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Reporting on the state of the New Zealand marine environment: recommendations for ocean indicators as part of the Atmospheric and Ocean Climate Change Tier 1 Statistic

New Zealand Aquatic Environment and Biodiversity Report No. 151

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This study has considered a wide variety of data that are relevant to reporting on trends, cycles and variability in the New Zealand marine environment including oceanic and coastal seawater as well as estuaries. Of particular interest are observations that may be linked to climate variability and long term climate change. The purpose of the study was to identify a set of indicators which together would form a new Tier 1 statistic on ocean climate change. The recommended indicators are given in the table below with a preliminary ranking of whether the indicator is: (1) of broad interest, including to policy makers, the business community, other stakeholders and the general public; (2) based on reliable data and robust analysis; (3) can be communicated effectively and can be understood (though it is not necessary to prove a causal link between climate change and the indicator for it to be useful as a Tier 1 statistic); (4) is likely to be available for the medium to long term (more than 10 years hence). Note that this ranking is based on expert opinion and is indicative only.

Recommended components for Ocean Tier 1 statistic. The recommended indicators are presented in decreasing order of how likely they are to be useful as part of the Ocean Tier 1 statistic. However, different people and organisations may have different criteria for "usefulness" so this order is indicative only.

Rank	Indicator	Brief description
1	Relative mean sea level	Sea level derived from coastal tide gauges round the New Zealand coast. This could be compared with the average sea level over the period for which consistent data exist.
2	Sea-surface temperature (coastal)	Sea surface temperature (SST) measured at 11 coastal sites across New Zealand. This could be compared with the average coastal SST over the period for which consistent data exist.
3	Ocean phytoplankton biomass	Concentration of chlorophyll-a, the ubiquitous phytoplankton pigment, as a proxy for the biomass of phytoplankton and hence potential ocean productivity. This could be compared with the average chl-a concentrations over the period for which consistent data exist.
4	Sea-surface temperature (satellite)	Temperature of the surface ocean of the New Zealand EEZ from satellite measurements. This could be compared with the average sea surface temperature over the period for which consistent data exist.
5	Ocean acidity (Munida pH)	The pH of seawater at the Munida time series site (offshore of Dunedin) as an index of ocean acidity. This could be compared with the average pH over the period for which consistent data exist.
6	Coastal extreme wave index	Area-by-area quantification of the number of large wave events in New Zealand coastal region in the previous year. This could be compared with the average number of such events over the period for which consistent data exist.
[1]7=	Open ocean extreme wave index	Area-by-area quantification of the number of large wave events in the previous year. This could be compared with the average number of such events over the period for which consistent data exist.
[1]7=	Ocean storm index (cyclone counts)	Number of deep low centres (cyclones) in four quadrants covering the New Zealand region. This could be compared with the average frequency of such events over the period for which consistent data exist.

Rank	Indicator	Brief description
8	Water masses/circulation	Changes to sea surface height measurements from satellite altimeters and inferred ocean circulation patterns.
9	Airflow index	Two circulation indices, derived from pressure gradients, which show how west-east and south-north airflow in the New Zealand region compared to the long-term average. This could be compared with the average pressure gradients over the period for which consistent data exist.
10	Coastal water quality (harmful algae)	Incidence of harmful or toxic algae detected from regulatory monitoring of shellfish harvesting and aquaculture. This could be compared with the average incidence of harmful algal bloom events over the period for which consistent data exist.

[1] Either only one of these indicators should be selected or they will be combined into a single indicator of extreme offshore weather events.

1 INTRODUCTION

As in other parts of the world, indicators are used in New Zealand to measure and disseminate information on changes in the environment. One important part of this is reporting on changes to the marine environment. For the purposes of this report, the domain of the marine environment is defined as the region extending from the mean high water mark to the edge of the New Zealand Exclusive Economic Zone (EEZ). Estuaries[1] are included in the marine domain.

This project (Ministry for Primary Industries, MPI project ZBD2012-02) is concerned with the development of the new Ocean Tier 1 statistic. Tier 1 statistics are the key official statistics used by the New Zealand government to underpin governance and communicate New Zealand performance domestically and internationally (Statistics New Zealand, 2007). "Performance" in this context depends on the type of activity or process that the Tier 1 statistic is reporting on. For environmental statistics, "performance" means the extent to which levels of natural capital and biodiversity are preserved to ensure that meeting the needs of the present does not compromise the ability of future generations to meet their own needs (Statistics New Zealand, 2008). The Ocean Tier 1 statistic will form part of the "Atmosphere and Ocean Climate Change" Tier 1 statistic.

Specific objectives

Specific Objective 1
The Contractor will perform a preliminary investigation and identify candidate datasets for examination against Tier 1 criteria, taking into account progress towards environmental reporting through the Environmental Domain Plan (Marine).
Completed February 2014

Specific Objective 2
The Contractor will host a collaborative and consultative workshop to introduce and discuss each potential ocean indicator for its usefulness as a Tier 1 statistic.
Key activities include:
i. Prepare summary of variables for collaborative workshop;;
ii. Determine workshop participants and schedule suitable workshop date; and
iii. Host / collaborate on hosting workshop.
Workshop held on Tuesday 11th March 2014 at NIWA, Wellington

Specific Objective 3
The Contractor will perform a detailed examination and production of selected datasets against Tier 1 criteria, including completing any additional investigations suggested from the workshop in specific objective 2.
Draft final report provided to MPI on 10th July 2014

Specific Objective 4
The Contractor will present a final workshop and introduce the indicators from objective 3. Key activities include:
i. Prepare summary of variables for collaborative workshop;
ii. Determine workshop participants and schedule suitable workshop date; and
iii. Host / collaborate on hosting workshop.
Final workshop held Friday 5th September 2014 at NIWA, Wellington

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[1] An estuary is defined as: "A partially enclosed coastal body of water that is either permanently or periodically open to the sea in which the aquatic ecosystem is affected by the physical and chemical characteristics of both runoff from the land and inflow from the sea" [Estuary Environment Classification, http://www.niwa.co.nz/coasts-and-oceans/nz-coast/learn-about-coastal-environments/estuary-types]

2 NEW ZEALAND ENVIRONMENTAL REPORTING

2.1 Purpose of indicators

In the New Zealand context, decisions about managing natural resources, and the development of environmental policy depend on reliable, evidence-based information on the state of the environment. New Zealanders in general, including the public and businesses, need information they can trust on the environment to participate in an informed debate about how we balance environmental goals with other social, cultural and economic aspirations (MfE, 2014a).

A wide range of threats and pressures on the New Zealand marine environment have been identified (Ministry for the Environment 2007, MacDiarmid et al. 2012a, b). Such threats include climate variability and change (and associated effects such as ocean acidification impacts, Caldeira & Wickett 2003, Willis et al., 2007), fishing impacts, land-based effects (such as sediment runoff and pollution), and risks associated with offshore engineering, shipping, and exploration and extraction of minerals and petrochemicals (MacDiarmid et al. 2012a, b).

Marine indicators can be used to help monitor changes to the marine environment in relation to the combined effects arising from threats such as those outlined above (OECD 1993, 1998, 2003; Garcia & Staples 2000). It is clear that there is not one "best" set of indicators because the utility of the indicator depends on the intended purpose. For example, indicators can also be classified by type using the European Environment Agency's typology (European Environment Agency, 2003). This typology distinguishes four types of indicator, each of which addresses a different question and provides different information.

- **Descriptive indicators**: What is happening in the environment and to people? These indicators describe key environmental issues and their impact on people, and show changes over time.
- **Performance indicators**: Is a policy or management approach making a difference? These indicators compare actual conditions against a set of reference conditions (for example, progress towards targets, goals, or environmental objectives).
- **Efficiency indicators**: Are we improving? These indicators relate environmental pressures to people's activities, and to the efficiency of products and processes. Activities are measured in terms of the resources they use and the emissions and waste they generate.
- **Total welfare indicators**: Are we better off? These indicators are one measure of social, economic, and environmental well-being. In this way, they are indicators of sustainability.

This report aims to identify information relevant to reporting on the state of New Zealand's ocean domain, including in relation to climate variability and change – i.e. a set of descriptive indicators focussed on the environment rather than its impact on people.

2.2 Framework for environmental reporting in New Zealand

New Zealand environmental reporting has included two State of the Environment Reports, co-ordinated by the Ministry for the Environment (MfE, 1997, 2007). Marine environmental reporting in New Zealand is under review at the time of writing, and in the future is likely to have two main strands: (1) environmental Tier 1 statistics co-ordinated by Statistics New Zealand ("Statistics NZ" henceforth) and updated as appropriate (probably annually) (Section 2.3); (2) a 3-year cycle of reporting on five environmental domains (one domain report published every six months) co-ordinated by MfE with Statistics NZ) as mandated under the Environmental Reporting Bill (introduced to Parliament 20 February 2014) (Section 2.4). There is also substantial work underway on marine indicators for particular management purposes (Section 2.6); for example, the development of indicators to help manage New Zealand's deepwater fisheries (Tuck et al., 2009, 2014).

2.3 Tier 1 statistics

2.3.1 What are Tier 1 statistics?

Information given here on Tier 1 statistics is largely taken from online information provided by Statistics NZ as of April 2014 (www.Statistics.govt.nz). Tier 1 statistics are the highest level of statistical reporting in a country (Statistics NZ, 2007, 2008). Tier 1 statistics are the key official statistics used by the New Zealand government to underpin governance and to communicate New Zealand's performance domestically and internationally. Thus, Tier 1 statistics:

- are essential to central government decision-making;
- are of high public interest;
- meet public expectations of impartiality and statistical quality;
- require long-term continuity of the data and are enduring (i.e. the set of Tier 1 statistics should not change frequently); and
- provide international comparability in a global environment.

Designating a portfolio of Tier 1 statistics:

- ensures that we focus on the most important statistics for New Zealand;
- enables the prioritisation and rationalisation of statistical investment and effort across the Official Statistics System, to ensure that a set of the most important statistics are produced; and
- ensures that Tier 1 statistics are of the highest quality and can be relied on as authoritative, relevant and trustworthy.

Tier 1 statistics are managed as part of the Official Statistics System (OSS), led by the Government Statistician and overseen by the OSS Chief Executives Steering Group and the Ministerial Advisory Committee on Official Statistics. The investment in Tier 1 statistics is managed through the Government Statistician's annual purchase advice and normal Budget processes.

2.3.2 Environmental Tier 1 statistics

In October 2012 the New Zealand Government signed off on a set of new Tier 1 Statistics to be developed under the Natural Resources Sector. This new set (Statistics NZ, 2012) includes the Tier 1 statistic "Atmosphere and Ocean Climate Change" (present project), "Coastal and Recreational Coastal Water Quality", "Ecological Integrity and Diversity" and "Marine Biodiversity".

A Tier 1 statistic can be either a single statistic or a specified set of statistics. The Tier 1 Ocean statistic will be the latter, i.e. it will include a small number of different indicators in the order of 4 – 8 separate indicators. These indicators taken together will provide a picture of environmental change in New Zealand's marine environment. Future candidates for Ocean Tier 1 statistics (or separate indicators within a Tier 1 statistic) can also be proposed where the statistical measurement framework is still under development and is expected to be finalised in the next five years.

2.3.3 Principles for Tier 1 statistics

Detailed principles and protocols for the development of Tier 1 statistics are given by Statistics NZ (Statistics NZ, 2007) and summarised in Table 1 and Table 2 Principles 7 (*Protecting respondent information*) and 8 (*Minimising respondent load*) are not relevant to the current project as no data considered in the present report are from respondent surveys.

Table 1: Principles for Tier 1 statistics. Note that this is a two page summary of Statistics NZ (2007), which is a 71 page document, so that some text has been shortened, especially when of less relevance to environmental reporting.

#	Principle	Key elements of principles
1	Relevance	• Meet the needs of government, business and the community (within available resources). • Have clear objectives (identify the information needs that they address). • Periodically reviewed/assessed to ensure their relevance and to justify continued data collection.
2	Integrity	• Follows international best practice (re data collection, confidentiality, privacy, and release). • Selection of data sources, methods and procedures is based on best scientific practice (taking into account cost implications to government and providers). • Decisions surrounding the prioritisation of statistical needs are transparent. • Impartial - analysis/compilation, reporting, and release of data is free from external influences. • Data are presented in a manner that is easy to understand. • Data sources are credited/acknowledged.
3	Quality	• Professional competence underpins all official statistics activity. • Culture of continuous improvement and statistical best practice and evaluation. • Processes and methods used to produce official statistics, including measures of quality such as estimated measurement errors, are fully documented and are available for users to understand the data and judge the quality. • Reliable and relevant data are collected from the most appropriate source. • Data revisions to ongoing statistical series follow a regular, well-established and transparent schedule. If a significant error is found in the data, the corrected data are made publicly available as soon as possible after the identification of the error.
4	Coherence	• Common statistical frames, definitions and classifications are used to provide consistency over time and between datasets. National and international frameworks and classifications are used wherever possible. • Automated processes/methods are used where practical to minimise bias in data. • All new surveys and administrative databases incorporate relevant standards into the planning and implementation phase. Existing surveys and administrative databases are progressively updated to meet the standards at the time of their next major revision or upgrade. • Statistics users and producers collaborate in setting national statistical standards. • Standards and classifications are documented carefully and in a form that can be readily accessed and used. • Classifications must be systematic and should classify observations consistently, using agreed criteria. Classification groups must be unambiguous, exhaustive and mutually exclusive.
5	Accessibility	• Tier 1 statistics producers will ensure equality of access. • Statistics are presented in a clear and understandable manner and are widely disseminated. • Release of Tier 1 statistics is by the chief executive of the producing agency, notified more than 6 months in advance. The timing of a release is not influenced by its content or set to create an advantage to any particular group or individual. • Because of potential for financial, political or other gain, strict security is maintained during preparation of, and prior to, the release of key results. • As much detail as is reliable and practicable is made available, subject to legal and confidentiality constraints. This includes information about the quality of the data and other relevant metadata. • Statistics intended for the broader public are easy to read and do not mislead. Statistical commentary, tables and graphs intended for general use are compiled with a view to their general interest value, impartiality and cost-effectiveness. • Official statistics producers listen to and respond openly to all enquiries and make records open to scrutiny on request (subject to constraints).

Table 1 (continued). Principles for producers of Tier 1 statistics (based on Statistics NZ, 2007).

6	Efficiency	• Surveys and processing systems are to the greatest possible extent designed with sufficient flexibility to accommodate changes in user needs. • Appropriate opportunities to reduce costs are actively sought. These include: economies of scale; data integration; methodologies and systems developments that use generic, automated processes; better exploitation of existing surveys; shared use of data, particularly administrative data; improved survey methods; use of sampling techniques.
7	Protecting respondent information	• Privacy refers to the ability of a person to control the availability of information about themselves. Confidentiality refers to the protection of individuals' and organisations' information. Security refers to how the publishing agency stores and controls access to the data it holds. • Legislative and ethical obligations governing the collection of data, confidentiality, privacy and release are rigorously followed. • Data provided by respondents is only used for statistical purposes. • Respondents are informed of the main intended uses and access limitations applying to the information they provide. • Respondent's anonymity is always strictly preserved unless there is explicit agreement to the contrary. Access to micro-data is subject to strict confidentiality agreements. • Everyone involved in the production of official statistics is aware of their obligation to protect provider confidentiality. Access to identifiable unit records of information supplied by respondents is restricted to appropriate staff. • Unless legal permission is provided to allow identification of information in data collected for administrative purposes, the same confidentiality and privacy standards will apply to statistics derived from administrative sources as apply to data collected for statistical purposes.
8	Minimising respondent load	• The need to collect data is assessed. Existing data sources, including administrative data, are assessed before undertaking new collections. • The 'best-supplier' principle is applied i.e., collect data from the most appropriate source after considering respondent load. • To enable respondents to understand their obligations to supply information, the need for the survey is clearly presented to them. • A continuous effort is made to develop techniques that reduce the burden on information providers. • All new or substantially revised surveys with a sample size of more than 2,500 are managed through the Government Statistician. • Summary respondent-load information for Statistics NZ's surveys is included in the department's annual report to Parliament.
9	Maximising existing data sources	• Data are treated as an enduring national resource, with their value increasing through widespread and long-term use. Statistical systems are designed to maximise the potential to add value through data integration and comparison. • Active data integration projects are publicly notified via government agency websites and annual reports. • Data integration projects comply with the Privacy Act and the regulations and policies that govern the data-supplying agencies. • Statistical coordination is enhanced through various forums, including the Advisory Committee on Official Statistics (ACOS), the Official Statistics System Committee, and involvement with professional statistical associations. • Statistical material likely to be of historical interest is archived, subject to security, confidentiality and statutory obligations. • Unit record datasets for all Tier 1 surveys, and Statistics NZ's holdings of Tier 1 administrative datasets and integrated statistical datasets, (including historical data and metadata) are deposited with the Data Archive for research and historical purposes.

Table 1 (continued). Principles for producers of Tier 1 statistics (based on Statistics NZ, 2007).

10	International participation	• Bilateral and multilateral cooperation contributes to the improvement of official statistics systems in all countries. • International concepts, classifications and methods are used wherever possible to make meaningful comparison of data between countries. • Opportunities to share statistical knowledge and build relationships with other professional statisticians are facilitated through international conferences/workshops, secondments and provision of technical assistance. • Obligations to supply statistical data to international agencies are met.

Table 2: Protocols for producers of Tier 1 statistics (based on Statistics NZ, 2007). Grey shaded cells indicate protocols of lower relevance to environmental Tier 1 statistics.

Protocol	Element	Element title	Comment
1. Quality (Q)	Q1	Professionalism	
	Q2	Good management practice	
	Q3	Continuous improvement	
	Q4	Relevance	
	Q5	Accuracy	
	Q6	Timeliness	Fixed periodical updates
	Q7	Consistency	
	Q8	Interpretability	Causality not necessarily required
2. Frameworks, standards and classifications (FSC)	FSC1	Common frameworks	
	FSC 2	Standard practice	
	FSC 3	National/international comparability	
	FSC 4	Promoting common standards	
3. Respondent management (RM)	RM1	Respondent load	These protocols were written to apply to surveys of respondents, which are not generally the main sources of environmental data.
	RM2	Collection value	
	RM3	Using administrative data	
	RM4	Data sources	
	RM5	Reducing load	
	RM6	Data collection methods	
	RM7	Effective communication	
	RM8	Participation by Maori	
4. Confidentiality privacy and security (CPS)	CPS1	Legal and ethical obligations	
	CPS2	Awareness of obligations	
	CPS3	Use for statistical purposes	
	CPS4	Managing privacy concerns	
	CPS5	Preserving confidentiality	
	CPS6	Security	
	CPS7	Administrative data	
5. Release practices (RP)	RP1	Accessibility	
	RP2	Presentation and dissemination	
	RP3	Release of Tier statistics	
	RP4	Pre-release security	
	RP5	Unbiased reporting	
	RP6	Unambiguous presentation	
	RP7	Errors in published data	
	RP8	Revisions	
6. Management, documentation and preservation of statistical records (MDP)	MDP1	Data retention policy	
	MDP2	Data custodians	
	MDP3	Contextual documentation	
	MDP4	Protection of statistical resources	
	MDP5	Historic preservation	

2.3.4 Key criteria for indicators within Tier 1 statistic

The principal aim of Ocean Tier 1 indicators is to provide information on the extent to which the marine environment is changing, where change includes trends, cycles and shorter-term variability. The value of these indicators is not necessarily dependent on the establishment of causality, i.e. quantifying change in the marine environment is valuable irrespective of whether the reason for the change is known (European Environment Agency, 2003; Cury & Christensen, 2005). Furthermore, the Ocean Tier 1 statistic is not linked to specific management actions. If any changes are observed in the descriptive or headline indicators, more specific indictors and analysis would generally be needed to infer causality and determine what the appropriate management action should be (Rice 2000; Link 2005; Rice & Rivard 2007).

Public policy indicators are generally required to be interpretable in terms of informing us if ‘things are getting better’ or ‘things are getting worse’ (Patterson, 2002). This requirement would imply some reference point or benchmarking system, such as policy targets, comparisons with other countries, environmental standards, and departures from a base year. For the Ocean Tier 1 statistic under development, this is not necessarily the case. Measuring and reporting change in the marine environment is valid even if we cannot say whether the change is “good” or “bad”. In some cases (e.g. sea level rise, increasing ocean acidity, warming ocean), people may agree the change is “bad” (for them personally or for the environment or society in general) but for other indicator changes (e.g. change in ocean circulation, changes in primary productivity) it may be harder to agree on the desirability of the change.

A number of previous studies (e.g. Opschoor & Reijnders, 1991; Gallopín, 1997; Patterson, 2002) have identified the desirable characteristics of useful public policy indicators. Based on these, Statistics NZ (2007, Table 1) and discussions at the Tier 1 Statistics workshop on 11 March 2014, the key selection criteria for indicators that will form part of the Ocean Tier 1 statistic are:

1. Importance: including interest, relevance and whether the information can be understood by decision-makers or the public (“comprehensibility”);
2. Quality; and
3. Longevity.

