abundance (eBird 2023)
Biological	Kaikōura	lockdown – after	Seabird – richness (eBird 2023)
Biological	Kaikōura	lockdown – after	Shorebird – abundance (eBird 2023)
Biological	Milford	lockdown – after	Seabird – richness (eBird 2023)
Biological	Milford	lockdown – after	Shorebird – richness (eBird 2023)
Biological	New Zealand	before – after	Biodiversity – richness (iNaturalist 2024)
Biological	New Zealand	before – after	Biodiversity – abundance (iNaturalist 2024)
Biological	New Zealand	before – after	Toothed whales and dolphins – richness (DOC 2023c)
Biological	New Zealand	before – lockdown	Toothed whales and dolphins – abundance (DOC 2023c)
Biological	New Zealand	lockdown – after	Biodiversity – richness (iNaturalist 2024)
Biological	New Zealand	lockdown – after	Biodiversity – abundance (iNaturalist 2024)
Biological	Otago	before – after	Biodiversity – richness (iNaturalist 2024)
Biological	Otago	before – after	Biodiversity – richness (OBIS 2024)
Biological	Otago	before – after	Biodiversity – abundance (iNaturalist 2024)
Biological	Otago	before – after	Biodiversity – abundance (OBIS 2024)
Biological	Otago	before – after	Seabird – richness (eBird 2023)
Biological	Otago	before – after	Seabird – abundance (eBird 2023)

Line of evidence	Area of interest	Period	Variables
Biological	Otago	before – after	Shorebird – abundance (eBird 2023)
Biological	Otago	before – lockdown	Biodiversity – richness (iNaturalist 2024)
Biological	Otago	before – lockdown	Biodiversity – abundance (iNaturalist 2024)
Biological	Otago	before – lockdown	Seals – abundance (DOC 2023c)
Biological	Otago	lockdown – after	Biodiversity – richness (iNaturalist 2024)
Biological	Otago	lockdown – after	Biodiversity – abundance (iNaturalist 2024)
Biological	Otago	lockdown – after	Seabird – richness (eBird 2023)
Biological	Otago	lockdown – after	Seabird – abundance (eBird 2023)
Biological	Otago	lockdown – after	Shorebird – abundance (eBird 2023)
Biological	Stewart	before – after	Biodiversity – richness (iNaturalist 2024)
Biological	Stewart	before – after	Biodiversity – abundance (iNaturalist 2024)
Biological	Stewart	before – lockdown	Biodiversity – richness (iNaturalist 2024)
Biological	Stewart	before – lockdown	Seabird – abundance (eBird 2023)
Biological	Stewart	lockdown – after	Biodiversity – richness (iNaturalist 2024)
Biological	Stewart	lockdown – after	Biodiversity – abundance (iNaturalist 2024)
Biological	Stewart	lockdown – after	Seabird – abundance (eBird 2023)
Biological	Stewart	lockdown – after	Shorebird – abundance (eBird 2023)

Table A.1.2. Results of the generalised linear model relationships between the response variables and temperature or vessel density (explanatory variables), and / or their interaction. Note that not all response variables were available for all areas of interests, or for the whole of the South Island of Aotearoa New Zealand. POC = Particulate organic carbon. DIC = dissolved inorganic carbon.

Line of evidence	Area of interest	Variable	Interaction p-value	Temperature p-value	Vessel density p-value
Water quality	New Zealand	POC (MODIS 2024)	0.038504072	0.027919772	0.032546487
Water quality	Akaroa	POC (MODIS 2024)	0.365499368	0.170415757	0.220199791
Water quality	Milford	POC (MODIS 2024)	0.177677855	0.313106528	0.180796821
Water quality	Stewart	POC (MODIS 2024)	0.938590994	0.721923669	0.857098052
Water quality	Otago	POC (MODIS 2024)	0.725506139	0.020467069	0.710506215
Water quality	Kaikōura	POC (MODIS 2024)	0.451776973	0.028677042	0.492155411
Water quality	New Zealand	Chl-*a* (MODIS 2024)	0.00083979	0.00799483	0.000517831
Water quality	Akaroa	Chl-*a* (MODIS 2024)	0.441634584	0.015101979	0.443847867
Water quality	Milford	Chl-*a* (MODIS 2024)	0.051656419	0.882288615	0.041049897
Water quality	Stewart	Chl-*a* (MODIS 2024)	0.701997614	0.378281877	0.64552442
Water quality	Otago	Chl-*a* (MODIS 2024)	0.02223047	0.032820059	0.007236994
Water quality	Kaikōura	Chl-*a* (MODIS 2024)	0.315394599	0.000264143	0.350765108
Water quality	Akaroa	Enterococci (MPN/100 ml) count (LAWA 2024)	0	2.65E-222	7.38E-235
Water quality	Kaikōura	Enterococci (MPN/100 ml) count (LAWA 2024)	0.434475668	3.53E-36	0.246908706
Water quality	Otago	Enterococci (MPN/100 ml) count (LAWA 2024)	0	0	0
Water quality	Stewart	Enterococci (MPN/100 ml) count (LAWA 2024)	1.34E-37	5.44E-12	2.09E-21
Water quality	Otago	Salinity (NZODN 2024b)	0.090902501	0.21197014	0.055875475
Water quality	Stewart	Salinity (NZODN 2024b)	0.672307295	0.650336554	0.556745465
Water quality	Otago	DIC (NZODN 2024b)	0.494559772	0.327297533	0.244456988
Water quality	Stewart	DIC (NZODN 2024b)	0.76297101	0.436951729	0.923922357
Water quality	Otago	pH (NZODN 2024b)	0.980179098	0.286695105	0.840922162
Water quality	Stewart	pH (NZODN 2024b)	0.116485176	0.657997429	0.185655381
Litter	Akaroa	Litter count per effort (LI 2024)	0.000283953	0.386085268	0.000260674
Litter	Kaikōura	Litter count per effort (LI 2024)	2.40E-06	0.513617707	3.42E-07
Litter	Milford	Litter count per effort (LI 2024)	0.282044662	0.307439473	0.280074244
Litter	Otago	Litter count per effort (LI 2024)	0.024054515	0.024304782	0.054371783
Litter	Stewart	Litter count per effort (LI 2024)	0.938572626	0.938579565	0.937095389