Importance is decided by whether a statistic meets one or more of the following criteria:

- The statistic satisfies broad public interest in the state of the environment.
- The statistic provides information that is useful for informing significant private and business decisions.
- The statistics are of high value in informing debate and decisions on issues of national importance and monitoring the outcomes of those decisions.
- The statistics are required for administration of legislation, operating important government funding and allocation models, or meeting government’s international commitments.

These needs could include identifying potential environmental risk factors so that businesses, local and central government and the public can be better prepared, whether it be for private or government decision-making; for example, conservation measures, placement of MPAs, or flood risks. The ongoing importance or relevance of the Tier 1 list is managed through the scheduled five-yearly review.

Quality requires that the statistic meets the following criteria:

- The statistic satisfies public expectations of authoritative and trustworthy information about their country.
- Information can be relied on as part of significant private and business decisions.
- The information is of appropriate quality for informing debate, decisions and monitoring of issues of national importance.
- Statistics are underpinned by a credible measurement framework and statistical analysis procedure. The statistics follow best international scientific and statistical practice, and are of comparable quality with similar data elsewhere in the world.

This is especially important for environmental statistics because our knowledge of natural systems is known to be imperfect, but the issue is whether the knowledge is “fit for purpose” (Statistics NZ, 2010). The quality of Tier 1 statistics is managed through the application of the Principles and Protocols for Producers of Tier 1 Statistics.

Longevity requires that it is reasonably expected that the statistic will continue to be collected for the medium term (next 5–20 years). The New Zealand government indicated the importance of being able to backdate selected indicators several years in order to establish trends (Patterson, 2002). The selected indicators should be suitable for long-term, repeated measurements. Care is needed to ensure that whatever variables are selected, there is a consistent historical time-series and a good prospect that these time-series will be maintained into the future. There should be an expectation that this will be the case even though longevity of data collection may not be able to be guaranteed because of changing priorities for research funding in New Zealand and overseas. The importance of maintaining time-series of environmental indicators is likely to be part of the 5-yearly review of Tier 1 indicators.

Presentation: Although not part of the selection criteria, the presentation of the Tier 1 Statistic is crucial. This includes presenting the information in an appropriate and accessible way. For example, if there are strong spatial variations in the property of interest, a graphical image, map or animation of the indicator may be easier for people to understand than showing a number of graphs. Also required are two levels of information about the methods used to produce the Tier 1 statistics: (1) a technical, detailed and comprehensive description of the methods, appropriate for peer review and to enable international comparison; and (2) a non-technical description of the methodology. Finally, a section of non-technical text is required. This should state why the statistic has been selected and what the statistic means. Establishing why the change has happened (causality) and what management action may be required if a change is observed is not required.

We also note that different users of indicators require different things (Patterson, 2002). Policy-makers prefer data that are related to policy objectives, evaluation criteria, and target and threshold values; information for policy makers should be condensed to a few "bits" (units of information) per message (Braat, 1991). In contrast, the public is assumed to prefer unambiguous messages, free of redundancy, in a single unit of information but potentially with a wider scope (Patterson, 2002). For example, "the sea in the last year was warmer than normal" is a single unit of information, whereas "the sea last year was warmer in the summer but colder in the winter" is two units of information. For Tier 1 indicators with a wide prospective audience, some compromise in the focus and complexity would seem inevitable. Also, the method of display (e.g. using maps or animations) may allow more information to be conveyed without losing comprehensibility. Presenting data in map form may also allow different groups of users to focus on different aspects of the information. For example, a map of the sea temperature last year compared to average might allow one person to look at the overall change (across the whole New Zealand ocean domain) and another person look at change just in a smaller area of particular concern to them (e.g. where their aquaculture facility is located). If time-series data for a particular area or application are required by a stakeholder, the indicator can act as a "signpost" to what data are available and from where they may be sourced.

2.3.5 Funding for environmental Tier 1 statistics

Considering the funding for marine environmental monitoring is important because the cost of providing indicators as part of a Tier 1 statistic is likely to be higher than the cost of using data for scientific publications. This means that if environmental statistics are included in the Tier 1 statistic reporting, this difference will need to be funded to ensure long-term viability of the statistics. In 2012, Cabinet approved a new Tier 1 Statistics list, which includes some statistics that are not currently funded. According to the Statistics NZ online resources[2], the process for identifying funding sources for Tier 1 statistics that cannot be covered by existing funding will be via the Government Statistician's annual purchase advice. The Government Statistician, in conjunction with the Official Statistics System (OSS) Chief Executives Steering Group, provides annual OSS purchase advice to the Minister of Finance. This purchase advice comments on all government's statistical investments across the OSS to ensure that spending is targeted toward priority areas (with Tier 1 statistics representing government's highest priority statistics). This advice does not alter Ministers' control of changes to investments

[2] www.Statistics.govt.nz, accessed December 2014

through the normal Budget decision-making; rather it supplements that decision-making and ensures across-Government consideration of priorities for investment in statistics.

2.4 National Environmental Reporting

In addition to the national Tier 1 statistics described above, the New Zealand government has also set about trying to improve environmental reporting across the country. The key elements of the Environmental Reporting Bill (MfE, 2014b) introduced to Parliament in 20 February 2014[3] are to:

- establish an environmental reporting system that provides comprehensive information on five environmental domains – air, climate and atmosphere, fresh water, marine and land, with biodiversity and ecosystems as a theme across all domains;
- develop an environmental reporting framework to provide a coherent picture of New Zealand's environment, covering the state, changes in state, pressures and impacts for each domain;
- allow MfE and Statistics NZ to undertake regular environmental reporting, on a 3-yearly cycle; and
- afford the opportunity for the Parliamentary Commissioner for the Environment to provide expert commentary and independent opinion on the quality of the underlying data and robustness of the analysis.

The National Environment Reporting framework will include three main types of information (MfE, 2014b):

- **Pressure**: Pressure indicators explain the human activities and natural factors that influence the environment. These answer the 'why?' questions about the domain – why the domain is in the condition it is in.
- **State**: State indicators describe the biophysical condition of the environment. These answer the 'what?' questions about the environment – what are the physical, chemical and biological characteristics of that domain and how have they varied over time?
- **Impact**: Impact indicators explain what the state and changes in the state means by informing the 'so what?' questions about the environment – what are the consequences of changes in the state for New Zealand's environment, economy and society?

One "environmental domain" (see Section 2.5) will be reported on every six months. Once every three years, a synthesis of the five domains will be produced. The synthesis will have a focus on the overall picture of the New Zealand environment, including interactions between each domain.

2.5 Environment domain plan

Statistics NZ, with MfE and the Department of Conservation (DOC), developed and published the Environmental Domain Plan (EDP) which considered 10 topic areas and identified key enduring questions relating to the environment for each of them (Statistics NZ et al., 2013):

1. atmosphere
2. **climate change**
3. **coastal and marine environment**
4. ecosystems and biodiversity
5. energy
6. freshwater
7. land
8. Māori environmental statistics

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[3] http://www.parliament.nz/en-nz/pb/legislation/bills/00DBHOH_BILL12994_1/environmental-reporting-bill

9. materials and waste
10. mineral resources.

Topic areas 2 and 3 (in bold) are directly relevant to the present project. The purpose of the EDP was to develop a shared understanding of the strengths, gaps, overlaps, and deficiencies within New Zealand environmental statistics. There were four steps to the EDP:

1. identify the enduring questions[4] and the supplementary enduring questions[5] for each topic area;
2. compile a stocktake of official data currently available;
3. analyse the stocktake with respect to the questions; and
4. host and facilitate 10 topic area workshops to identify and prioritise initiatives to improve environmental information.

Examination of the supplementary enduring questions showed that about 40% of the EDP initiatives are aligned with an existing or proposed Tier 1 statistic (Statistics NZ et al., 2013).

2.5.1 Climate change topic area

Enduring questions

1. How is New Zealand's[6] climate changing?
2. How are New Zealand’s greenhouse gas levels[7] changing?
3. How are we adapting to the physical impact[8] of climate change?
4. Which environments are most likely to be affected by climate change?

Supplementary enduring questions

A. Where and how are New Zealand’s climate and atmospheric composition changing?
B. Where and how are New Zealand’s anthropogenic greenhouse gas emissions, and removals, changing?
C. What and where is the impact of climate change on Māori and Māori-owned assets?
D. Where and how are ecosystems, people, and New Zealand institutions most affected by changes to climate and atmospheric composition, and how are they adapting?
E. What greenhouse gas mitigation technologies and practices are we adopting?

2.5.2 Coastal and marine environment topic area

Enduring question

1. How is the quality and use of our marine environment changing and what is the impact of human activity, including resource use, on the marine environment?

Supplementary enduring questions

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[4] Enduring questions: ‘big picture’ questions – those you’d be likely still to be asking in 20 years.
[5] Supplementary enduring questions: focus at a more detailed level within each topic.
[6] Includes the Ross Dependency and the Chatham Islands.
[7] Refers to emissions and sinks of climatically-active gases such as carbon dioxide.
[8] Includes physical impact on sea temperature, sea-level, ocean currents, river flows, and winter snow cover.

A. What are the spatial and temporal biophysical trends in the coastal and marine environment[9] and how are these predicted to change in the future?

B. What is the current use of natural resources[10] in the coastal and marine environment, what is the intensity of this use, how is this use changing spatially and temporally, and how is it predicted to change in the future?

C. What ecosystem services are currently provided by New Zealand's coastal and marine environment and how are these predicted to change in the future?

D. What is the impact of human activity on the coastal and marine environment, including the cumulative effects on its resilience, and how is this changing over time?

E. What is the current relationship between Māori and the coastal and marine environment, how is this changing, and what is the impact of human activity, resource use, and climate change on this relationship?

F. What is the conservation and environmental protection effort[11] for the coastal and marine environment?

2.5.3 Available data identified in the EDP

The EDP also identified how well official data informs supplementary enduring questions (Table 3) and suggested the top-priority initiatives for addressing these information needs over the next five to eight years (i.e. up to 2018 or 2021) (Table 4).

Table 3: How well official data informs supplementary enduring questions in the "Climate change" and "Coastal and marine environment" domain plans (Statistics NZ et al., 2013).

	Supplementary enduring question					
	A	**B**	**C**	**D**	**E**	**F**
Climate change	High	High	Medium	Medium	Medium	N/A
Coastal and marine environment	Medium	Low	Low	Low	Low	Low

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[9] "Coastal and marine environment" includes the areas usually covered by or containing sea water, including seas and oceans, harbours, river estuaries, salt-water marshes and mangroves, and coasts and beaches – including biological and physical elements such as water temperature, salinity, and the composition and spread of marine species.

[10] Natural resources include renewable and non-renewable resources in the coastal and marine environment such as fish, mineral and gas reserves, and the resources supporting aquaculture.

[11] Environmental protection effort includes remediating environmental damage, resource management, expenditure, areas protected under regulation and legislation, damage avoidance, research, and minimising natural hazards.

Table 4: Top-priority initiatives identified by the "Climate change" and "Coastal and marine environment" topic area workshops (Statistics NZ et al., 2013).

Number	Initiative name	Complexity	Helps inform which supplementary enduring question
Climate change			
CC.A1.1	Gather information on national climate change adaptation responses	Moderate	D
CC.i1.1	Assess the climate change impacts on ecosystem services	Highly complex	D
CC.i1.2	Gather national infrastructure topography data – LIDAR for sea level change projections	Moderate	C, D
CC.A2.1	Develop a map of projected sea level rise around NZ's coastline	Moderate	C, D
CC.i1.3, CC.i1.4	Assess the impacts of climate change on Māori	Highly complex	C
Coastal and marine environment			
CM1	Identify baseline habitat state	Highly complex	A, B, D, E
CM2	Expand statistical governance over coastal and marine data	Highly complex	All
CM3	Review existing datasets	Moderate	All

2.6 Other indicators and environmental reporting

2.6.1 Marine Environmental Monitoring Programme (MEMP)

The MPI Marine Environmental Monitoring Programme (MEMP) project (ZBD2010-42) began before the EDP and Environmental Reporting Bill were underway in recognition that a key resource management action for New Zealand would require the design, implementation and commitment to a comprehensive long-term monitoring programme for our oceans, coasts and estuaries. The project was initially a joint initiative between MPI and MfE. The first part of MEMP was to locate all existing and past time-series of marine environmental data and place high level information about these data into an online catalogue (Hewitt et al., 2014). This work has improved awareness and access to these datasets and allowed them to be evaluated as to their fitness-for-purpose in the sense of providing reliable information on environmental variability and change. Having identified and evaluated current datasets, MEMP will contribute to the development of a monitoring programme that can encompass the existing datasets and tie them into a more coherent nationwide network.

2.6.2 MPI deepwater ecosystem indicators

Internationally, reviews of ecosystem indicators have concluded that no single indicator addresses all aspects of an ecosystem, and that a suite of indicators are required to monitor and summarise change in ecosystems (Cury & Christensen, 2005; Rice & Rochet 2005). Such a suite of indicators should be sensitive to change across the range of scales and processes. MPI projects ENV2006-04 and DEE2010-05 produced recommendations on the development of environmental indicators for use in managing New Zealand's fisheries (Tuck et al. 2009; Tuck et al., 2014). Tuck et al. (2014) examined and identified indicators across the following eight categories: (1) climate indices; (2) oceanographic indices; (3) primary productivity indices; (4) food-web indicators; (5) fisheries and fisheries management indicators; (6) indicators of the fish community (especially those from Tuck et al., 2009); (7) indicators of benthic communities and habitats (sea-floor integrity); and (8) indicators of top predators, threatened and endangered species.

3 OCEAN TIER 1 STATISTIC: RECOMMENDATIONS

3.1 Sea level

3.1.1 Scientific background

Knowledge on how mean sea-level (MSL) varies seasonally, annually and over periods of decades to centuries is of high relevance to planning processes for coastal communities, local/central government, infrastructure agencies, the insurance sector and the maritime sector. MSL serves as an anchor to establishing appropriate elevations for coastal development and infrastructure design, and is the reference point for monitoring or designing for extreme coastal water levels during hazard events e.g., storm-tide and wave overtopping and inundation, tsunami inundation, including exacerbation of these types of events with projected sea-level rise due to climate change. With sea-level rise projections due to climate change of up to 1 metre predicted by 2100 (and higher values cannot be entirely ruled out), and associated coastal hazards, there will be increasing pressure on communities and infrastructure that are currently less than several metres elevation above mean high water. This is important because, based on the 2006 New Zealand Census, around 150 000 people reside in coastal plains no higher than 3 m above mean high water.

Hence a robust measure of annual MSL and how it is tracking long-term with climate change is essential to any form of coastal re-development, new "greenfields" developments or infrastructure projects. Information on sea-level change would hence potentially have high economic relevance and be important for central and local government. There is also likely to be high public interest in (and understanding of) measures of sea-level change. Tracking sea-level nationally relative to ongoing and previous global-average sea-level rise projections will also help inform what the more-likely range is for projected sea-level change in New Zealand.

Sea-level has been measured from coastal tide gauges around New Zealand since the late 19th century, primarily for maritime uses. Scientific studies of coastal and estuaries sea-level measurements started with analysis of tides and how the tidal wave propagates around New Zealand. More latterly, there has been a wide range of studies focusing on:

- coastal hazards e.g., storm-tide inundation, perigean-spring ("king") tides, wave run-up and overtopping, seiching and tsunami inundation;
- climate variability effects on sea-level, particularly the seasonal (annual) cycle, El Niño–Southern Oscillation cycles (2–4 years), the longer 20–30 year Interdecadal Pacific Oscillation (IPO) cycle and sea-level rise; and
- future projections of mean sea-level, both globally and downscaled to the New Zealand region.

New Zealand has five sea-level gauge sites that are part of the Global Sea Level Observing System (GLOSS) as listed in Table 5. GLOSS is an international research programme that aims to develop high quality global and regional sea-level networks for application to climate, oceanographic and coastal sea-level research. The programme became known as GLOSS as it provides data for deriving the 'Global Level of the Sea Surface'. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea-level stations around the world for long-term climate change and oceanographic sea-level monitoring.

Table 5: New Zealand's Global Sea Level Observing System (GLOSS) Core Network stations.

GLOSS ID	Station
101	Wellington
127	Auckland
128	Waitangi (Chatham Island)
129	Bluff
134	Scott Base (Antarctica)

New Zealand contributes sea-level data to the Permanent Service for Mean Sea Level (PSMSL) database. PSMSL is the global data bank for long-term sea-level change information from tide gauges and bottom pressure recorders. In terms of fulfilling New Zealand international commitments, while there is no formal treaty or obligations on New Zealand to supply sea-level data to the PSMSL database, there is a strong international expectation that New Zealand will do so given that New Zealand is one of the few places in the Southern Pacific where sea-level has been and will continue to be measured over long periods (decadally) with sufficient accuracy. This is also important in a global sense because sea-level measurements in New Zealand allow the wider Pacific region to be represented in the global dataset of sea-level change.

3.1.2 Base datasets[12]

At present, coastal/estuarine sea-levels (tides) are measured at nearly 70 gauge sites around New Zealand including offshore islands and Antarctica (Figure 1). Sea-level data are measured for various purposes supporting maritime activities, coastal inundation hazards, tsunami observations and monitoring sea-level variability and trends. A variety of agencies are responsible for these sea-level gauges, including Regional Councils, Port Authorities and research organisations, including New Zealand universities. The lengths of historic records for most of these sites are quite short (e.g., most would be no more than 10–15 years in length) apart from the Standard Ports (red sites in Figure 1), for which Land Information New Zealand (LINZ) produce tide tables in the annual Nautical Almanac.

LINZ has a key role to play in the development of a MSL statistic, through:

(a) their funding and oversight of the GeoNet[13] components associated with the tsunami sea-level gauge and cGPS sensor networks;
(b) their role as custodian of sea-level data for New Zealand through the New Zealand Hydrographic Authority, which is part of LINZ; and
(c) their role in setting local and national vertical MSL datum's – which may require adjustments as MSL changes.

[12] "Base" datasets explain what actual measurements are available
[13] GeoNet is the official source of geological hazard information for New Zealand. (http://www.geonet.org.nz/)

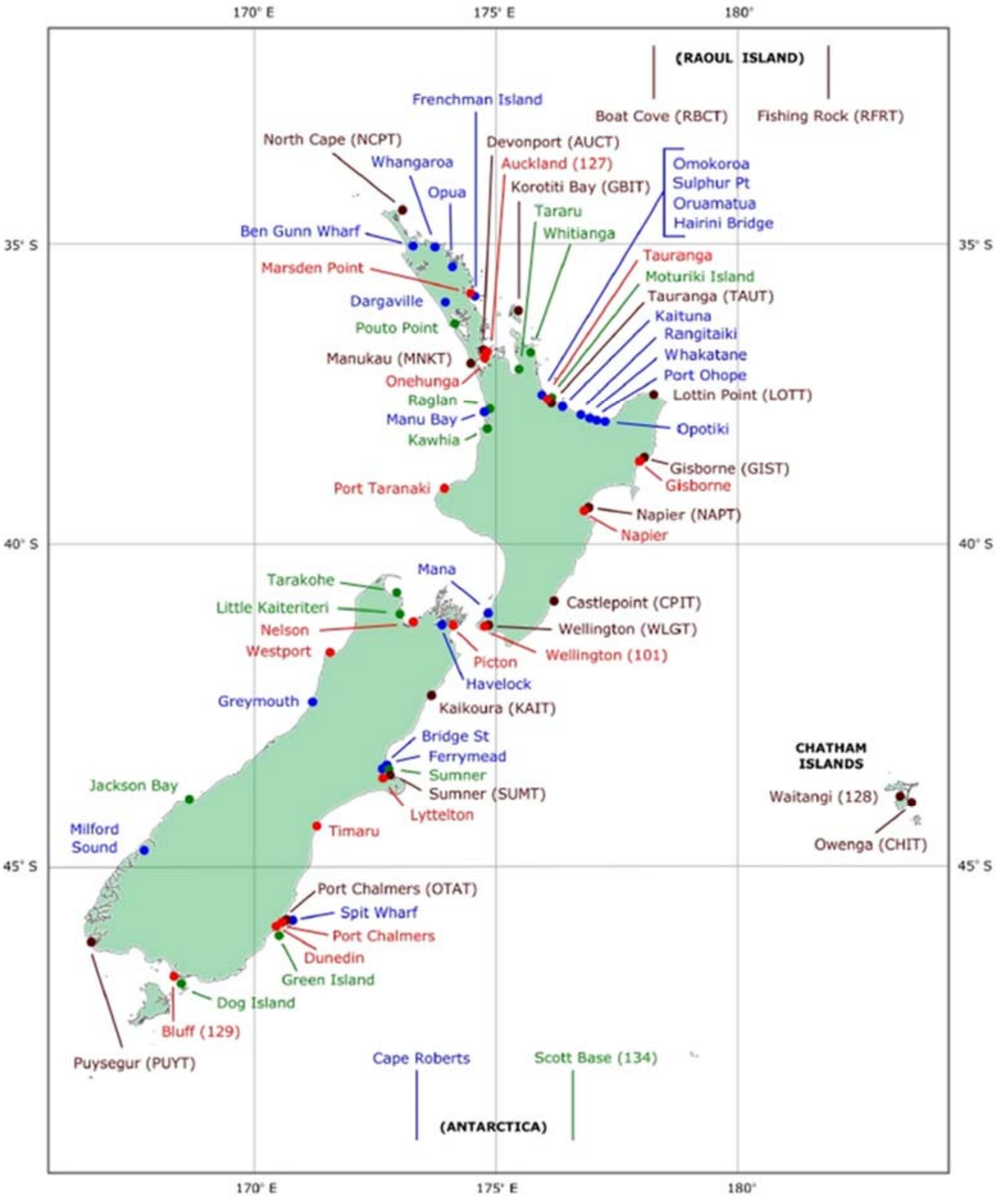

Figure 1: Coastal, port and estuarine sea-level gauges in New Zealand in 2013. Major port sites (red), open coast sites (green), tsunami monitoring sites (brown), and other sites (blue). [*Source*: National Report for New Zealand for GLOSS (IOC) by Rowe & Bell (2013)]

3.1.3 Candidate indicators

Two sets of indicators could be produced:

- Relative annual MSL for each location where sea-level is measured; and
- New Zealand-wide average based on the annual MSL values from each coastal measurement station.

Initially, only the first indicator is assessed as it can be made available quickly (within a year). The second candidate indicator is likely to take a few years to make available. Important considerations when defining an Ocean Tier 1 indicator for sea-level include: (1) which coastal measurement stations to use; (2) whether to use absolute or relative (to the land) sea-level; and (3) the baseline period to which the annual MSL is tied to in order to convert it into a meaningful anomaly or above a recognisable datum.

While there are currently around 70 sea-level gauges operating in New Zealand (Figure 1), most have short records and stations are continuing to close, while new ones are being established. A record length of 30–50 years is required to definitively distinguish trends from natural climate variability (although that record length requirement will decrease as sea-level rise accelerates). The four main Standard Ports (Auckland, Wellington, Lyttelton, Dunedin) have records extending back to 1900. An additional six gauge sites (Whangarei – now Marsden Point, Mt Maunganui (Moturiki Is.), New Plymouth, Nelson, Timaru, Bluff) were analysed for trends in a recent paper by Hannah & Bell (2012), and go back to the 1930s to 1950s albeit with lengthy interrupted periods without measurements in most cases. Hannah & Bell (2012) show that such an interrupted record can be used to derive long-term sea-level trends. Long-term continuity of all these 10 sites is likely, with all but Moturiki (NIWA gauge) being operated by a significant port. Past measurements from these 10 sites have been made available to the Permanent Service for Mean Sea level (PSMSL) global database, which is maintained by National Oceanography Centre in Liverpool (UK), [14] on behalf of the UN GLOSS programme.[15] This database is the primary source of observations used worldwide to determine historic global-average trends in sea-level rise. Initially we propose that the Ocean Tier 1 indicator on sea-level be based only on measurements from the four sites with the longest uninterrupted record (main Standard Ports: Auckland, Wellington, Lyttelton, Dunedin), but this may be broadened to include the additional six gauge sites in the future.

Time series measurements of sea-level recorded by the gauges are typically recorded at 1 or 5 minute intervals, or in the case of the tsunami gauges operated by GeoNet under LINZ funding, at more than 10 samples per minute. Processes operating at a wide range of scales from seconds (wind waves) up to inter-decadal climate cycles and sea-level rise will all contribute to the final measured sea-level at any one time. “Relative mean sea-level” is therefore a processed quantity from an analysis of the time-series data to isolate the longer-period variation (more than a few days, especially tides) and determine monthly and annual averages.

Given that the MSL measure is relative to the land mass that the gauge sits on, estimation of the absolute change in sea-level requires an accurate registration of the gauge sensor with a survey datum via regular checks against two or three survey benchmarks. Detecting changes in mean sea-level requires very accurate sensors (less than ±3–5 mm) and regular checks on calibration, vertical datum and quality assurance of the data.

To enable a global comparison, the local rate of vertical land movement (mm/yr) must be removed from the MSL trend (mm/yr). All four Standard Ports in New Zealand have a co-located continuous GPS (cGPS) recorder operated by GeoNet with funding from LINZ, with other sites having cGPS recorders in reasonable proximity. These records cover a much shorter historic period of only the last decade, but the intention is to monitor land movement in the long-term (being particularly useful for assessing ground deformation from tectonic strain and volcanic activity). For the purposes of Ocean Tier 1 reporting, we propose that the vertical rate of land movement would not be removed from the sea-level measurements, i.e. relative MSL would be reported.

The third important consideration is the baseline period to which the annual MSL is tied. The International Panel on Climate Change (IPCC) 5th Assessment Report (2013) has tied the baseline (zero) period for their future projections of sea-level rise to measurements of MSL over the two-decade period 1986–2005. Alternatively, an earlier baseline could be considered or it could be tied to the New Zealand Vertical Datum 2009 at each gauge site, to make it more relevant to engineers, planners and local government. Initially, we would recommend using the period 1986–2005 as datum for consistency with IPCC.

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[14] http://www.psmsl.org/
[15] http://www.gloss-sealevel.org/

3.1.4 Assessment against Tier 1 principles and protocols

The relative mean sea-level indicator is assessed against key Tier 1 principles and protocols in Table 6.

Table 6: Relative mean sea-level: scoring the key criteria for selection.

Title:		Relative Mean sea-level
Brief description:		Sea-level relative to the land measured at four sites with the longest uninterrupted record: main Standard Ports: Auckland, Wellington, Lyttelton, Dunedin.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High.
	Business/financial relevance?	High. Direct relevance to financial and infrastructure implications of adaptation
	Government strategy/policy?	High. Of direct interest to local and central government.
	Scientific or intrinsic importance?	High.
	Will people be able to understand it?	Medium/high. Likely to be intuitively understood by public in general, but scientifically there is still the challenge of explaining variability in MSL vs long-term trend (some years the MSL will go down (e.g. El Niño episodes) – and even longer climate cycles e.g. Interdecadal Pacific Oscillation (20–30 yr cycle) will affect the trend (see Fig. 2). But provides an opportunity for public awareness on variability vs underlying upward trend.
Quality	Are base data reliable?	Medium/high. Would need more work to tighten up the specifications, maintenance and quality assurance of the data. Also most of the gauges are operated by various agencies, especially ports.
	Are base data open-access / freely available?	Medium. Some data are open-access, other sites could be made available, but data from one port (Auckland) must be purchased.
	Analyses robust? Does it “tell the story”?	Medium. Robust protocols needed for analyses – but it will tell the story.
	Similar overseas example?	High. Australia (CSIRO), University of Hawaii Sea-Level Center (global database), Permanent Service for MSL (UK) – global database for gauge sites which is used as basis for establishing global average sea-level rise.
Longevity	Will data still be collected in 5, 10, 20y?	High. Will become an essential measure as sea-level continues to rise and accelerate.

3.1.5 Recommended indicator(s) for Ocean Tier 1 statistic

We recommend that the relative mean sea-level indicator be included as an Ocean Tier 1 statistic (Table 7).

Table 7: Relative mean sea-level: recommended Ocean Tier 1 indicator.

Title:	Relative mean sea-level (MSL)
Brief description:	New Zealand-wide average annual MSL over 4 (or later 10) stations above an agreed baseline of vertical survey datum, plus supplying the historic equivalent from back-processing the historic annual MSL datasets.
Base data:	A 4-station series is available back to around 1900, but a wider 10-station series (using "continuous" digital data) would only apply back to the late 1970s or early 1980s.
Update frequency:	Initial suggestion would be to update annually (with a 3 month latency for analysis).
Meaning:	Provides a record of how mean sea-level is tracking, which has important implications for: (a) coastal hazard management, (b) survey and design levels for coastal infrastructure, (c) helps define the coastal marine area landward boundary (by anchoring the mean high water spring mark), and (d) informing climate-change adaptation, particularly when local tipping point sea-level thresholds are being approached or reached.
Summary method:	Sea-level is measured using coastal tide gauges and processed to extract the long-term signal from shorter-term variations due to weather, waves, and tides.
Technical method:	See text in Section 3.1.3 for technical description of method to produce recommended statistic.
Example picture	Figure 2

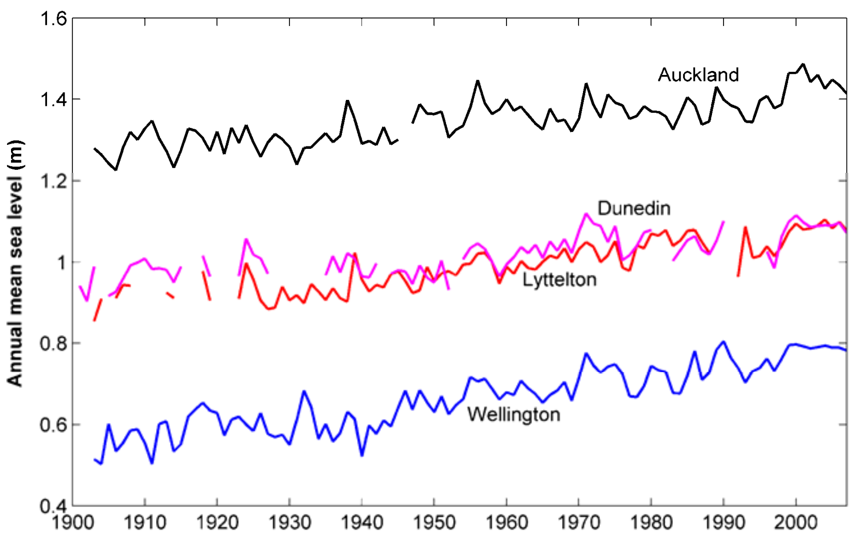

Figure 2: Example of sea-level component of Ocean Tier 1 statistic.

3.1.6 Future steps

The production of accurate MSL values and detection of trends requires a high level of commitment to producing good quality sea-level data. A number of different agencies (e.g. different port authorities) are responsible for different measurements that are then made available to LINZ and relevant science agencies. One of the issues to be addressed if a MSL statistic is included in an Ocean Tier 1 statistic is the reliability, quality and accessibility of sea-level measurements in the medium- to long-term. We consider the base data for MSL to be robust and fit for purpose (in the sense that a Tier 1 statistic based on these data would be scientifically valid), but work may be required to formalise this quality control. Also, as discussed previously, many of the sea-level stations are primarily operated by port companies, whose primary focus is on use of the sea-level data for immediate navigation purposes and on running a commercial enterprise. Currently, Ports of Auckland require payment by any agency requesting sea-level datasets, and stopped providing data to the PSMSL global database in 1998. This availability and cost of acquiring sea-level data from the Ports of Auckland will need to be considered as part of the design of the Ocean Tier 1 Statistic if selected.

In conclusion, we consider that annual relative MSL at several key sites (Ports of Auckland, Wellington, Lyttelton and Otago), with a New Zealand average, would provide an informative statistic, and preliminary work on this has already been completed (Hannah & Bell, 2012). Further work (estimated to be a few months work) would be required to bring the data handling and robustness of the analysis up to the standard required for regular reporting as a Tier 1 statistics. This would include developing automated and documented processes/protocols for:

- Measurement standards.
- Regular tie-back surveys to local benchmarks.
- Assessment of vertical land movement (cGPS network).
- Protocols for quality control on the measurements (gaps, glitches, drifting baselines).
- Protocols for processing the data for monthly and annual means (e.g., de-seasonalising, de-tiding the data).
- Latency of the measurements and subsequent processed MSL data.
- Reporting cycle.

3.2 Sea surface temperature

3.2.1 Scientific background

Ocean temperature is affected by climate variability (including cycles) and long-term change. Sea surface temperature (SST) is also scientifically important as it constitutes the bottom boundary condition for the atmosphere and so affects climate-ocean interactions. Changes to SST may affect New Zealand weather patterns and climate because of links between atmospheric and oceanic processes. Marine organisms, communities and ecosystems may be impacted in several important ways by ocean warming (e.g. Rijnsdorp et al., 2009; Hollowed et al., 2013). Changes in ocean temperature can lead to changes in biodiversity and ecosystem structure and function, and may have implications for the sustainability of fisheries (Kirby et al., 2009; Perry et al., 2010).

3.2.2 Base datasets

Sea-surface temperature from satellites

Sensors on satellites have been used to measure SST for several decades (Uddstrom & Oien 1999). Satellite SST data from NIWA have been published in SeaFood New Zealand and extensively used by commercial and recreational fishers throughout New Zealand and internationally. Satellite SST data can be downloaded from the US National Oceanic and Atmospheric Administration (NOAA). There are several products, including the 4 km pathfinder data set[16] which provides daily (or more frequent) data from about 1985, and is ongoing at the time of writing. The higher resolution (1.1 km) NIWA SST archive extends over the period January 1993 to the present and is derived from re-analysis of high resolution picture transmission (HRPT) data from NOAA and based on the Advanced Very High Resolution Radiometer (AVHRR) satellite sensor series (Uddstrom & Oien 1999). Sea surface temperature data at 1 km resolution are also obtained daily from overpasses of the NASA MODIS[17] sensors. There are two MODIS sensors, MODIS-Terra (2000 to later than 2014) and MODIS-Aqua (2002 to later than 2014).

Bulk water temperature

The most accurate measure of water temperature in the interior of the ocean (i.e. below the surface) is made using CTD (Conductivity Temperature Depth) instruments deployed from research vessels. The CTD is a fundamental oceanographic tool, and is deployed on almost all oceanographic research voyages to make temperature and salinity profiles down through the water column. This instrument measures temperature and salinity profiles through the water column with high accuracy. For example, the SeaBird[18] CTD sensor used on NIWA's *RV Tangaroa*, has a specified accuracy of ±0.001°C (traceable to international calibration standards) over the entire oceanographic range.

Measurements of water temperature at depth have also been made from CTD sensors attached to fisheries bottom trawls. The CTD sensors are similar in specification and design to those deployed from research vessels. These instrumented trawls have been used on trawl surveys of the Chatham Rise and elsewhere. This sampling potentially provides a consistent (same instrument used each time), high quality (the CTDs have regular scientific-quality calibration), large-area (by virtue of the stratified-survey nature of the deployments) and regular (approximately annual) time-series of temperature at depth.

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[16] http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/
[17] http://modis.gsfc.nasa.gov
[18] http://www.seabird.com/

Disadvantages of CTD data for an Ocean Tier 1 indicator are that the data only exist in particular areas, and that the locations of sampling vary between years. Instead of fixed stations (which are often used in oceanographic time-series), approximately the same number of stations are carried out in each fisheries stratum in each survey and the locations of the stations vary between years. The strata used in fisheries surveys on which CTD data are available have been chosen so that the abundance of the target fish species vary less within strata than between strata, consistent with the primary purpose of the survey to obtain an estimate of the abundance of the target species. It is possible that near-bed temperature is quite variable within each fisheries stratum, especially in a frontal area with large variations in water depth, like the Chatham Rise. Hence, variations in station locations between years within each stratum is likely to compromise the use of this dataset for detection/monitoring of long-term change.

Expendable bathythermographs (XBTs) have been deployed from ships traversing the Tasman Sea between New Zealand and Australia, starting in 1991 and ongoing at the time of writing (2014) (Sutton et al., 2005). XBTs are expendable instruments that are dropped from a vessel and used to measure the profile of temperature in the water column. The probe consists of a temperature sensor in a weighted, streamlined case. It falls freely at a fixed, known rate so that the elapsed time can be converted to depth. It is connected by a thin, freely unwinding wire to a small buoy with a radio transmitter through which the data are transmitted to the vessel, which continues its journey. These instruments have lower accuracy than temperature sensors on scientific-quality CTDs but can be deployed from ships of opportunity (e.g. container ships). The data from the Wellington-Sydney transect show that the eastern Tasman Sea warmed between 1996 and 2002, with this warming extending to the full depth of the sampled water column (i.e. to about 800 m). The in situ measurements of warming agreed with measurements from satellite sea surface temperature and sea surface height products (since the water expands as it warms leading to higher mean water levels).

Coastal water temperature

There are 11 sites at which coastal SST data have been recorded over an extended period. Nine of these are NIWA monitoring stations that have recorded temperatures over the last 20–30 years, just below low tide in 1–2 m of water. Many of these have been automated in recent years and the frequency of data recording has changed from about daily to several hours. The other two are university marine stations that have the longest records of coastal SST in New Zealand: Portobello, in Otago Harbour since 1953, and Leigh, north of Auckland since 1967 (data courtesy of Portobello Marine Laboratory, University of Otago and Leigh Marine Laboratory, University of Auckland, respectively). The locations of these monitoring sites are shown in Figure 3. Monthly averages (where there are more than five observations) and annual running (i.e., 12 monthly) mean records are presented in Figure 4. Collection dates for the data series are shown in Table 8.

Table 8: **Coastal SST monitoring sites and periods sampled.**

Site	Date
Ahipara Bay, Northland (NIWA)	1991 – 2007
Leigh Marine Station (University of Auckland)	1967 –
Tauranga – Motoriki Island (NIWA)	1990 –
Napier (NIWA)	1977 – 2005
New Plymouth (NIWA)	1977 –
Wellington – Evans Bay (NIWA)	1981 –
Wellington – Lyall Bay (NIWA)	1982 – 2006
Lyttelton – Little Pigeon Bay (NIWA)	1978 –
Jacksons Bay (NIWA)	1991 –
Portobello Marine Station (University of Otago)	1953 –
Bluff (NIWA)	1978 – 1986, 1991 –1999

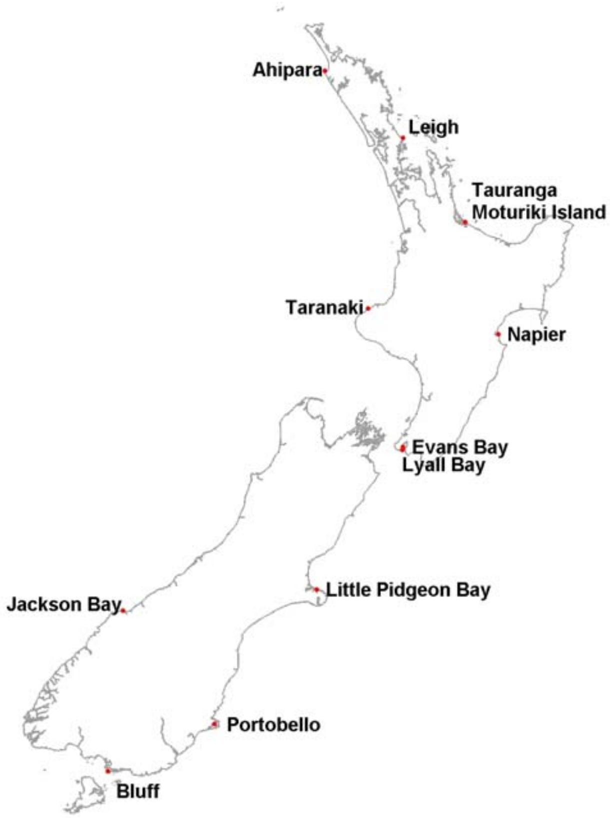

Figure 3: Location of coastal SST monitoring sites.

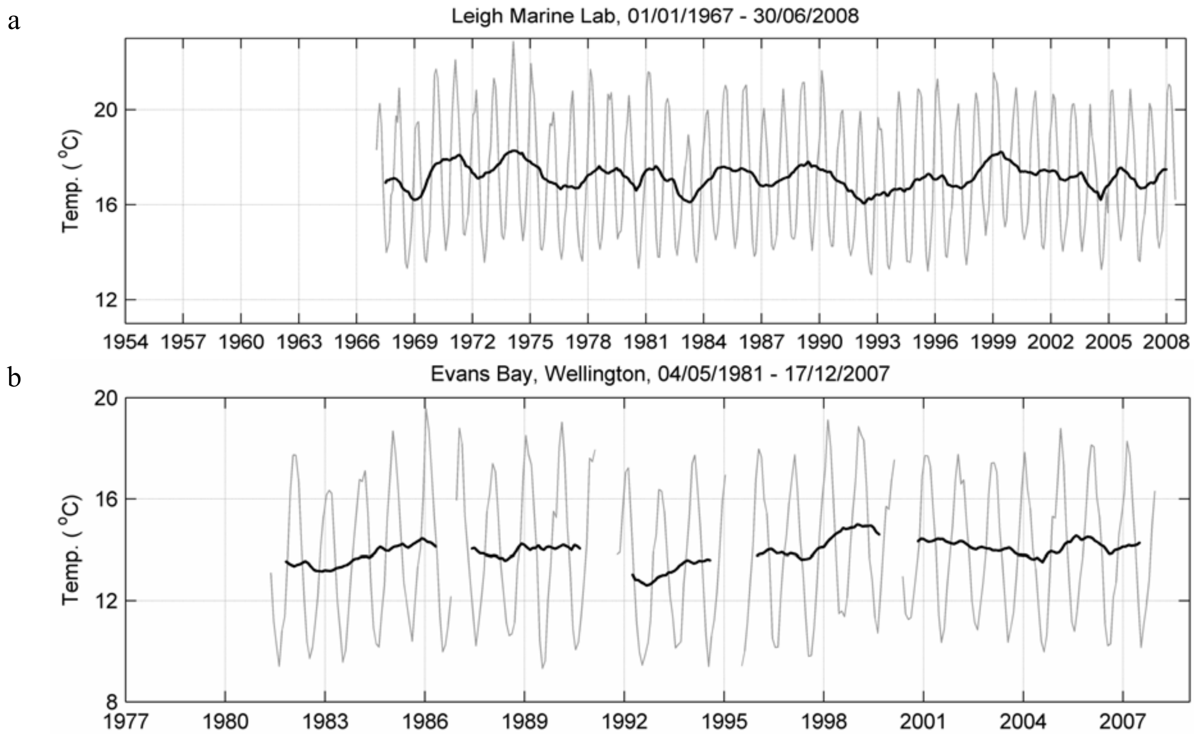

Figure 4: Example of two SST series from the 11 coastal monitoring sites. a: Leigh Marine Laboratory; b:Evans Bay, Wellington, showing seasonality in the temperature records and the low-pass (deseasonalised, 12-month running mean) trend lines.