Line of evidence	Area of interest	Variable	Interaction p-value	Temperature p-value	Vessel density p-value
Litter	Akaroa	Litter weight per effort (LI 2024)	0.958323093	0.045653879	0.962360443
Litter	Kaikōura	Litter weight per effort (LI 2024)	0.846523918	0.386568665	0.881342668
Litter	Milford	Litter weight per effort (LI 2024)	0.185900446	0.237113967	0.183867324
Litter	Otago	Litter weight per effort (LI 2024)	0.026534219	0.005224774	0.043792643
Litter	Stewart	Litter weight per effort (LI 2024)	0.065257702	0.065207618	0.065018326
Biological	Otago	Seals – count (DOC 2023c)	0.013441849	0.419170616	0.011834448
Biological	Otago	Seals – richness (DOC 2023c)	0.392188886	0.921047374	0.383892758
Biological	Otago	Seal death – richness (DOC 2023a)	0.740629597	0.781820923	0.742178976
Biological	Otago	Seal death – count (DOC 2023a)	0.952782155	0.636918265	0.863165648
Biological	Akaroa	Richness (OBIS 2024)	0.337284915	0.217102992	0.283035522
Biological	Kaikōura	Richness (OBIS 2024)	0.618516869	0.174318481	0.656255255
Biological	Milford	Richness (OBIS 2024)	0.998594843	0.828807895	0.92279267
Biological	Otago	Richness (OBIS 2024)	0.176152119	0.874015274	0.110300686
Biological	Stewart	Richness (OBIS 2024)	0.955467833	0.557744378	0.957861088
NA	Akaroa	Abundance (OBIS 2024)	0.752427969	0.361759873	0.725792491
NA	Kaikōura	Abundance (OBIS 2024)	0.493043077	0.212340432	0.559820617
NA	Milford	Abundance (OBIS 2024)	0.83447848	0.773543294	0.911480111
NA	Otago	Abundance (OBIS 2024)	0.756177173	0.267534419	0.951223973
NA	Stewart	Abundance (OBIS 2024)	0.986694833	0.39111994	0.972623412
Biological	Akaroa	Richness (iNaturalist 2024)	0.815576569	0.34718169	0.773848395
Biological	Kaikōura	Richness (iNaturalist 2024)	0.733933719	0.952837654	0.955277881
Biological	Milford	Richness (iNaturalist 2024)	0.524734712	0.559344015	0.432721831
Biological	Otago	Richness (iNaturalist 2024)	0.007186025	0.011758688	0.012860375
Biological	Stewart	Richness (iNaturalist 2024)	0.980101057	0.008797613	0.909208812
NA	Akaroa	Abundance (iNaturalist 2024)	0.767250423	0.500535095	0.780040001
NA	Kaikōura	Abundance (iNaturalist 2024)	0.413687843	0.733106619	0.548903346
NA	Milford	Abundance (iNaturalist 2024)	0.443429851	0.476276426	0.385062106
NA	Otago	Abundance (iNaturalist 2024)	0.011049618	0.001413851	0.018227822
NA	Stewart	Abundance (iNaturalist 2024)	0.463869481	0.018178407	0.535454098
Water quality	New Zealand	POC (MODIS 2024)	0.038504072	0.027919772	0.032546487
Water quality	Akaroa	POC (MODIS 2024)	0.365499368	0.170415757	0.220199791
Water quality	Milford	POC (MODIS 2024)	0.177677855	0.313106528	0.180796821
Water quality	Stewart	POC (MODIS 2024)	0.938590994	0.721923669	0.857098052

Line of evidence	Area of interest	Variable	Interaction p-value	Temperature p-value	Vessel density p-value
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Water quality	Milford	Chl-*a* (MODIS 2024)	0.051656419	0.882288615	0.041049897
Water quality	Stewart	Chl-*a* (MODIS 2024)	0.701997614	0.378281877	0.64552442
Water quality	Otago	Chl-*a* (MODIS 2024)	0.02223047	0.032820059	0.007236994
Water quality	Kaikōura	Chl-*a* (MODIS 2024)	0.315394599	0.000264143	0.350765108
Water quality	Akaroa	Enterococci (MPN/100 ml) count (LAWA 2024; MODIS 2024)	0	2.65E-222	7.38E-235
Water quality	Kaikōura	Enterococci (MPN/100 ml) count (MODIS 2024)	0.434475668	3.53E-36	0.246908706
Water quality	Otago	Enterococci (MPN/100 ml) count (MODIS 2024)	0	0	0
Water quality	Stewart	Enterococci (MPN/100 ml) count (MODIS 2024)	1.34E-37	5.44E-12	2.09E-21
Water quality	Otago	Salinity (NZODN 2024b)	0.090902501	0.21197014	0.055875475
Water quality	Stewart	Salinity (NZODN 2024b)	0.672307295	0.650336554	0.556745465
Water quality	Otago	DIC (NZODN 2024b)	0.494559772	0.327297533	0.244456988
Water quality	Stewart	DIC (NZODN 2024b)	0.76297101	0.436951729	0.923922357

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