3.2.3 Candidate indicators

Four candidate indicators are considered as part of an Ocean Tier 1 indicator: (1) sea surface temperature derived from satellite measurements; (2) bulk water temperature derived from measurements by profiled scientific equipment: conductivity-temperature-depth (CTD) sensor either from research vessels or attached to bottom trawls on fisheries surveys (especially Chatham Rise trawl surveys); (3) bulk water temperature derived from expendable bathythermographs (XBTs) deployed from ships of opportunity (transect across the Tasman Sea); and (4) coastal SST monitoring from 11 New Zealand sites.

In all four cases, the Tier 1 indicator would be a summary of the measurements for the last year (probably last calendar year). To provide context to help interpretation, it would be useful to provide information on the present year's data in comparison to the historical data from previous years. This would allow questions like "is it getting warmer?" to be addressed. We note that simply fitting linear trends to the existing data (even on a pixel-by-pixel basis) is not likely to be useful in this regard. Ocean temperature tends to vary in response to climate and other cycles, such as Interdecadal Pacific Oscillation (IPO), the Southern Oscillation Index (SOI) for El Niño-La Niña variations and the Antarctic Oscillation (or Southern Annular Mode, Southern Hemisphere Annular Mode). This means that the determination of a statistically significant trend, and the sense (increasing/decreasing) and magnitude of any trend, are highly dependent on the period over which the data were collected. An alternative to simple trend analysis would be spatial analysis methods akin to principal components analysis (PCA). Statistical techniques such as rotated empirical orthogonality function analysis (EOF) and PCA have become standard methods for the extraction of characteristic spatio-temporal patterns from such time-series of meteorological and oceanographic measurements (Preisendorfer 1988; Emery & Thomson 1997). As has been carried out elsewhere (e.g. Polovina & Howell 2005), combined and/or separate EOF analyses of satellite datasets including SST may be able to provide an indicator of oceanographic change in the New Zealand EEZ (Brierley & Kingsford 2009). The drawback of using

EOF, PCA or other spatio-temporal analysis methods is that the interpretability of the results by the public and other stakeholders is usually difficult.

As an alternative, it may be useful to simply compare the value of the indicator in the last year with the average of all historical measurements of the indicator. This would give an easily-understood measure of how the last year fits into the historical context without needing to assume any particular form of that relationship.

3.2.4 Assessment against Tier 1 principles and protocols

Four candidate indicators for ocean temperature are considered: (1) satellite SST (Table 9); (2) bulk water temperature derived from CTD sensors (Table 10); (3) bulk water temperature derived from XBTs on the transect across the Tasman Sea (Table 11); and (4) SST from 11 coastal monitoring sites (Table 12).

Table 9: Sea surface temperature from satellites: scoring the key criteria for selection.

Title:	Sea surface temperature	
Brief description:	Temperature of the surface ocean of the New Zealand EEZ from satellite measurements.	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High. Public likely to understand sea surface temperature (e.g. because of swimming at beach) so intuitive relevance.
	Business/economic relevance?	Medium/high. Changes to SST are likely to have economic implications. For example, changes to SST may be indicative of changes to bulk water temperature that may affect fisheries (including recruitment). SST and ocean productivity likely to be linked.
	Government strategy/policy?	Medium. No government strategies linked to SST at present but changes to SST are relevant to sea-level and extreme weather events.
	Scientific or intrinsic importance?	High. Monitoring SST is important to understand, monitor and predict ocean-climate feedbacks (the effect of ocean changes on the atmosphere and vice versa)
	Will people be able to understand it?	High. Maps of sea surface temperature likely to be easily understood by public.
Quality	Are base data reliable?	High. Considerable international effort into ensuring reliability and consistency of satellite measurements of SST. Measurement uncertainty (including sensor aging, algorithm performance) relatively high but can be characterised.
	Are base data open-access / freely available?	High. Data made available from satellite operators or via NIWA X-band satellite receiver.
	Analyses robust? Does it "tell the story"?	High. Likely to be well understood by public and other stakeholders. Clear message.
	Similar overseas example?	High. SST forms part of much environmental monitoring and indicators internationally.
Longevity	Will data still be collected in 5, 10, 20 y?	High. Commitment to long-term data collection for climate change research in US, Europe and Japan.

Table 10: Ocean water temperature: scoring the key criteria for selection.

Title:		Ocean water temperature
Brief description:		Temperature of water (with depth) in EEZ.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High
	Business/economic relevance?	Medium. Likely relation between some parts of ecosystem (including potentially fisheries) and water temperature, but the nature of these relationships are poorly understood.
	Government strategy/policy?	Medium. No government strategies linked to ocean temperature at present but changes to bulk water temperature are relevant to sea-level and extreme weather events.
	Scientific or intrinsic importance?	High. Related to heat storage by the ocean.
	Will people be able to understand it?	Medium. People are likely to understand ocean temperature but might not understand relevance.
Quality	Are base data reliable?	High. Profiling CTDs are regularly calibrated to high standard.
	Are base data open-access / freely available?	High. Data freely available but significant initial cost in upgrading how data are processed and subsequently managed according to Tier 1 standard.
	Analyses robust? Does it "tell the story"?	Medium/low. Combining non-systematic data into coherent picture may not be possible. Spatial and temporal aliasing may mean that data cannot be used as indicator of change. Some data only collected in relatively small part of EEZ (e.g. Chatham Rise trawl survey data covers about 5% of the area of the EEZ).
	Similar overseas example?	None known.
Longevity	Will data still be collected in 5, 10, 20y?	Likely yes.

Table 11: Tasman Sea temperature: scoring the key criteria for selection.

Title:		Tasman Sea temperature
Brief description:		Temperature of the Tasman Sea from expendable bathythermographs.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Medium. Relevance may be difficult to convey e.g. involving understanding the link between temperature in the Tasman Sea and the strength of the East Australia Current.
	Business/economic relevance?	Low/medium. May affect New Zealand climate, coastal water temperatures (by link with East Australia Current) or Challenger fisheries, but hard to quantify robust economic implications.
	Government strategy/policy?	Low/medium. Climate change effects on fisheries have been identified by MPI as being important, but implications of temperature change in the Tasman Sea on fisheries/biodiversity are hard to predict.
	Scientific or intrinsic importance?	High. Evidence of large-scale ocean change can help to understand links between climate forcing and ocean response in the southwest Pacific region
	Will people be able to understand it?	Medium. Simple to convey but relevance of any change may not be obvious.
Quality	Are base data reliable?	High. Good quality data and good sampling design.
	Are base data open-access / freely available?	High. Data available and some published (Sutton et al., 2005).
	Analyses robust? Does it "tell the story"?	Medium. Story clear but wider relevance to New Zealand not intuitive.
	Similar overseas example?	None.
Longevity	Will data still be collected in 5, 10, 20y?	Possible/likely but not guaranteed.

Table 12: Coastal temperature: scoring the key criteria for selection.

Title:	Coastal sea surface temperature	
Brief description:	Temperature of coastal surface waters measured in situ at 11 sites.	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Very high. Public likely to understand sea temperature at coastal sites (e.g. because of swimming at beach) so intuitive relevance. Coastal sites will be known to many people. Measurement method simple.
	Business/economic relevance?	Medium/low. Few direct/clear economic implications of changes to coastal SST. May be related to coastal productivity.
	Government strategy/policy?	Low. No known government or regional council strategies/policies linked to coastal SST at present.
	Scientific or intrinsic importance?	High. Of high scientific value for providing context to ecosystem change at highly-studied coastal sites (e.g. Leigh, Otago). Combined, the data provide direct picture of change in the New Zealand coastal zone.
	Will people be able to understand it?	Very high. Direct measurements of sea surface temperature at well-known coastal sites likely to be easily understood by public.
Quality	Are base data reliable?	High. Considerable effort invested in ensuring data are well calibrated.
	Are base data open-access / freely available?	High/medium. NIWA data available. Data from other sites requires agreement of Portobello Marine Laboratory (University of Otago) and Leigh Marine Laboratory, (University of Auckland).
	Analyses robust? Does it "tell the story"?	High/medium. Likely to be well understood by public and other stakeholders. Clear message. But, potential for changes in local hydrodynamics/land use to affect long-term relationship between SST measurements and climate change signal. For example, changes to river flow or building of coastal structures may alter currents and hence measurements of SST irrespective of climate change.
	Similar overseas example?	High. SST forms part of much environmental monitoring and indicators internationally.
Longevity	Will data still be collected in 5, 10, 20y?	High/medium. Commitment to long-term data collection by NIWA. Anticipated longevity of coastal SST data collection by universities of Otago and Auckland not known but likely to be very good as these long-term datasets are recognised as being scientifically valuable.

3.2.5 Recommended indicator(s) for Ocean Tier 1 statistic

Two Tier 1 statistics based on temperature are recommended: (1) first priority: satellite SST indicator (Table 13); and (2) second priority: coastal SST (Table 14). The first recommended indicator has several strong attributes: the base data are collected over all of the New Zealand EEZ; data have been consistently collected over a long period (more than 60 years in one case) and are very likely to continue to be in the medium- to long-term; the concept of change in the temperature of the ocean surface is intuitive and likely to be of broad interest to the public, and is of high scientific value.

Table 13: Sea-surface temperature from satellite: recommended Ocean Tier 1 indicator.

Title:	Sea-surface temperature from satellite
Brief description:	Part 1: Average temperature in the previous year Part 2: Climatological anomaly - difference between last year's SST and average of all previous measurements.
Base data:	Satellite measurements of SST in New Zealand EEZ
Update frequency:	Annual
Meaning:	The temperature of the upper part of the ocean is affected by climate and oceanographic drivers. Water temperature affects all parts of the ecosystem living there, including primary producers and fish.
Summary method:	A series of satellites operated by the US agency NOAA measures infra-red light at the top of the atmosphere. Data from these satellites are used this to infer the temperature of the New Zealand ocean surface.
Technical method:	Since January 1993, NIWA has archived all data received from NOAA series satellites. The Advanced Very High Resolution Radiometer (AVHRR) instrument on board these satellites senses radiation with a spatial resolution of the data at the surface of 1 km. In the infrared the AVHRR measures thermal radiation emitted by the Earth's surface, atmospheric water vapour and clouds, while in the visible, it measures reflected (solar) radiation. These data may be used to retrieve estimates of sea surface temperature (SST) over cloud free regions. The data used in this analysis, the NIWA SST Archive (NSA), have been derived using a Bayesian cloud detection algorithm and non-linear SST retrieval algorithm, with each orbit's data being remapped onto a Lambert Conformal map projection having 1 km resolution pixels. These data in turn have been temporally composited in order to estimate the monthly mean SST at each location on the map grid. Depending on the number of satellites available, and the cloud cover encountered, the SST at any point could be computed from as many as 300 or more individual observations. For full details of the methods used, see Uddstrom & Oien (1999) and Uddstrom et al. (1999).
Example picture	Figure 5

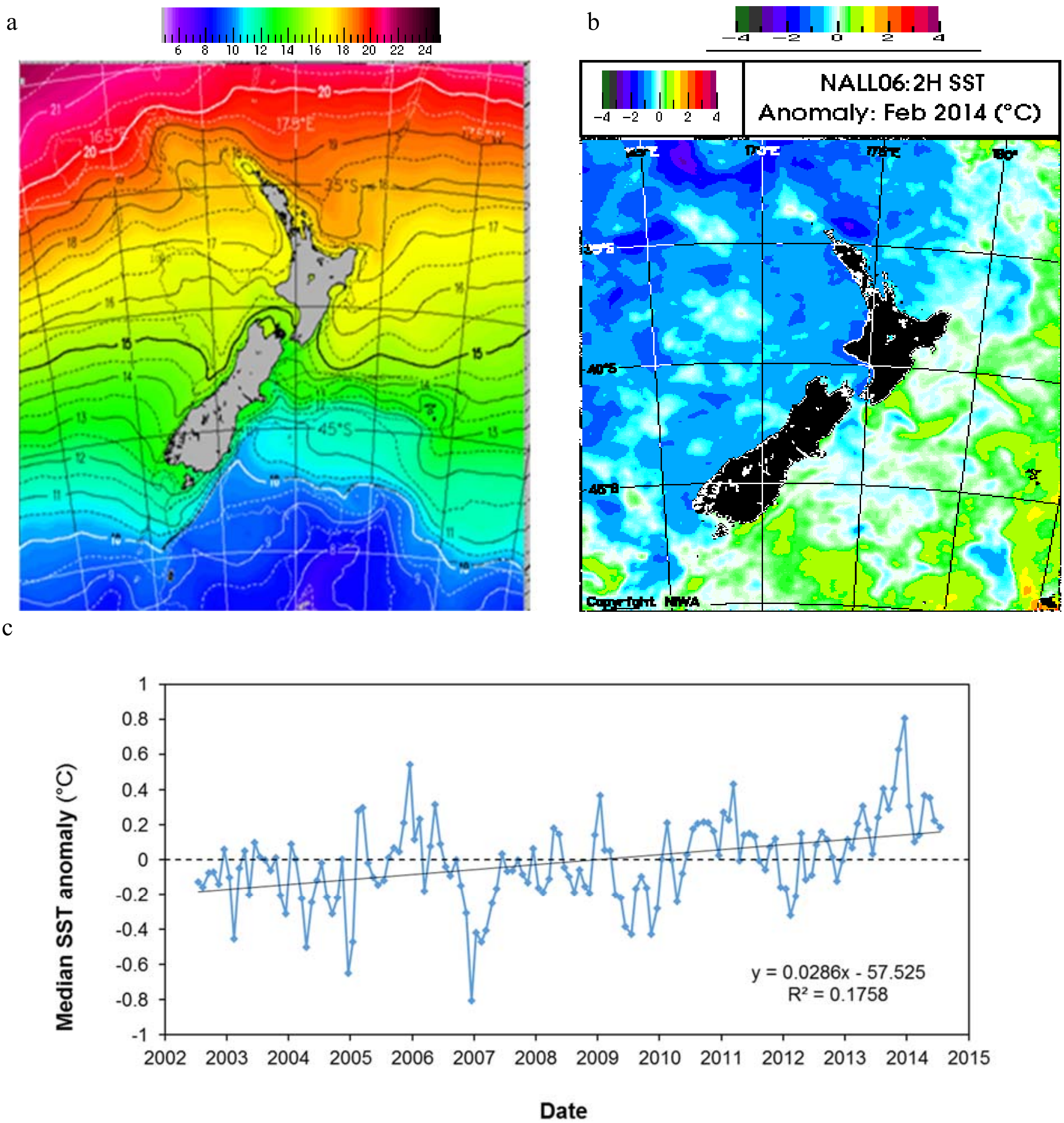

Figure 5: Example of Sea Surface Temperature component of Ocean Tier 1 statistic. a: Average sea-surface temperature in previous year; b: Climatological anomaly - difference between last year's temperature and average (or median) of all previous measurements; c: deseasonlised monthly anomaly for period 2002 – 2014 based on MODIS-Aqua SST data averaged across the EEZ. The regression line and equation are also shown.

Table 14: Coastal sea-surface temperature at 11 sites: recommended Ocean Tier 1 indicator

Title:	Coastal sea-surface temperature at 11 sites
Brief description:	Sea surface temperature measured at 11 coastal sites across New Zealand.
Base data:	NIWA coastal SST measurements and from Portobello Marine Laboratory, University of Otago and Leigh Marine Laboratory, University of Auckland.
Update frequency:	Annual
Meaning:	The surface temperature of coastal waters are affected by climate and oceanographic drivers, as well as local changes to currents and river outflows. Water temperature will affect coastal ecosystems, productivity and human use.
Summary method:	Coastal sea surface temperature from 11 sites round New Zealand: (1) Ahipara Bay, Northland; (2) Leigh Marine Station; (3) Tauranga – Motoriki Island; (4) Napier; (5) New Plymouth; (6) Wellington – Evans Bay; (7) Wellington – Lyall Bay; (8) Lyttelton – Little Pigeon Bay; (9) Jacksons Bay (West Coast South Island); (10) Portobello Marine Station; (11) Bluff.
Technical method:	Coastal sea surface temperature from 11 sites (9 NIWA, Portobello Marine Laboratory, Leigh Marine Laboratory). Data recorded just below low tide in 1–2 m of water. Monthly averages (where there are more than 5 observations) and annual (12 month) running means calculated to show trends.
Example picture	Figure 6

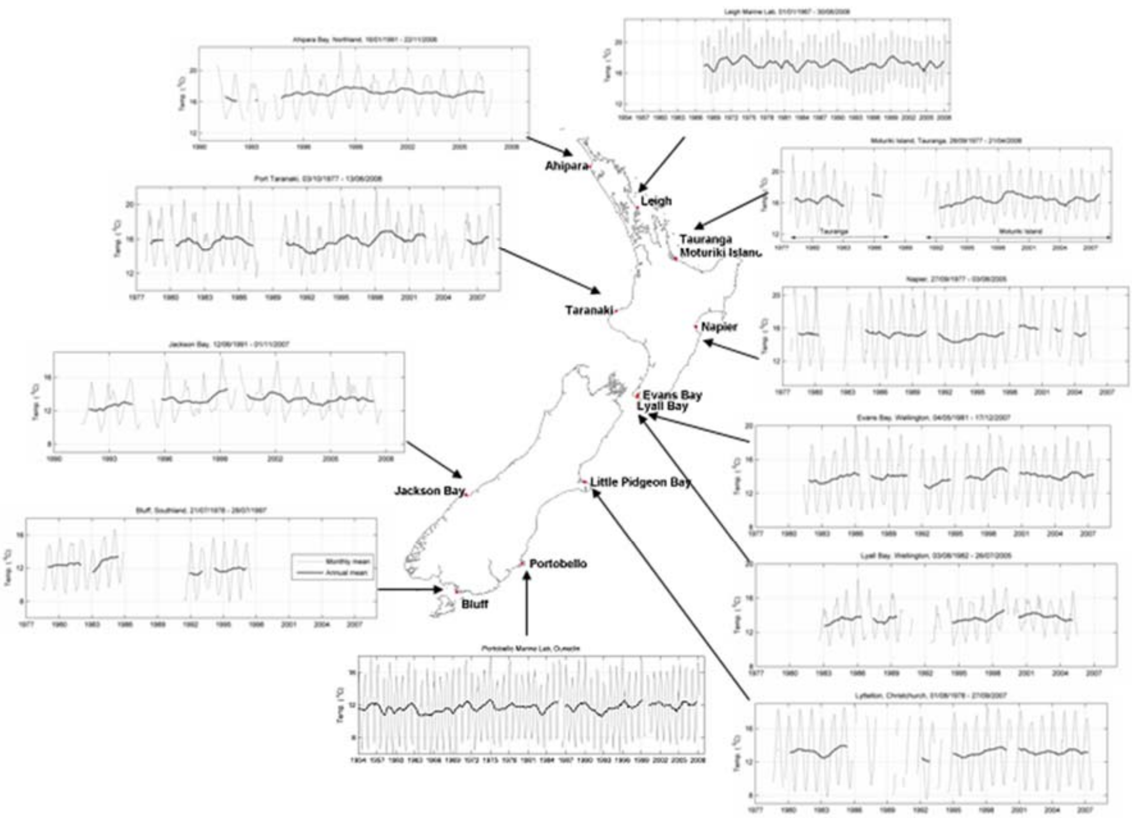

Figure 6: Example of coastal sea surface temperature statistic, showing 11 time-series from monitoring stations. Sections of the time-series could be colour-coded to show high (warm) and low (cold) periods (the methodology for this would have to be determined).

3.2.6 Future steps

Satellite SST statistic

- At present, AVHRR data provides the longest and most consistent set of satellite measurements of SST so we would recommend that this data source be used first. In the future, it may be useful to merge SST data from the MODIS sensors with AVHRR data to increase temporal coverage.

  A considerable quantity of CTD measurements of ocean temperature exist in New Zealand waters. These data could be used to validate the satellite SST product.

Coastal SST statistic

- The anticipated longevity of coastal SST data collection by NIWA, University of Otago and Auckland should be confirmed.
- Local changes that may have affected the integrity (consistency) of data series from each of the coastal time-series stations should be investigated if this recommended statistic is selected. For example, changes to coastal morphology (e.g. building sea-defence structures such as sea-walls; construction of marinas; sedimentation, dredging) could affect coastal dynamics and may hence affect the temperature as measured in a particular location. It is important to determine whether such changes are likely before interpreting changes in coastal SST measurements.

3.3 Ocean circulation / water masses

3.3.1 Scientific background

Changes in ocean circulation and water masses around New Zealand are relevant as indicators of large-scale change occurring in the marine system. It is likely that changes observed can only be meaningfully interpreted at the typical oceanic time scales (decades). Ocean circulation is not "directly" observed, but rather derived from satellite measurements (via sea surface height, SSH), from data assimilating models (which may use a variety of data sources) and from autonomous floating drifters (e.g. the Global Drifter Program, GDP[19]). Satellite-observed SSH anomalies are referenced to long-term mean absolute height to produce total SSH from which circulation can be derived. Data assimilating models produce so-called "ocean analysis" model fields that combine real-time observations with models to produce a best-fit "state estimate". Autonomous floating drifters include: (1) the surface floats of the GDP, and (2) Argo[20] floats (which drift near the surface and at 1000 meters below the surface). Autonomous floating Argo drifters produce long-term mean flows at these two depths (surface and 1000 m) and measurements of water properties (temperature and salinity) to 2000 m below the surface, although this has statistically low power to detect variability and change due to the limited number of samples. The spatial scales at which such ocean circulation can be constructed is typically upwards of 50 km or so, hence at "oceanic" scales at present.

Water masses are generally not sampled routinely (either in time or space), although the fleet of profiling Argo floats with their expanding sensor technology are helping to fill that gap. At present, Argo floats routinely measure conductivity, temperature and depth and use these to estimate salinity. Ship-based in situ measurements remain valuable but expensive, and typically provide for detailed repeat measurements at typical climate time-scales of decades. Satellite measurements of sea surface temperature (SST) (see Section 3.2) can also be used to monitor and understand changes to ocean circulation.

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[19] http://www.aoml.noaa.gov/phod/dac/index.php
[20] http://www.argo.ucsd.edu/

Ocean gliders (autonomous, mobile, underwater sampling platforms) are also an emerging technology for measuring a variety of ocean properties (for instance, see the efforts of the Integrated Marine Observing System (IMOS) network in Australia), but they only provide small-scale detail at the local coastal scale (so will be relevant for routine measures of local change) or intermittently at the larger scale. As with Argo floats, the glider's sensor packages are evolving to provide a wide range of oceanic and biogeochemical observations (such as dissolved oxygen concentration) that will allow for detailed inspection of potential changes in the water properties and quality.

For New Zealand, detecting changes in ocean properties that are related to climate from relatively sparse sampling over relatively short time-scales is complicated by the fact that events on seasonal timescales such as ENSO introduce a large natural variability signal. This high natural variability in ocean properties can mask any signal of significant climate-related change.

3.3.2 Base datasets

Reliable satellite measurements of SSH go back to around 1993; however the absolute SSH (and hence the measure of the complete circulation pattern) requires either: (1) a knowledge of the shape of the geoid – the sea-level if the ocean was not moving – or (2) the generation of a long-term mean that necessarily accounts for natural variability such as ENSO. Research to establish the true geoid is on-going internationally via the Grace program[21]. There seems to be international commitment to on-going satellite observing over the medium- to long-term (i.e. more than 10 years from present), so that SSH may well be a good basis for founding a measure of long-term change in New Zealand ocean circulation.

The GDP drifters have been reporting since the mid-1990s, and the Argo floats since the early 2000s, but significant numbers of both have only been attained since 2005 or so. Further, the GDP drifters and Argo floats are at the mercy of the oceanic currents (as designed), which means that the data density is not as uniform in space as would be preferable. This means that observations of oceanic circulation based on these platforms are inherently limited by the relative lack of data points in some areas. For example, there will be fewer profiles of water properties collected in shallow waters (less than 2000 m deep) and in areas of flow divergence than elsewhere. The emergence in particular of Argo floats has made the generation of ocean model analysis fields (see below) more robust; nevertheless, the oceanic domain remains relatively under-sampled for the scales of interest, and the deep ocean below 2000 m depths is not routinely observed at all. This gap is being addressed through the development of "Deep Argo" (which profile to 6000 m rather than 2000 m) especially for climate analysis of the global heat content. Given these developments, and how much the GDP drifters and Argo floats underpin analysis and data assimilation, their on-going future looks assured.

Sea-based (in situ) measurements of ocean circulation in the New Zealand region extend back further in time, but are typically scattered in time and space. Repeated sampling on pre-set stations was developed by the World Ocean Circulation Experiment (WOCE[22]) to measure change in ocean circulation over periods of decades or so. Given the relative expense of ship-based voyages to re-sample the WOCE stations on a routine basis, it is perhaps more likely that data from Argo will provide the future platform for measuring changes to ocean structure and circulation.

Relatively high resolution analyses of ocean circulation have been around since the early 2000s. For example:

- ECCO (Estimating the Climate and Circulation of the Ocean[23]) was established in 1998 as part of WOCE with the goal of combining a general circulation model (GCM) with diverse

[21] http://earthobservatory.nasa.gov/Features/GRACE/page3.php
[22] http://www.nodc.noaa.gov/woce/
[23] http://www.ecco-group.org/index.htm

observations in order to produce a quantitative depiction of the time-evolving global ocean state;

- SOSE (Southern Ocean State Estimate) is a high resolution version of ECCO for the region south of 24°S.
- GODAE (Global Ocean Data Assimilation Experiment[24]) is a practical demonstration of near-real-time, global ocean data assimilation that provides regular and complete descriptions of the temperature, salinity and velocity structures of the ocean in support of operational oceanography, seasonal-to-decadal climate forecasts and analyses, and oceanographic research;
- GOOS (Global Ocean Observing System[25]) is a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide.
- Bluelink[26] is an Australian ocean modelling and analysis tool used for accurately forecasting ocean conditions in the region around Australia (and including the New Zealand EEZ).

The accuracy of these products relies both on the data density of the observing network itself (above) as well as the quality of the model used to assimilate the observed data. The analysis models represent our best synoptic estimate of ocean state (water mass and circulation). To that end they represent a powerful tool for synthesising all the measurements with the dynamics of a model. Their relative success relies on on-going data assimilation and model improvements allied to computing infrastructure, and the critical maintenance of data-dense observations so that the highest possible spatial and temporal resolution model analyses can be generated. The likelihood then of on-going oceanic observing suggests that the model analyses will continue for more than a decade hence.

3.3.3 Candidate indicators

Absolute SSH and mean flow patterns could be deduced from the satellite altimetry products. These flow patterns could be compared to the long-term (since 1993) estimates to investigate changes to circulation, including variability, cycles and long-term trends (Table 15).

The GDP drifters and Argo floats could be used to provide, for example, monthly mean circulation patterns at the surface and at 1000 metres depth, respectively, from which changes could be considered over the recorded period (as for SSH). As noted, the limitations of these datasets are the relatively short historical period of the records (since about 2005) and the relative paucity of observations themselves.

A more useful approach could be to use the in situ observations of temperature and salinity from the Argo floats to build up monthly maps of these ocean properties between the surface and a depth of 2000 metres for the New Zealand region. These maps could then be used to produce anomalies (compared to an underlying mean) to indicate potential significant change occurring in the oceanic system. Finally, and perhaps almost certainly for the future, combining in situ measurements, satellite observations and ocean circulation models together using an assimilating model will provide for the most complete picture of oceanic circulation and properties. Such data assimilation into circulation models is presently used on a climatic time-scale (e.g. decades) to look at changes in the large scale oceanic system. However, it is possible that future model-data products will be output more regularly and at spatial resolutions that are useful at the regional (New Zealand) scale.

[24] http://www.usgodae.org/
[25] http://www.ioc-goos.org/
[26] http://www.csiro.au/Outcomes/Oceans/Oceans-and-climate/BLUElink.aspx

3.3.4 Assessment against Tier 1 principles and protocols

Table 15: Water-masses candidate Ocean Tier 1 indicator: scoring the key criteria for selection.

Title:	Water masses / circulation	
Brief description:	At present, based on historical data and data availability, absolute SSH for ocean circulation patterns.	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Medium/low. There may be general interest in large-scale changes to water circulation round New Zealand, but many may not understand it
	Business/economic relevance?	Medium/low. Direct economic relevance may be difficult to establish.
	Government strategy/policy?	Medium/low. No Government policies related to oceanic circulation known.
	Scientific or intrinsic importance?	High. Circulation and water masses affect ocean ecosystems (for example by affecting the mixing of nutrients into surface waters), biogeochemical cycling, ocean productivity and feedback links to weather/climate processes.
	Will people be able to understand it? no	Low. Effort will be required to present the information in a way that can be easily understood.
Quality	Are base data reliable?	High. Data sourced from international programmes with long-term commitment to data quality.
	Are base data open-access / freely available?	High. Data sourced from international programmes with open access principles.
	Analyses robust? Does it "tell the story"?	Medium. Synthesizing the data into a clear picture of changes to water masses or ocean circulation in the New Zealand region may be difficult. The relationship between changes to water masses/circulation and climate drivers are not scientifically clear.
	Similar overseas example?	High/medium. Monitoring of circulation and water masses is part of international science programmes but less so in terms of use as Tier 1 indicators.
Longevity	Will data still be collected in 5, 10, 20y?	High. Long-term data collection key priority for international programmes.

3.3.5 Recommended indicator(s) for Ocean Tier 1 statistic

The recommended indicator for changes in water/masses circulation is given in Table 16.

Table 16: Water masses/circulation: recommended Ocean Tier 1 indicator.

Title:	Water masses / circulation
Brief description:	Absolute SSH for ocean circulation. Would provide monthly maps, say, of changes in the SSH pattern and hence its influence on the circulation.
Base data:	Satellite sea surface height (altimetry) 1993 to the present.
Update frequency:	Annual (base data updated monthly)
Meaning:	The absolute SSH and variability will indicate large scale changes to water masses and ocean circulation in the NZ region. These changes may have ecosystem implications. For example, El Niño appeared to be associated with an extension in the range of the Chilean jack mackerel into New Zealand waters in the mid-1980s (Taylor, 2002), and this species now dominates the jack mackerel fishery in some areas.
Summary method:	Satellite SSH anomalies from international research programme.
Technical method:	Compare the monthly mean SSH anomalies and changes to the long-term record and produce map(s) detailing changes of significance as indicators of potential change occurring in the dynamical system.
Example picture	Figure 7

3.3.6 Future steps

The routine download and analysis of the SSH products already occurs. This is likely to continue in the foreseeable future as the production of the SSH outputs is critical to global assimilation and forecast centres. The final step would be the production of an anomaly map, or selected changes to key circulation/water-mass features. A brief narrative providing interpretation of significance and the impact of potential change implied, would be required to help the public and stakeholders understand the information.

In the longer term we would envisage that high resolution oceanic "re-analysis" products would provide the next-best way to compile the present "state of the ocean" in terms of combining both data and model dynamics in a complete synthesis. For example, flows at all depths would be available, supplementing those that are presently proposed based on the SSH product. Such analysis products should be considered for use in environmental reporting when their spatial resolution improves (down to about 10 kilometres or less), and they are more routinely and reliably used in state of the ocean analyses internationally.

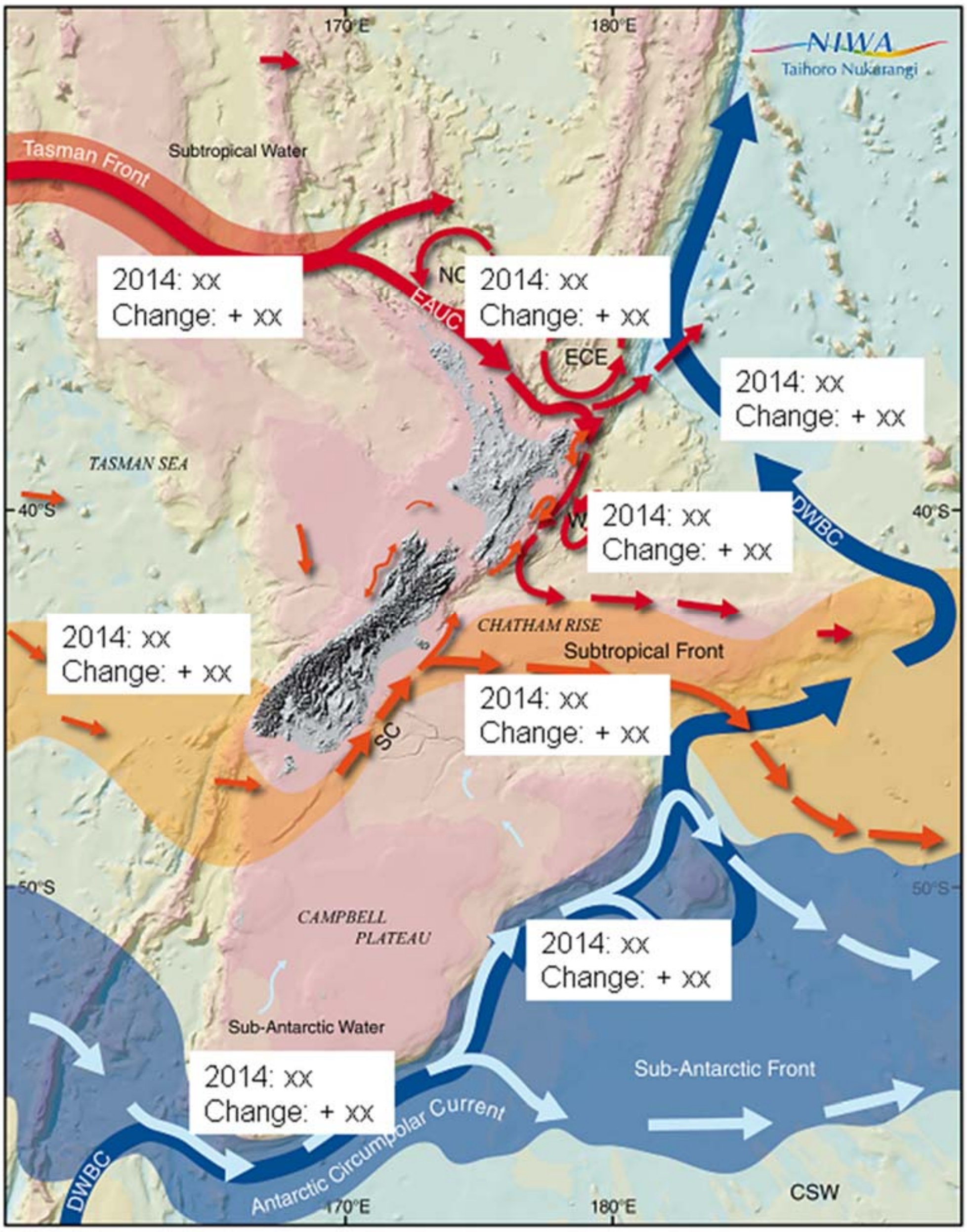

Figure 7: Example of water masses / circulation component of Ocean Tier 1 statistic. The base diagram shows the schematic ocean circulation and water mass frontal systems in the New Zealand region. Superimposed on this (white boxes) could be key indicators of conditions over the last year and changes from "normal" (mean of conditions since measurement began). The Tasman Front (TF), the Subtropical Front (STF) and the Subantarctic Front (SAF) approach New Zealand from the west. The STF represents the meeting of Subtropical Water (STW) and Subantarctic Water (SAW), while the SAF is formed by the meeting of SAW and Circumpolar Surface Water (CSW). The fronts contain or generate currents and there are several permanent eddies off the eastern North Island: (EAUC, East Auckland Current; WAUC, West Auckland Current; ECC, East Cape Current; DC, D'Urville Current; WC, Westland Current; SC, Southland Current; ACC, Antarctic Circumpolar Current; NCE, North Cape Eddy; ECE, East Cape Eddy; WE, Wairarapa Eddy). There are also areas of strong tidal mixing in Foveaux Strait between Stewart Island and the South Island, in Cook Strait between the North and South islands, and north of Cape Reinga.

3.4 Ocean Primary Productivity

3.4.1 Scientific background

The growth of phytoplankton in the upper layers of the ocean provides the vast majority of the energy that fuels biological productivity in most marine ecosystems. Photosynthesis is the process by which plants and marine algae (including phytoplankton) use the energy in sunlight to produce organic material. The organic material formed by phytoplankton is available for consumption by the heterotrophic community (including via the detrital and bacterial pathways), and ultimately supports fisheries, marine mammals and seabirds. We refer to this available energy flow as net primary production (NPP, units of mgC m^{-2} d^{-1}). "Net production" is the production after respiration by phytoplankton. Monitoring for changes in the magnitude and patterns of NPP in the New Zealand EEZ is likely to provide valuable context for understanding change in fisheries, changes to New Zealand marine biogeochemistry and climate-related changes to ocean productivity. In the context of Tier 1 statistics, marine primary productivity could be monitored either in terms of phytoplankton biomass or estimates of the actual rate of NPP.

3.4.2 Base datasets

Phytoplankton biomass

Phytoplankton biomass is often quantified in terms of the mass of organic carbon in a column of water from the surface to the seabed, or a specified depth in the water column; this is called "vertically integrated" biomass (units of gC m^{-2}). This can be measured accurately (within a few percent) from laboratory measurements of water samples collected from various depths on research voyages. As phytoplankton biomass varies substantially over very large ranges of time (minutes to decades) and space (centimetres to thousands of kilometres), in situ measurements are not able to quantify phytoplankton biomass at the scale of the New Zealand EEZ or monitor for change at annual or longer scales. Instead, phytoplankton biomass is often monitored via the proxy of the concentration of chlorophyll-a (chl-a) as measured by ocean colour satellite remote sensing. The chlorophyll-a pigment is ubiquitous in marine phytoplankton and its concentration is related to the biomass and growth potential of the whole phytoplankton assemblage over medium to large spatial and temporal scales such as the New Zealand EEZ over an annual period (Hawes et al., 1997; Murphy et al., 2001; Gall & Zeldis, 2011).

Satellite measurements of ocean colour provide an acceptable estimate of the concentration of chl-a in the surface ocean (Hooker et al. 1992; Murphy et al., 2001). The satellite-based method of observing, characterising and monitoring phytoplankton biomass has become standard for management and research purposes at moderate to large spatial and temporal scales (tens to thousands of kilometres; weeks to decades). The accuracy of the satellite based method (typically a target accuracy of within 35%) is much less than in situ methods, and data from research voyages have been used to show that this target accuracy is generally being achieved in the offshore New Zealand region but not near the coast (Pinkerton et al. 2005). Some opportunistic and dedicated validation data already exists, but future data collection will be necessary to ensure that satellite measurements of chl-a are suitable for quantifying long-term variability and change in phytoplankton biomass in the EEZ. For example, changes to the dominant functional groups of phytoplankton in different areas at different times of the year may make it harder to interpret changes in chl-a estimated from ocean colour sensors (Dierssen, 2010).

More than 16 years (1997–present) of satellite measurements of ocean colour are currently available. Two ocean colour satellite sensors are used most often: OrbImage Sea Viewing Wide Field-of-view Sensor (SeaWiFS) covering September 1997 to 2010; and the NASA Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua), providing data from July 2002 to present. Earlier measurements of ocean colour (e.g. the Coastal Zone Color Scanner, 1979–1986; MODIS-Terra sensor, operational from 2000) are probably not of sufficient quality to extend the time-series of measurements back beyond

1997. In the New Zealand region, SeaWiFS data have a spatial resolution of 4 km and MODIS-Aqua data have a 1 km resolution. For open ocean regions, 4 km spatial resolution is adequate for monitoring for changes in ocean productivity. However, for coastal regions such as the Hauraki Gulf, ocean colour data at better than 1 km spatial resolution is appropriate for monitoring.

Satellite ocean colour data availability is limited by cloud cover and solar elevation. In the New Zealand region, typically only 10–30% of images are cloud-free, depending on location and season. The long-term mean based on satellite data can be biased if the property observed is correlated with the probability of observation. This effect is generally assumed to be insignificant. Ocean colour data availability in New Zealand subantarctic waters during the winter is limited by solar elevation, i.e. the sun is so low in the sky when the satellite is overhead that there is not enough light leaving the water to allow a reliable measurement of ocean colour. These data gaps can be accommodated by excluding periods where no data are available and by considering subregions separately.

Phytoplankton primary production

Light, temperature, and nutrient concentrations are major factors controlling phytoplankton growth rates, community structure, and primary production in the surface mixed layer of the ocean (Parsons et al. 1977). Net primary production can be measured accurately from ships (typically using radioactive carbon incubations), but, as for chl-a, because of the high spatial and temporal variability, ship-based sampling cannot adequately observe NPP at scales appropriate to the size of the New Zealand EEZ. Instead, remotely-sensed data from Earth-observing satellite sensors are typically used to estimate NPP at basin scales. There are many different methods of estimating NPP from satellite data, and these differ by a factor of more than 2 (Campbell et al. 2002). It is not yet known whether any of these satellite estimates of NPP bracket the true value in the New Zealand region (Schwarz et al. 2008).

The original empirical models of NPP (e.g., Platt 1986) have been superseded by simple mechanistic models based on three factors:

- phytoplankton biomass, usually estimated via the proxy of chl-a obtained from ocean colour satellite sensors;
- average light intensity for phytoplankton, which is affected by the intensity of incident light at the sea-surface and the depth to which phytoplankton mix in the surface ocean. Light availability for phytoplankton is usually estimated using four interlinked models: (1) model of light at the sea surface (downwelling cosine irradiance at wavelengths 400–700 nm) using measurements of cloud reflectivity from ocean colour satellite sensors and a knowledge of solar and viewing geometry; (2) model of light penetration through wave-roughened sea surface; (3) effect of phytoplankton and other coloured material in the water column on downwelling light attenuation (the rate at which the intensity of light decreases with depth); and (4) model of mixed layer depth (e.g. CSIRO Atlas of Regional Seas, CARS2000) (Condie & Dunn, 2006); and
- yield function which incorporates the physiological response of the phytoplankton to light, nutrients, temperature and other environmental variables such as temperature, macro and micronutrient availability, and phytoplankton photo-physiology (e.g. functional groups of phytoplankton present, adaptations to light availability). Phytoplankton physiology accounts for a large proportion (probably the majority) of variability in measured NPP in the ocean, but is poorly measured remotely and is likely to vary at relatively small time and space scales. In the absence of other information at appropriate scales, remotely-sensed sea surface temperature (SST) is often used to parameterise this yield function.

A range of such modelling approaches exist (e.g., Platt & Sathyendranath, 1993; Antoine & Morel 1996a, 1996b; Behrenfeld & Falkowski, 1997b; Westberry et al. 2008). The various NPP algorithms based on chl-a have different methods of integrating over depth and irradiance, and have different ways of estimating the photosynthetic yield function (Behrenfeld & Falkowski 1997a). The main methods based on chl-a are: (1) Standard-Vertically Generalized Production Model algorithm (VGPM) (Behrenfeld & Falkowski 1997a); and (2) Eppley-VGPM algorithm. This model differs from the

Standard VGPM only in the use of an exponential temperature-dependent description of photosynthetic efficiencies (Eppley 1972). A relatively recent new approach to NPP modelling is based on satellite-observed carbon rather than chlorophyll. This method takes advantage of recent developments in inherent optical property (IOP)[27] retrievals from ocean colour instruments, and the realisation that there might be important information on phytoplankton physiological state in these IOPs (Behrenfeld et al. 2005, Westberry et al. 2008).

Results of applying these three leading NPP algorithms to global satellite data are available from the Oregon State University "Ocean Productivity" project (web.science.oregonstate.edu/ ocean.productivity). These products have a spatial resolution of 10' in latitude and longitude, which equates to resolution of approximately 18.6 km (latitude) and 12–16 km (longitude) for the New Zealand EEZ. This resolution is sufficiently high for the purposes of developing an Ocean Tier 1 statistic with a focus on the open-ocean region. As the carbon-based method has not been validated at present, the more established methods based on chl-a are generally still preferred, with the VGPM method the best candidate for the New Zealand EEZ.

3.4.3 Candidate indicators

Two candidate Ocean Tier 1 indicators for ocean primary production are considered here: (1) offshore chl-a as a proxy for phytoplankton biomass; and (2) satellite-based estimate of NPP based on a selected satellite algorithm. Note that both candidate indicators would be evaluated for the offshore New Zealand region only as the satellite products currently have much higher uncertainty near the coast due to the presence of suspended sediment and/or riverine run-off (Pinkerton et al., 2005, 2006).

3.4.4 Assessment against Tier 1 principles and protocols

The chl-a candidate indicator is assessed in Table 17 and the NPP candidate indicator is assessed in Table 18.

[27] "Inherent optical properties" include absorption, scattering and backscattering.

Table 17: Ocean phytoplankton biomass: scoring the key criteria for selection.

Title:		Ocean phytoplankton biomass
Brief description:		Concentration of chlorophyll-a, the ubiquitous phytoplankton pigment, as a proxy for the biomass of phytoplankton and hence indicative of ocean productivity at medium-large space and time scales.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Moderate. Information on phytoplankton blooms often/sometimes appear in newspapers.
	Business/economic relevance?	Moderate/high: Changes to ocean primary productivity could impact fisheries.
	Government strategy/policy?	Moderate: Monitoring for changes in NPP is relevant to managing New Zealand fisheries in an ecosystem context. Other management of the New Zealand marine realm also potentially affected by changes to ocean primary productivity (e.g. changes to threatened/endangered species).
	Scientific or intrinsic importance?	High: Ocean productivity is of fundamental importance for biogeochemical cycling, and likely to be affected by climate change.
	Will people be able to understand it?	Moderate. "Ocean productivity" may be understood generally to be important, but the specifics of the indicator would need explaining in simple terms.
Quality	Are base data reliable?	High. Significant international effort on long-term consistency of base data. Local validation exist, but more likely to be required on on-going basis. This is an important part of the research plan for NIWA core-funded research over the next decade.
	Are base data open-access / freely available?	High. Core data freely available from international space agencies, especially NASA.
	Analyses robust? Does it "tell the story"?	High. Chl-a, phytoplankton biomass and ocean NPP are closely related. Data are available over the whole EEZ at high frequency (at least monthly for most of the EEZ).
	Similar overseas example?	High. Widely used overseas for monitoring and understanding change.
Longevity	Will data still be collected in 5, 10, 20y?	High. Long term commitment to consistent dataset from international community (especially NASA/NOAA).

Table 18: Ocean primary productivity: scoring the key criteria for selection.

Title:	Ocean primary productivity	
Brief description:	Estimates of the rate of primary production by phytoplankton based on satellite remote sensing of the ocean.	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Moderate. Information on phytoplankton blooms often/sometimes appear in newspapers.
	Business/economic relevance?	Moderate/high: Changes to ocean primary productivity could impact fisheries.
	Government strategy/policy?	Moderate: Monitoring for changes in NPP is relevant to managing New Zealand fisheries in an ecosystem context. Other management of the New Zealand marine realm also potentially affected by changes to ocean primary productivity (e.g. changes to threatened/endangered species).
	Scientific or intrinsic importance?	High: Ocean productivity is of fundamental importance for biogeochemical cycling, and likely to be affected by climate change.
	Will people be able to understand it?	Moderate. "Ocean productivity" may be understood generally to be important, but the specifics of the indicator would need explaining in simple terms.
Quality	Are base data reliable?	Moderate. Different NPP algorithms vary considerably, though annual averages vary less than seasonal values. More validation data needed for the New Zealand region. This is an important part of the research plan for NIWA core-funded research over the next decade.
	Are base data open-access / freely available?	High. Core data freely available from international space agencies, especially NASA.
	Analyses robust? Does it "tell the story"?	High. NPP estimates are available over the whole EEZ at high frequency (at least monthly for most of the EEZ).
	Similar overseas example?	Moderate/low. Chl-a used more widely than NPP overseas for monitoring and understanding change in ocean primary productivity.
Longevity	Will data still be collected in 5, 10, 20y?	High/moderate. Long term commitment to consistent dataset from international community (especially NASA/NOAA). The commitment to long-term NPP processing by the University of Oregon is not known.

3.4.5 Recommended indicator(s) for Ocean Tier 1 statistic

We recommend using the ocean phytoplankton biomass (chl-a) satellite data as a Tier 1 indicator of ocean productivity (Table 19).

Table 19: Ocean phytoplankton biomass: recommended Ocean Tier 1 indicator.

Title:	Ocean phytoplankton biomass (chlorophyll-a)
Brief description:	There are two parts to the proposed statistics: (1) Spatial map of last year's average concentration of chlorophyll-a (chl-a). Chl-a is the ubiquitous pigment in marine phytoplankton and its concentration is used as a proxy for the biomass of phytoplankton and hence potential ocean productivity (2) Map of the difference between the average chl-a from the last year and the long-term average chl-a. This anomaly image would provide an indication of whether the last year's ocean productivity was unusually high, low or was normal.
Base data:	Data at 1 km from the NASA MODIS-Aqua sensor will be used. Standard band-ratio empirical algorithm. No data access issues. Initially, data back to July 2002 will be used for context (MODIS-Aqua only). The intention would be to include SeaWiFS data back to September 1997 when a local check of consistency between these sensors has been carried out.
Update frequency:	Annual
Meaning:	The growth of phytoplankton in the upper layers of the ocean provides the vast majority of the energy that fuels marine ecosystems, including fisheries, seabirds and marine mammals. Climate change is likely to affect phytoplankton growth. Monitoring for changes in phytoplankton biomass hence tells us if the carrying capacity of the ocean is changing.
Summary method:	Chlorophyll-a is a pigment (coloured compound) found in phytoplankton, that changes the colour of the water from blue to green. This colour change can be seen from space by sensors on satellites and used to estimate the biomass of phytoplankton in the water. More phytoplankton means that the water is more productive. We use images from the NASA MODIS-Aqua satellite sensor.
Technical method:	MODIS-Aqua mapped level 3 data. 4 km resolution, annual composites produced from daily overpass data received by NIWA X-band satellite receiver. Standard band-ratio chlorophyll-a algorithm. Changes to processing (e.g. during SeaDAS updates) will be applied retrospectively to ensure consistency of data series.
Example picture	Figure 8, Figure 9

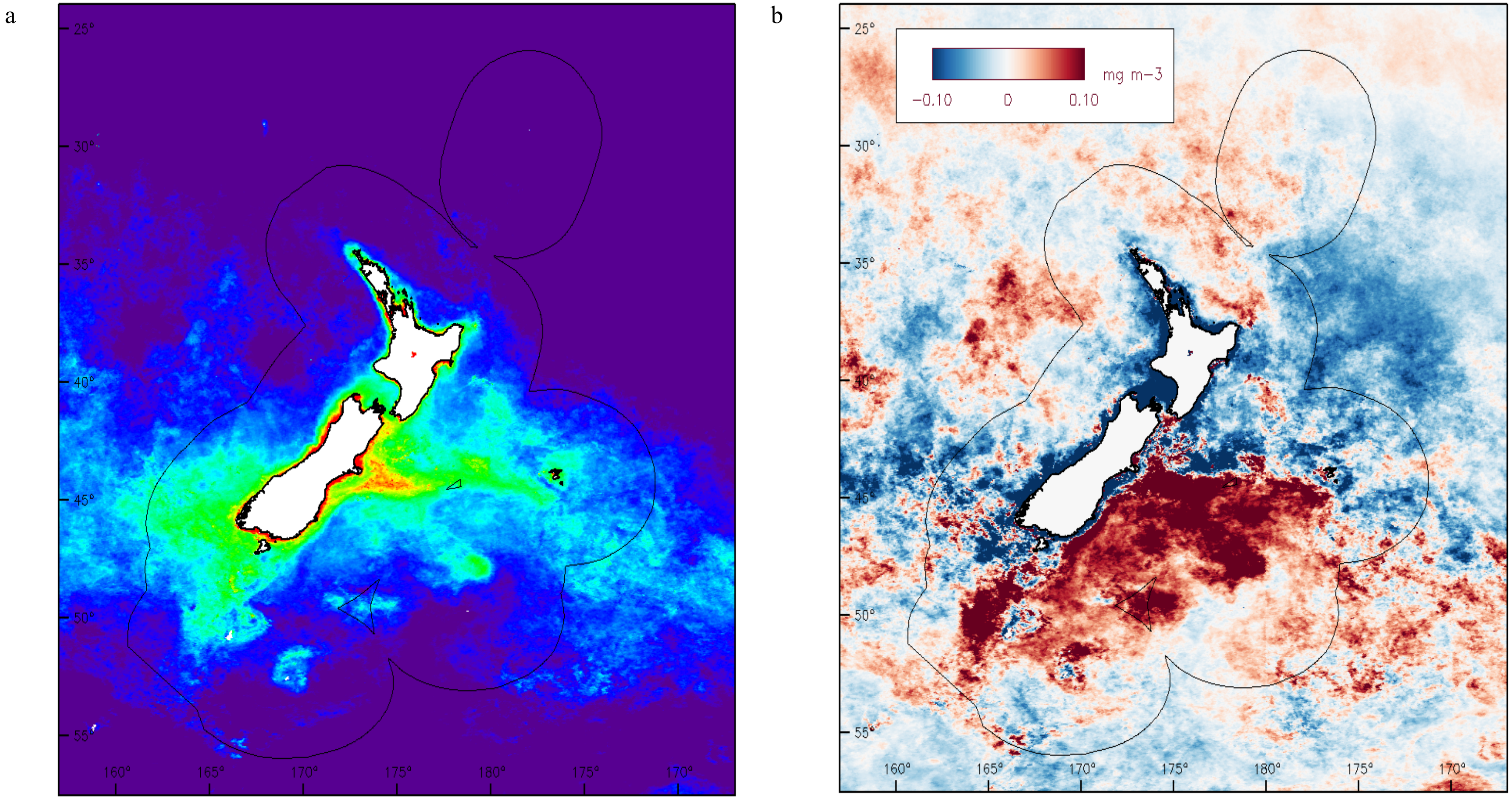

Figure 8: Example of the mapped part of the proposed Ocean Productivity (phytoplankton biomass) component of Ocean Tier 1 statistic. a: annual average chl-a in 2013 from MODIS-Aqua sensor. b: spatial difference between the average chl-a from 2013 and the long-term (2002 – 2013) average chl-a. This anomaly image provides an indication of where the productivity in 2013 was unusually high (red), low (blue) or normal (white).

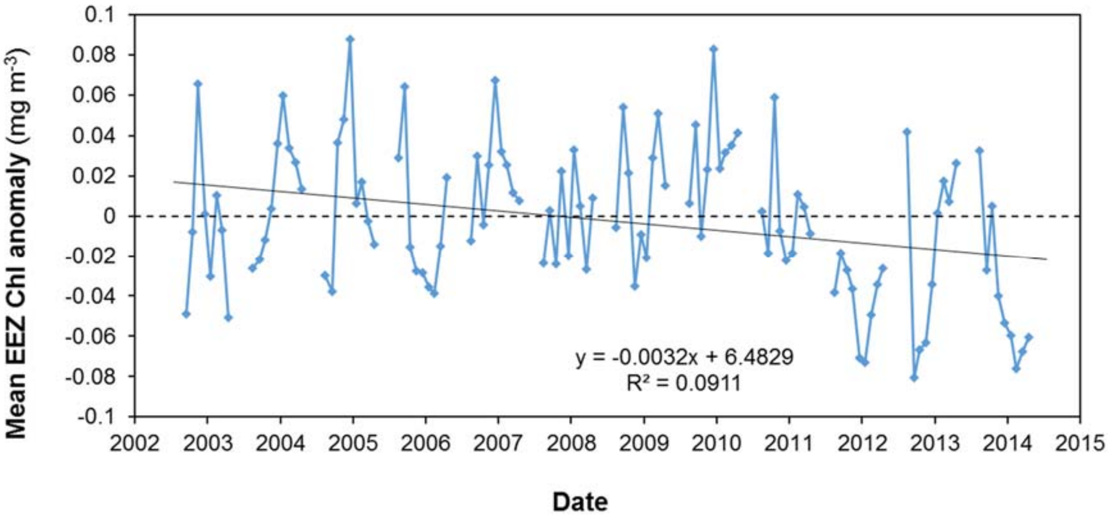

Figure 9: Example of the time-series part of the Ocean Productivity (phytoplankton biomass) component of Ocean Tier 1 statistic, showing the deseasonalised anomaly in monthly average chl-a over the EEZ from MODIS-Aqua sensor compared to the long-term average (2002–2013). Note that winter data are excluded because no ocean colour data are available for the subantarctic waters in winter as explained in the text. The regression line and equation are also shown.

3.4.6 Future steps

Part 1 and part 2 of this recommended Ocean Tier 1 statistic could be provided relatively quickly if selected. There are no problems with data access and no research required before this dataset is produced, assuming that only MODIS-Aqua data are used to estimate the long-term mean (11+ years, July 2002 to present). The intention would be to include SeaWiFS data back to September 1997 to calculate the long-term average, but this would require a local check of consistency between these sensors to have been carried out first. This may take a few months to accomplish and is part of the science plan for core-funded research at NIWA.

NASA update their software for processing ocean colour satellite data (SeaDAS) approximately once every two or three years. At these times, it is necessary to reprocess all ocean colour data for the New Zealand region, including SeaWiFS and MODIS-Aqua data. This reprocessing will take about 3 months and will be carried out under NIWA core funding.

The spatial limitations of the ocean colour data in the New Zealand area will need to be assessed in order to exclude from analysis those coastal areas where chl-a and suspended sediment can be confused (Pinkerton et al., 2006).

3.5 Coastal Storm Events

3.5.1 Scientific background

New Zealand has low-lying coastal areas that are vulnerable to coastal storms. This vulnerability is associated with inundation (flooding) by the sea during storms, but also has associated factors such as wind- and wave-damage (Gibb et al., 1992). Coastal storm surge occurs when low-pressure weather systems affect the coast and continental shelf. In this case, sea-level rises in response to falling barometric pressure whilst at the same time strong winds and waves force water up against the coast (Basco et al., 2008). These phenomena combine and so contribute to storm surge, which if they coincide with high tides, produce higher than normal sea-levels. This places emphasis on identifying when high tides, wind-driven storm surge and/or large waves are likely to occur at the same time. Perigean spring tides (i.e. "king" tides) occur around a full or new moon, when the moon is also closest in its monthly orbit around Earth (at its perigee). Small to moderate storm surge and/or waves will be exacerbated by these higher perigean spring tides and can cause coastal flooding. Exposed shorelines are vulnerable to wave-impacts as are rivers or creeks when the combined tide/wave/wind-forcing will cause the rivers to rise far inland. With global sea-level rise and potential increases in storm intensity (strength and duration), areas that are inundated only occasionally now are likely to be inundated more frequently in the future (Ruggiero, 2013).

Potential consequences of coastal storms include:

- Flooding through inundation.
- Wind-damage.
- Marine hazards (rip currents; redistribution of submerged sand banks).
- Beach erosion.
- Stormwater and drainage networks overwhelmed.
- Salinity inundation affecting potable water supplies and pasture.

Notable coastal storm events around New Zealand include:

- March 2014 – Earthquake-induced lowering of land enhanced vulnerability of Christchurch coastal suburbs such that they were heavily impacted by storm-induced inundation. Similar events occurred in June 2013 and April 2014.
- June 2013 - Wellington Storm – southerly wind event described as having the largest waves on record plus winds putting it amongst the top six storms in Wellington since records began.
- January 2011 – Auckland storm-tide. The highest on the Waitemata record and was primarily associated with a low pressure system.
- February 2002 – The Waitangi Day Storm of 2002 saw 13 m waves generated by a local depression to the east of the South Island. Roads, seawalls and jetties were damaged in and around Wellington.
- July 1995 – a small-scale, high intensity, low-pressure storm generated a large storm surge in the Firth of Thames that coincided with a high perigean-spring tide. The resulting storm tide flooded extensive areas of low-lying coastal land around Thames.
- September 1976 – The Kapiti Storm resulted from a large stationary depression off Stewart Island resulting in damage to the Kapiti/Taranaki coast with over 10 m of beach lost along with houses.
- April 1968 – Ex-tropical cyclone Giselle crossed New Zealand on 9–10 April 1968. It generated one of the largest recorded storm surges in Tauranga Harbour of 0.88 m, and caused severe sea conditions in Wellington including 10–12 m high waves, which contributed to the sinking of the interisland ferry TEV *Wahine* with the loss of 51 lives.
- See also the New Zealand Historic Weather Events Catalog http://hwe.niwa.co.nz/

3.5.2 Base datasets

The key base datasets for developing a statistic of the incidence of coastal storms are:

- Tides. These are predictable through well-calibrated models and unlikely to change in the future. Examples of tools include https://www.niwa.co.nz/services/online-services/tide-forecaster.
- Sea-level – see Section 3.1.
- Waves – derived using global models of wave energy growth and decay, driven by satellite inferred wind speeds and calibrated by satellite and buoy observations. The models are available for past conditions (hindcasts), now-casts and also some future predictions.
- Atmospheric Pressure and Wind Speed – significant archives are available through both the MetService and NIWA. It is likely that more of these data types will be recorded as data acquisition networks become cheaper to install and the value of such data becomes more recognised. Data proprietary may be an issue in the future in that organisations may start charging for data re-use.

3.5.3 Candidate indicators

A measure of the incidence of coastal storm events would be a good candidate for an Ocean Tier 1 statistic; there is high public interest in coastal storms, and information on the frequency and severity of coastal storms potentially has high importance to local and central government and high economic value (e.g. to the insurance industry). The development of a coastal storm Tier 1 index would build on a recent NIWA project aiming to forecast and communicate red-alert days for perigean-spring tides[28]. This includes development of estimates of recurrence intervals for extreme coastal events as well as short-term (48 hours) forecasting and information services.

Development of a useful index requires synthesizing a range of processes (e.g. Gibb et al., 1992). Existing options tend to focus on details of storm surge run-up and/or the "resilience" of the coastal morphology and infrastructure (e.g. Sallenger, 2000). A large basin-to-beach scale modelling system is possible (e.g. CosMos; Barnard et al. 2014) or alternately an entirely empirical scheme can and has been applied elsewhere (e.g. the Saffir-Simpson Hurricane Scale – see Dolan & Davis 1992).

It is noteworthy that while the Saffir-Simpson scale is appealing due to its simplicity, it is formally targeted at mid-Atlantic Hurricanes and the impact in a variety of coastal situations is not readily gauged. Note that the table below uses the version that incorporates effects beyond wind-speed. The currently used scale (the Saffir/Simpson Hurricane Wind Scale) considers wind speed alone (Table 20). A NOAA informal response to a request for development of an extended Saffir-Simpson index for coastal inundation is quoted here (http://www.nhc.noaa.gov/pdf/sshws_statement.pdf):

> *Storm Surge Scales and Storm Surge Forecasting - During the open public comment period for the draft of the Saffir-Simpson Hurricane Wind Scale, many people suggested that the National Weather Service develop a storm surge specific scale as well as improve its forecasting of storm surge. It is acknowledged that there are some researchers who advocate developing another scale for hurricanes specifically geared toward storm surge impact by incorporating aspects of the system's size. However, the National Hurricane Center does not believe that such scales would be helpful or effective at conveying the storm surge threat. For example, if 2008's Hurricane Ike had made landfall in Palm Beach, Florida, the resulting storm surge would have been only 8', rather than the 20' that occurred where Ike actually made landfall on the upper Texas coast. These greatly differing surge impacts arise from differences in the local bathymetry (the shallow Gulf waters off of Texas enhance storm surge while the deep ocean depths off of southeastern Florida inhibit surge). The proposed storm surge scales that consider storm size do not consider these local factors that play a crucial role in determining actual surge impacts.*
>
> *The National Weather Service believes that a better approach is to focus directly on conveying the depth of inundation expected at the coast and inland. Because storm surge- induced flooding has killed more people in the United States in hurricanes than all other hurricane-related threats (freshwater flooding, winds, and tornadoes) combined since 1900, the National Oceanic and Atmospheric Administration is working to enhance the analysis and prediction of storm surge. Direct estimates of inundation are being communicated in the NHC's Public Advisories and in the Weather Forecast Office's Hurricane Local Statements. New ways of communicating the threat have also been developed. NHC's probabilistic storm surge product, which provides the likelihood of storm surge values from 2 through 25 feet, became operational in 2009, and the NWS's Meteorological Development Laboratory is providing experimental, probabilistic storm surge exceedance products for 2010. In addition, coastal WFOs will provide experimental Tropical Cyclone Impacts Graphics in 2010; these include a qualitative graphic on the expected storm surge impacts. Finally, the NWS is exploring the possibility of issuing explicit Storm Surge*

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[28] https://www.niwa.co.nz/natural-hazards/physical-hazards-affecting-coastal-margins-and-the-continental-shelf/storm-tide-red-alert-days-2014

Warnings, and such warnings could be implemented in the next couple of years. In all of these efforts, the NWS is working to provide specific and quantitative information to support decision-making at the local level.

This suggests an approach as proposed in CoSMoS that combines a number of models to arrive at measures of inundation and coastal impact may be appropriate as a potential Ocean Tier 1 statistic. The CoSMoS system incorporates the global WAVEWATCH III wave model, TOPEX/Poseidon satellite altimetry-based global tide model, and atmospheric-forcing data from the US National Weather Service that are combined to determine regional wave and water-level boundary conditions. This forcing is then used to drive shallow water wave and flow models that in-turn drive coastal erosion (including cliff-face failure) and inundation (Barnard et al. 2014). This provides an approximately 100 m scale metric for failure likelihood along coastlines.

Table 1. ***The Saffir-Simpson Scale for Hurricanes and Halsey's Scale for Northeasters.***

Saffir/Simpson Hurricane Scale

Scale Number (category)	Central Pressure (millibars)	Winds miles/hour (meters/second)	Surge feet (meters)	Damage
1	≤980	74–95 (32–42)	4–5 (1.32)	Minimal
2	965–979	96–110 (42–49)	6–8 (2.13)	Moderate
3	945–964	111–130 (50–57)	9–12 (3.20)	Extensive
4	920–944	131–155 (58–68)	13–18 (4.57)	Extreme
5	>920	>155 (>69)	>18 (>5.49)	Catastrophic

Northeast Storm Scale (Halsey)

Class 1: (up to 1 tide) Beach erosion and dunes sustain some scarping.

Class 2: (up to 2 tides) Besides heavy beach erosion, dunes moderately to significantly scarped; overwash in weak areas, especially down street ends; sections of unprotected boardwalks popped or lifted off; flooding begins.

Class 3: (2 to 3 tides) Serious beach erosion: dunes not only scarped, but some areas flattened by overwash; flooding serious; widespread boardwalk damage.

Class 4: (3 to 4 tides): Erosion reaching to marsh "basement" in some areas; most manmade dunes flattened; significant overwash; fans coalescing; deeper flooding widespread; breaching in natural dunes increasing.

Class 5: (4 to 5 tides) Surge platforms and incipient inlets present; washover sands completely clog low-lying islands and roads, natural dunes heavily eroded.

Table 20: The Saffir-Simpson Hurricane Scale as referenced in Dolan & Davis (1992).

The Wave and Storm-Surge Projections (WASP) project[29] created 30-year hindcast simulations of wave and storm-surge conditions around the entire New Zealand coastline (Stephens et al., 2013). Outputs were produced at the location where the depth was 50 m (i.e. the projections were for points a little way out from the coast).Along with the "present-day" hindcasts, the project also simulated wave and storm-surge time-series for two climate change scenarios, driven by global climate models. It may be difficult to generate accurate metrics on extreme events, because global climate models tend not to simulate

[29] http://www.niwa.co.nz/coasts-and-oceans/research-projects/wave-and-storm-surge-projections-wasp

these extreme events well; however, the simulations could be used to generate *relative* measures, i.e. are extreme events becoming more or less frequent and more or less severe? There are potential difficulties with long-term data continuity, because as models continue to evolve they will increasingly use better temporal and spatial resolution. If there is change in quality of the models with time this could lead to spurious "drift" in the comparison of recent and historical (WASP) estimates of wave and storm-surge conditions, and hence could affect the change in these *relative* measures of the frequency or severity of coastal storm events. Following the Saffir-Simpson debate above, single metrics are not yet developed for this type of data.

3.5.4 Assessment against Tier 1 principles and protocols

Three candidate indices to measure the incidence of coastal storm events are suggested:

(1) Coastal wave index (Table 21);
(2) Coastal storm index – empirical (Table 22); and
(3) Coastal storm index – modelled (Table 23).

Table 21: Coastal wave index: scoring the key criteria for selection.

Title:		Coastal wave index
Brief description:		A parameter synthesized from wave "hindcasts". Select representative zones around New Zealand (e.g. marine sea areas as used by Met Service, Figure 10) then look for wave events exceeding a height/duration threshold. For example, a critical wave height might be 6 m with a critical duration of 6 hours – there might be four storms ("major") exceeding this criterion per year. Wave period would also need to be included – at this stage perhaps just a splitting into a few different categories (i.e. <10 s, 10–14s and >14s waves) would be useful.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High. Public are likely to understand the importance of coastal waves. Coastal inundation often feature in media reports.
	Business/economic relevance?	High. Potentially a high cost of coastal inundation to insurance, land value and coastal protection schemes to changes in climate.
	Government strategy/policy?	High. Regional Councils responsible for coastal infrastructure, including to protect against flooding. Potential impact on coastal housing.
	Scientific or intrinsic importance?	Medium. Of more local impact/importance than fundamental scientific interest,
	Will people be able to understand it?	High. Coastal flooding is intuitive to understand.
Quality	Are base data reliable?	Mostly, but the quality (and perhaps parameters/resolution) of hindcasts will improve over time so there will be a need to maintain consistency between recent hindcasts and those produced historically.
	Are base data open-access / freely available?	Mostly
	Analyses robust? Does it "tell the story"?	Partly – not all storm damage will be associated with wave events. Sequential moderate storms often have far greater impact on beach erosion than a single extreme storm.
	Similar overseas example?	Some, e.g. Gillibrand et al., 2011
Longevity	Will data still be collected in 5, 10, 20y?	Yes, but ensuring consistency of predictions over time will be challenging because models improve.

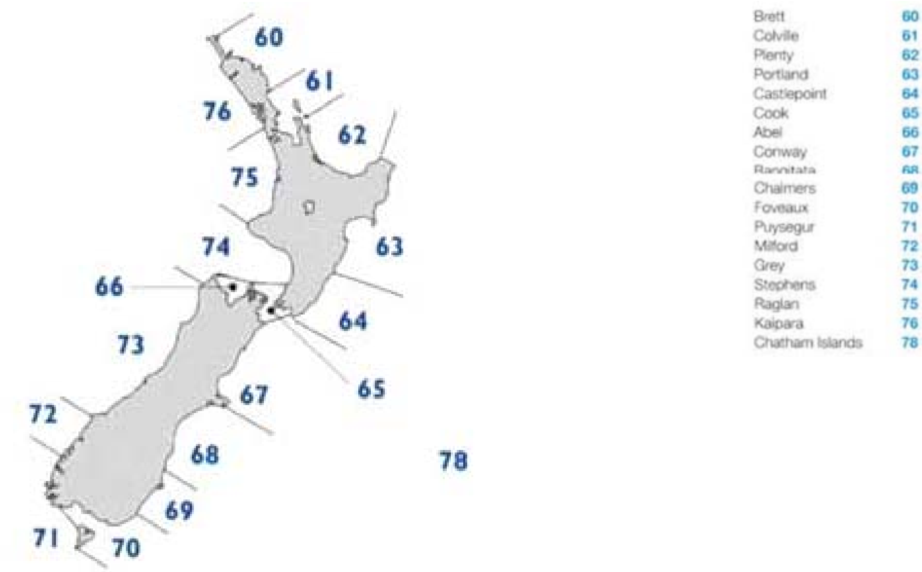


Figure 10: Metservice Sea Area Key.

Table 22: New Zealand coastal storm index (empirical): scoring the key criteria for selection.

Title:		Coastal Storm Index – empirical
Brief description:		A parameter synthesized from wind, wave and sea-level data in an ad hoc/heuristic way. As with the Saffir-Simpson Hurricane index, set up 5 categories of wind, sea-level and waves. Select for a number of sampling locations/zones. The indicator might then be the number of category 4 storms in a year (either in total or in a region by region).
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High. Public likely to be interested in coastal storms. Often feature in media reports.
	Business/economic relevance?	High. Potential implications to insurance and building industry.
	Government strategy/policy?	High. Regional Councils responsible for coastal infrastructure, which may include protection of buildings.
	Scientific or intrinsic importance?	Medium. Of more local impact/importance than fundamental scientific interest,
	Will people be able to understand it?	Medium. Coastal storm frequency and intensity are intuitive, but the index used may need careful explanation.
Quality	Are base data reliable?	Yes, good quality and consistent data.
	Are base data open-access / freely available?	Mostly, and much data held by NIWA and Regional Councils.
	Analyses robust? Does it "tell the story"?	Partly. The method of combining data will need to be carefully explained to public.
	Similar overseas example?	Some, e.g. Ruggiero, 2013
Longevity	Will data still be collected in 5, 10, 20y?	Yes. Likely to be of increasing concern in the future so data collection and analysis likely to continue.

Table 23: Coastal storm index (modelled): scoring the key criteria for selection.

Title:		Coastal Storm Index - modelled
Brief description:		A parameter synthesized from mechanistic modelling of wind, wave and sea-level data. This is based on the WASP approach and combines a hindcast wave field and storm surge field. If New Zealand is divided up into sectors then the index would capture the number of events above a threshold. The techniques for this approach are not yet complete and would require work to develop and make the tool reliable.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High. The public is likely to understand the importance of coastal storms and these often feature in media reports.
	Business/economic relevance?	High. Potentially a high cost of coastal storms to insurance industry, land/building value and protection of coastal infrastructure.
	Government strategy/policy?	High. Regional Councils likely to be concerned with climate-related changes to coastal hazards, including storms.
	Scientific or intrinsic importance?	Medium. Of more local impact/importance than fundamental scientific interest.
	Will people be able to understand it?	Medium. Coastal storm frequency and intensity are intuitive, but the index used is likely to need careful explanation.
Quality	Are base data reliable?	Mostly, but hindcasts will improve so there will be a need to maintain consistency between recent and historical hindcasts.
	Are base data open-access / freely available?	Mostly; much data held by NIWA and Regional Councils.
	Analyses robust? Does it "tell the story"?	Partly. The index used will balance measures of the impacts due to wind, waves and sea-level.
	Similar overseas example?	Some, e.g. Sallenger (2000); Dolan & Davis (1992).
Longevity	Will data still be collected in 5, 10, 20y?	Yes. Coastal storms are likely to be of increasing concern in the future. Maintaining comparability between models over time as models improve may be challenging.

3.5.5 Recommended indicator(s) for Ocean Tier 1 statistic

From the candidate indices, we recommend the New Zealand coastal wave index for an Ocean Tier 1 statistic (Table 24).

Table 24: Coastal extreme wave index: recommended Ocean Tier 1 indicator.

Title:	Coastal extreme wave index
Brief description:	An area-by-area quantification of the number of large wave events in New Zealand coastal region in the previous year. This could be compared with the average number of such events over the long-term period.
Base data:	The data, depending on what hindcast is chosen, go back about 40 years (see Figure 11).
Update frequency:	Annual update although it could be produced as a cumulative number through EcoConnect.
Meaning:	This parameter gives an indication of the occurrence and distribution of large wave events. These are potentially damaging and also influence coastal ecology and amenities.
Summary method:	Use height exceedance/duration analysis (Figure 12) to look for periods when waves exceeding a certain threshold persist for a certain time. This would need some initial fine-tuning to determine sensible thresholds.
Technical method:	See Gorman et al. (2003).
Example picture	Figure 13

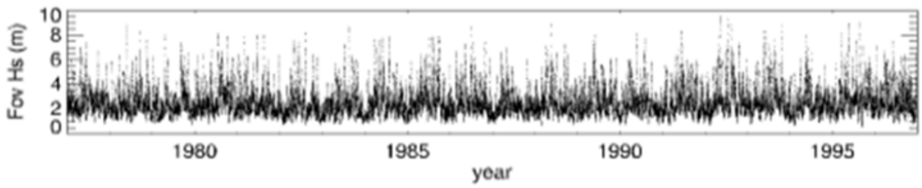


Figure 11: Significant wave height (Hs) in Foveaux Strait. This is shown as an example of the base data for generating indices of extreme wave events (see Gorman et al. (2003) for more details).

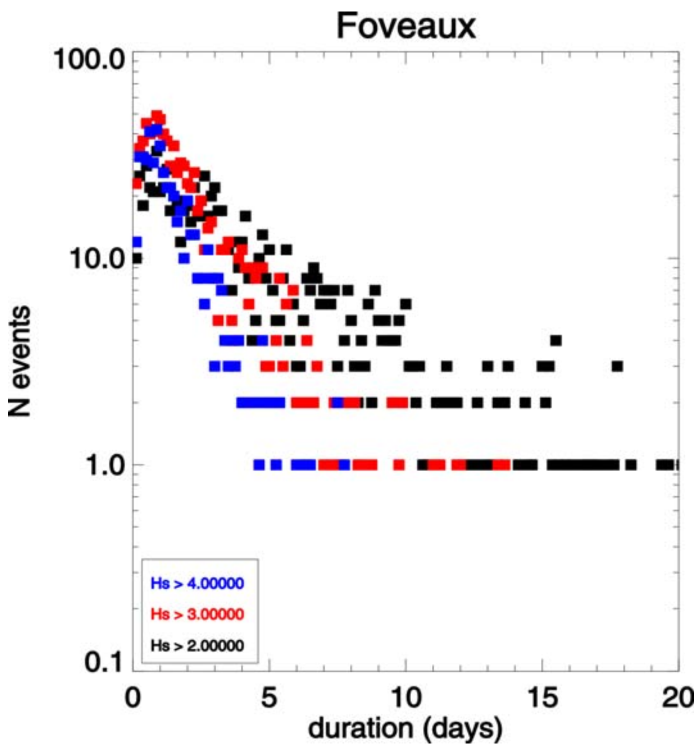


Figure 12: Example of wave events as function of duration and significant wave height for 20 year hindcast in Foveaux Strait.

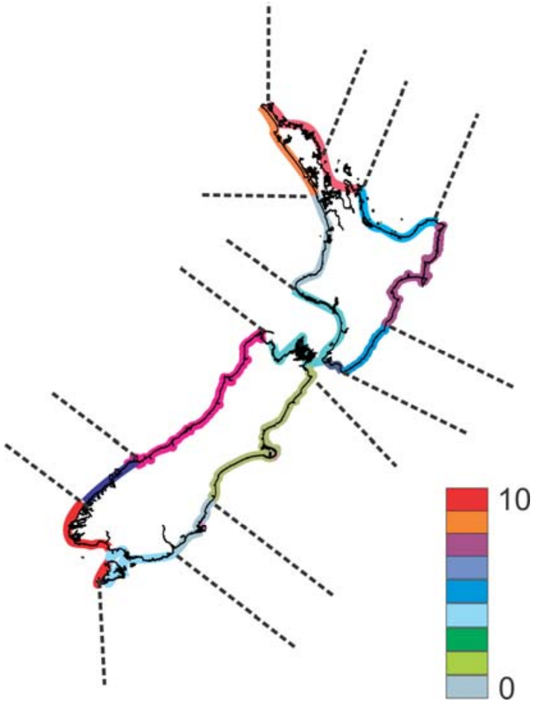


Figure 13: Example of Waves / Storm Events component of Ocean Tier 1 statistic. The figure shows a mock-up of potential output: a diagram showing, through colour coding, the number of threshold exceedances in the past year in the given maritime areas.

3.5.6 Future steps

The coastal extreme waves indicator provides a simple and easy to interpret quantity that is likely to be of high interest to many policy makers/managers, businesses and to the general public. If it is selected as part of an Ocean Tier 1 statistic, we recommend that work commence on combining this with sea-level/storm surge information because a combination of wind and waves might provide an improved coastal inundation parameter (e.g. Gillibrand et al. 2011). This should be achievable fairly quickly with relatively low investment (of the order of a month or two of work) if required.

3.6 Open ocean extreme wave events

3.6.1 Scientific background

New Zealand has substantial public and private investment in offshore activities. It is likely that an index representing the incidence of extreme weather events in the offshore New Zealand EEZ would be of high relevance as part of an Ocean Tier 1 statistic. Here we seek an indicator that represents open-ocean sea state. Sea state here refers primarily to wave conditions but also in some aspects wind is relevant too. In seeking an open-ocean sea state indicator, we note that this has many elements in common with coastal inundation indicators but also some key differences. Not the least among differences is that the end users are quite different; the open ocean economic sector is mainly focussed around transport infrastructure, fisheries and extractive industries (including mineral and petroleum exploration/extraction). In the future, offshore power generation and offshore aquaculture are also likely to be affected by changes in the frequency or intensity of offshore weather events. With changing climate (e.g. Dowdy et al., 2014; Emanuel, 2013), indicators of sea-state are likely to prove useful in gauging increased or decreased challenges to open ocean marine activities such as these (Wang et al. 2009a).

Classical indicators for extreme offshore weather events have largely been event-focused. The well-known Beaufort Scale helps mariners classify sea- and wind state conditions from largely qualitative information. More recently, large-scale and long-time numerical models and satellite data have made broad-scale analysis of changes in wind and sea state in the open ocean possible, especially in terms of assessing the frequency and severity of extreme weather events offshore. Stephens & Gorman (2006) used an offshore wave hindcast for the New Zealand region in conjunction with wave-buoy data to evaluate extreme significant wave height at multiple sites around New Zealand. As hindcast storm wave heights were under-predicted compared with wave-buoy measurements, a method for scaling the hindcast data to improve the comparison of predicted extreme wave heights was developed. Extreme wave heights were identified, with larger waves in the south and in the west. At the most energetic site to the southwest of the South Island, a 1 in 100-year return significant wave height of 19.3 m and maximum wave height of 45 m were predicted (Stephens & Gorman, 2006).

3.6.2 Base datasets

The base dataset used for this proposed index would be wave height in the offshore EEZ (see example in Figure 14). These wave heights would be derived using global models of wave energy growth and decay, driven by satellite-inferred wind speeds and calibrated by satellite and buoy observations. The models provide information on past conditions (hindcasts), present conditions ("now-casts"), and also provide some future predictions (Gorman et al., 2003). The wave height predictions are calibrated using observations from fixed instrumented moorings, of which, there are unfortunately few in the New Zealand EEZ region. Although measurements of wind speed and direction are available directly from shore-based climate stations these are of little use further offshore. Methods based on satellite observations have instead been developed (Swail & Cox, 2000), and these remotely-sensed wind data are typically used in forecasting of offshore sea state.

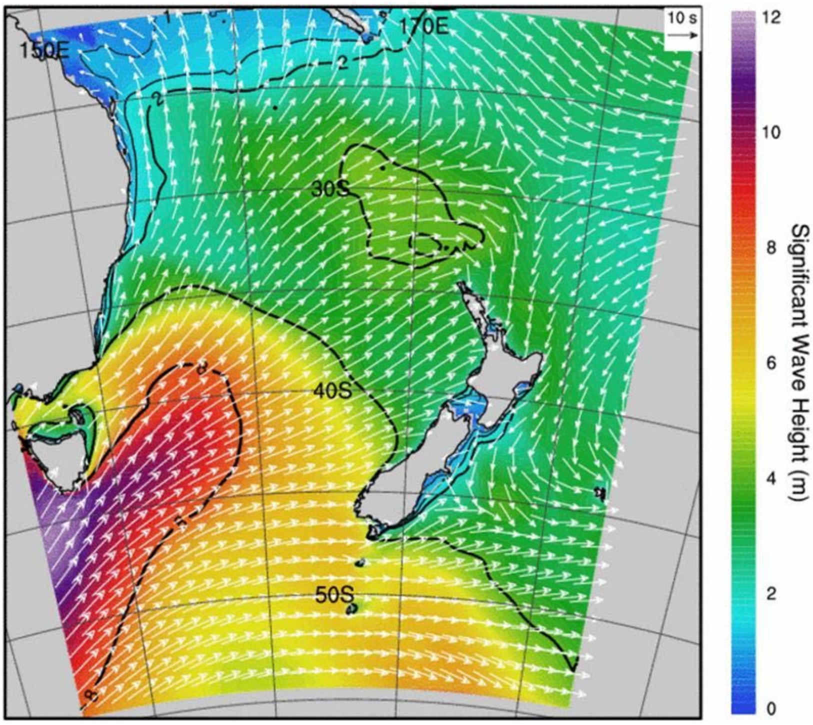


Figure 14: Wave conditions forecast for 1800 NZST on the 16th of September 2014, from the New Zealand regional wave forecast.

3.6.3 Candidate indicators

At this stage, we consider an open-ocean extreme sea-state indicator based only on wave height. We suggest a dual-criteria threshold exceedance metric. This requires identifying a threshold wave height and duration and then summing the number of events that exceed this dual condition. While coastal, it is instructive to note that Cook Strait ferries review their operating procedures at significant wave heights of 4 m and higher. For example, an initial approach might be to count the number of events where significant wave height is greater than 4 m for 24 hr or longer. To produce an indicator of extreme sea-state as part of the Ocean Tier 1 statistic, the indicator of wave events also need to be aggregated regionally, spatially and temporally.

3.6.4 Assessment against Tier 1 principles and protocols

An assessment of the open ocean extreme wave index is given in Table 25.

Table 25: Open-ocean extreme wave index: scoring the key criteria for selection.

Title:		Open ocean extreme wave index
Brief description:		A parameter synthesized from wave "hindcasts" for the survey period. Select representative zones around New Zealand (these could be MetService sea areas, for example) then look for wave events exceeding a height/duration threshold. For example, a critical significant wave height of 4 m and a critical duration of 24 hours could be used. There might be about 20 storms ("major") exceeding this per year in each region.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High/medium. At least some of the public is likely to be interested in sea state offshore
	Business/economic relevance?	High/medium. Offshore transportation (shipping) and offshore petroleum/mineral industries are likely to be interested.
	Government strategy/policy?	High. The government is keen to increase use of the New Zealand marine zone.
	Scientific or intrinsic importance?	Medium/low. May affect upper ocean ecological processes, but likely to be a weak effect.
	Will people be able to understand it?	High. Likely to be easily understood by the public.
Quality	Are base data reliable?	Mostly, but hindcasts will improve/evolve so there will be a need to maintain consistency.
	Are base data open-access / freely available?	Mostly
	Analyses robust? Does it "tell the story"?	Partly –other factors can influence deep ocean operations.
	Similar overseas example?	Some (e.g. Dowdy et al., 2014; Hemer, 2010; WASA, 1998; Wang et al., 2009b) but the US EPA marine indicators do not consider extreme offshore waves at present.
Longevity	Will data still be collected in 5, 10, 20y?	Yes, but the hindcast is always improving.

3.6.5 Recommended indicator(s) for Ocean Tier 1 statistics

The open ocean extreme wave index in Table 26 is recommended as an Ocean Tier 1 indicator. It scores highly in terms of the likely public, economic and statutory interest (because of interest in offshore industries such as shipping and mineral/petroleum exploration and extraction), the robustness of the data, and the large-scale nature of the analysis possible. The open ocean extreme wave index is hence recommended as an Ocean Tier 1 indicator.

Table 26: Open ocean extreme wave index: recommended Ocean Tier 1 indicator.

Title:	Open ocean extreme wave index
Brief description:	An area-by-area quantification of the number of large wave events in the region in a year.
Base data:	Hindcasts go back about 40 yr (see Gorman et al (2003)) (e.g. Figure 11, Figure 15)
Update frequency:	Annual update although it could be produced as a cumulative number.
Meaning:	This parameter gives an indication of the occurrence and distribution of large wave events. These events affect maritime operations including transport, cable laying, fishing and mineral/petroleum exploration and exploitation.
Summary method:	Use height exceedance/duration analysis to look for periods when waves exceeding a certain threshold persist for a certain time. This would need some initial fine-tuning to determine sensible thresholds.
Technical method:	See Gorman et al. (2003).
Example picture	Figure 15

D: Northwest

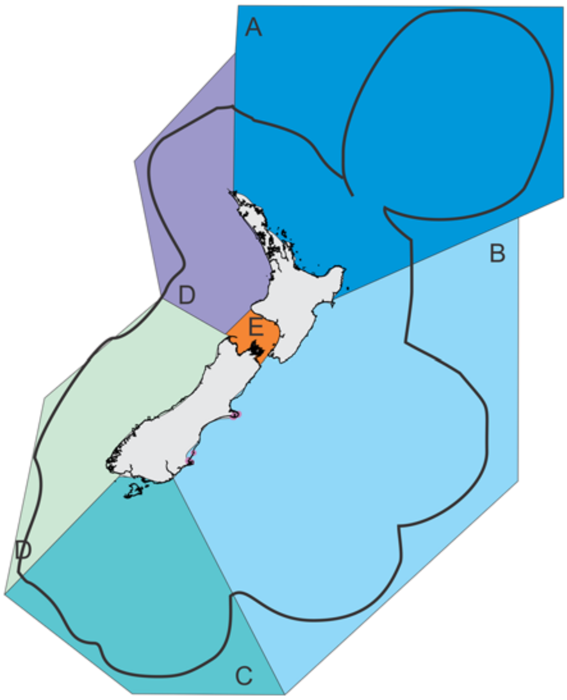
2014: 8 events/y
Long-term: 13 events/y
2014 anomaly: -5

E: Cook Strait

2014: 6 events/y
Long-term: 2 events/y
2014 anomaly: +4

F: West

2014: 12 events/y
Long-term: 12 events/y
2014 anomaly: 0



A: Northeast

2014: 15 events/y
Long-term: 18 events/y
2014 anomaly: -3

B: East

2014: 10 events/y
Long-term: 11 events/y
2014 anomaly: -1

C: South

2014: 23 events/y
Long-term: 25 events/y
2014 anomaly: -2

Figure 15: Open ocean extreme wave index: mock-up of potential output. The MetService sea areas or coastal areas (Figure 13) could alternatively be used. The diagram shows, through colour coding, the number of times waves have exceeded an extreme wave threshold in the past year. Values added to each area show the number of extreme wave events per sector in the last year, the long-term average of number of events and the anomaly for the last year (this may need to be normalised for variability in each region to indicate the significance of the change). The anomalies could be combined into a national index if required.

3.6.6 Future steps

The proposed open ocean extreme wave index provides a simple and easy to interpret quantity that could be implemented relatively easily. In the future, a combination of wind and wave information might provide a more useful indicator than that based on waves alone. An entirely empirical scheme can and has been applied elsewhere (e.g. the Saffir-Simpson Hurricane Scale – see Dolan & Davis 1992, Table 20). If it is selected as part of an Ocean Tier 1 statistic, we recommend that work commence on combining hindcast significant wave height with wind information for an improved operational parameter of extreme offshore events. This should be achievable fairly quickly if selected, with relatively low cost (of the order of a month or two of work).

3.7 Ocean Acidity

3.7.1 Scientific background

The oceans have absorbed approximately 30% of the carbon dioxide released to the atmosphere since the Industrial Revolution in the 1750s (Global Carbon Project, 2010). This has resulted in a change in the carbon chemistry of the oceans, including an increase in seawater acidity, measured as a decrease in ocean pH. The magnitude of the ocean response varies with local oceanographic environmental factors such as water temperature, biological activity and ocean currents. These factors vary on daily, tidal, seasonal and annual timescales, as well as spatially. There are several global long term measurement programmes measuring change in ocean acidity (Bates et al., 2014), including one in New Zealand waters: the Munida Time Series off the Otago coast (Currie et al., 2011).

The increasing acidity and associated chemical changes in seawater will have impacts on ecosystems, in particular phytoplankton (e.g. coccolithophores) and animals that form calcium carbonate shells (e.g. mussels, oysters). Juvenile stages of sensitive organisms are especially vulnerable. Shellfish are important to New Zealand both commercially, culturally and socially; the New Zealand aquaculture industry generated over $400 million dollars revenue in 2011.

3.7.2 Base datasets

NIWA and the University of Otago Research Centre for Oceanography have been measuring ocean acidity in the waters off Otago since 1998 (Munida Time Series), the longest such measurement programme in the Southern Hemisphere and the only one in the New Zealand region (Currie et al., 2011). Underlying the seasonal and interannual variability, the long-term trend is a gradual increase in ocean acidity in subantarctic waters of 0.0013 pH unit per year, which is consistent with other observations around the world (Bates et al., 2014) The programme collects data six times per year (bi-monthly), and will continue in the medium-term (over the next 10 years at least).

A coastal ocean acidification observing network is in the process of being established, with samples being taken fortnightly from 14 sites around New Zealand. Two of these sites, including the Munida Time Series, will be included in the Global Ocean Acidification Observing Network (GOA-ON)[30]. The New Zealand network will give spatial information on how ocean acidity varies at representative sites around the coast, as well as temporal information, indicating how ocean pH varies at each site over time. The network will also provide a baseline against which future change can be assessed, and context for spatially extrapolating the long-term Munida Times Series data. Once established, this network is expected to continue for the next ten years (or more); at present, funding is secured for the next two years (until 2016).

3.7.3 Candidate indicators

There are several possible indicators of ocean acidification, both directly measured parameters, and calculated parameters:

- pH is a direct measure of the ocean acidity.
- Saturation state of aragonite (Ω_a): this parameter describes the status of the water with respect to shell stability. At values less than 1 (Ω_a <1) the aragonite form of calcium carbonate is unstable and tends to dissolve, whereas at values greater than 1, aragonitic shells are

[30] http://www.goa-on.org/

thermodynamically stable. Mussels and cockles mostly use the aragonite form of calcium carbonate for their shells.

- Saturation state of calcite (Ω_c): similar to Ω_a above, but for the calcite form of calcium carbonate, used by oysters and kina.

Currently, the measured or derived ocean acidity indicators can be provided along one transect, from the Otago coastline to subantarctic waters, 65 km offshore. The station at the end of the Munida transect is in subantarctic water which is representative of the waters east and south of the South Island, New Zealand. The indicators can be back-calculated to 1998. The data can be presented in a table, and as a simple time-series graph (see example below).

At present the spatial variability in ocean acidity throughout the New Zealand coastal and open ocean sites means that it is not practical to derive a single, New Zealand wide ocean acidity indicator based on the measurements from the single Munida transect. However, the measurement of ocean acidity at the outermost (offshore) station on the Munida transect is likely to be indicative of changes to subantarctic waters near New Zealand generally, but not necessarily of what is happening near the coast where most shellfish harvesting and aquaculture takes place. The ocean acidity indicator could be presented simply as a data table of ocean acidity at each site, or a visual representation such as a map with the data summarised as a box-and-whiskers type plot showing the annual mean values and standard deviation at each site. In the near future (before the end of 2015) measurements of ocean acidity will be underway at 14 other sites around New Zealand. However, measurements over more than 5–10 years from these new stations are likely to be required before meaningful local trends can be identified and before the data can be used for spatial extrapolation.

3.7.4 Assessment against Tier 1 principles and protocols

An assessment of two proposed Tier 1 indicators for ocean acidity in the New Zealand EEZ are given in Table 27 and Table 28.

Table 27: New Zealand ocean acidity (Munida pH): scoring the key criteria for selection.

Title:	New Zealand ocean acidity (Munida pH)	
Brief description:	The pH of seawater at the Munida Time Series site = "Ocean Acidity".	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Medium/high. Is a direct measure of the parameter, although can be difficult to interpret. The value will have high inter-annual variability, and the long-term trend will be small
	Business/economic relevance?	Medium/high. Is of direct relevance to the aquaculture and shellfish industry, although changes in acidity measured on the Munida transect are not necessarily indicative of changes in acidity in coastal regions. Ocean acidity is also of relevance to finfish fisheries and marine ecosystems generally,
	Government strategy/policy?	Low/medium. Current Government policy does not require measurement of this parameter at present, but management of shellfish fisheries and aquaculture requires changes such as in ocean acidity to be considered. Political awareness of the importance of ocean acidification likely to increase in the future.
	Scientific or intrinsic importance?	High. A unique long-term record, that ties in with a global monitoring network.
	Will people be able to understand it?	Medium. Would require some interpretation for public, government and other stakeholders.
Quality	Are base data reliable?	High. The base data have been internationally calibrated, and are part of a global monitoring network.
	Are base data open-access / freely available?	High. The data are available on an international database.
	Analyses robust? Does it "tell the story"?	High/medium. The data are robust; the interpretation of data trends is complex. Interannual variability is high, therefore the "story" is complex (as for other indicators).
	Similar overseas example?	High, e.g. Bates et al., (2014) • Ocean Acidity (pH) is one of five oceanic climate change indicators in the United States (US EPA). • pH data area collected at several sites around the world, as part of scientific research programmes. The number of these sites is increasing as the recognition of ocean acidification as an ecosystem threat increases. The two longest running programmes are at Bermuda and at Hawaii[31, 32]
Longevity	Will data still be collected in 5, 10, 20y?	High. Collection of the base data is part of an on-going NIWA/Otago research programme. The measurement programme is being expanded to include other coastal sites.

[31] www.epa.gov/climatechange/science/indicators/oceans/acidity.html
[32] hahana.soest.hawaii.edu/hot/trends/trends.html

Table 28: Calcite and /or Aragonite Saturation Index at the Munida site: scoring the key criteria for selection.

Title:		Calcite and /or Aragonite Saturation Index at the Munida site
Brief description:		Saturation index for calcite and/or aragonite as measured on the Munida transect off Otago.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Low. Is not a parameter that most people will have heard of
	Business/economic relevance?	Medium/high. Is of direct relevance to the aquaculture industry.
	Government strategy/policy?	Low/medium. Current Government policy does not require measurement of this parameter at present, but management of shellfish fisheries and aquaculture requires changes such as in ocean acidity to be considered.
	Scientific or intrinsic importance?	High. A unique long-term record, that ties in with a global monitoring network.
	Will people be able to understand it?	Low. The general public will probably not be interested unless it is interpreted. Even then it is hard to understand.
Quality	Are base data reliable?	High. The base data have been internationally calibrated, and are part of a global monitoring network.
	Are base data open-access / freely available?	High. The data are available on an international database.
	Analyses robust? Does it “tell the story”?	High. The data are robust, the interpretation of data trends is complex. Interannual variability is high, therefore the “story” is complex.
	Similar overseas example?	Low. None known for calcite or aragonite saturation rather than pH.
Longevity	Will data still be collected in 5, 10, 20y?	High. Collection of the base data is part of an on-going NIWA/Otago research programme. The measurement programme is being expanded to include other coastal sites.

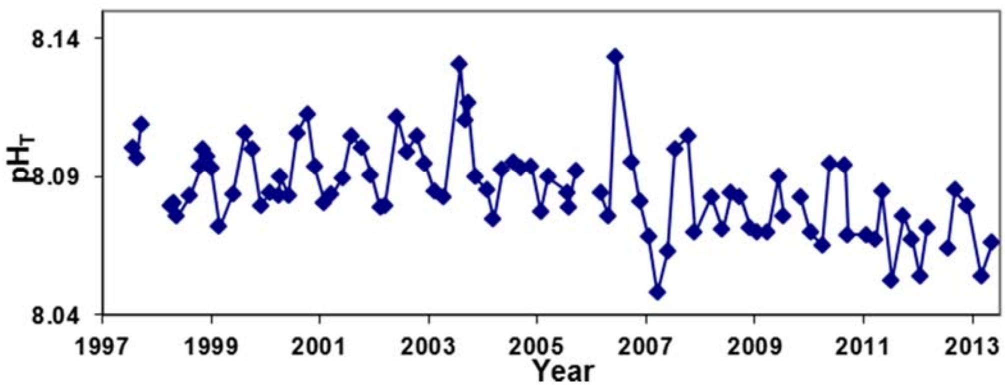
3.7.5 Recommended indicator(s) for Ocean Tier 1 statistic

Because of its more direct interpretation and use elsewhere, Munida pH is recommended as the ocean acidity component of the Ocean Tier 1 statistic (Table 29).

Table 29: New Zealand ocean acidity (Munida pH): recommended Ocean Tier 1 indicator.

Title:	New Zealand ocean acidity (Munida pH)
Brief description:	The pH of seawater at the Munida Time Series site.
Base data:	pH measured every 2 months, starting in 1998.
Update frequency:	Annually, data will be provided from the previous year (6 data points)
Meaning:	The ocean is becoming more acidic as carbon dioxide from human activities is being absorbed by the oceans. This is a gradual and on-going process and will have impacts on shellfish and other organisms. In the North West United States the shellfish industry is already adversely affected by increasing ocean acidity levels.
Summary method:	pH is directly measured as part of a research programme undertaken by the NIWA/University of Otago Research Centre for Oceanography, using internationally recognised, calibrated and validated techniques.
Technical method:	At this stage, data at only one site can be provided. The measured parameter (pH) would be used directly. The new data (1 year) would be provided in a table and the time series graph updated. In future, data from 14 more sites will be available. At that stage an extended or alternative product would be implemented, with a map showing annual mean values and standard deviations at each site.
Example picture	See Figure 16.

a



b

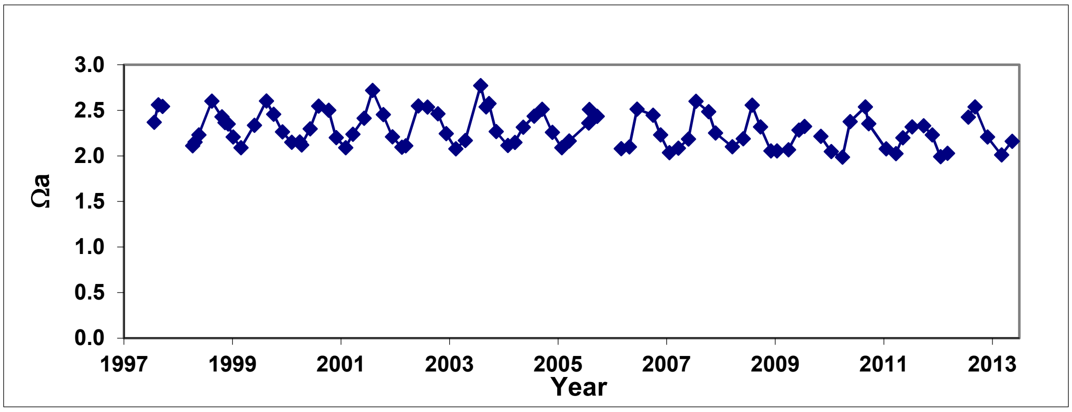


Figure 16: Example of a: Ocean Acidity (pH) component of Ocean Tier 1 statistic. b: Aragonite saturation state.

3.7.6 Future steps

The data for the recommended pH indicator are available and no further work needs to be done before these are used as proposed. Annual update of the data would be done as part of an existing research programme (NIWA core funding). The interpretation of the data could be via a simple written statement provided annually. When data from the additional 14 sites proposed for ocean acidity monitoring are available, the indicator would require an additional plot for each site to show annual anomalies and interannual variability.

3.8 Climate Indices

3.8.1 Scientific background

This section focusses on ocean "Climate Indices", derived from measurements of atmospheric circulation, but which can be expected to significantly influence the New Zealand coastal and marine environment. The atmosphere is the upper boundary for the ocean, at which large energy exchanges take place. Surface winds influence ocean currents, and persistent air flow from the north or south will affect sea surface temperatures. Periods of stormy weather or settled weather can directly impact the use of inshore marine resources, be it commercial (shipping, fishing or mining) or recreational (fishing). From an ocean productivity viewpoint, variations in vertical mixing of the upper ocean will affect ocean stratification, which in turn influence phytoplankton production. Year-to-year variability in sea surface temperature has been related to changes in changes in abundance of some fish species (Dunn et al., 2009).

The use of atmospheric data has the advantage of providing much longer time-series than oceanographic observations; for example, many atmospheric properties have been well sampled in the New Zealand region for at least 50 years, initially from ships and more recently from satellites. Atmospheric circulation indices are thus useful for giving a 'big picture' perspective, which helps understanding of more complex, regionally varying indicators. Year-to-year variability is the dominant signal in atmospheric climate indices, but very long time-series enable us to see trends related to global warming. For example, some trends in the Southern Ocean circulation and storm tracks have already been observed and associated with global warming (Bengtsson et al., 2006), and continuing trends are expected (Mullan et al., 2011). In particular, Mullan et al., (2011) concluded that it was likely that there will be an increase in the activity of low pressure centres over the Tasman Sea in summer and a decrease in activity south of New Zealand.

3.8.2 Base datasets

The two climate indices proposed below are both derived from measurements of mean sea-level pressure (MSLP). This is a "well-behaved" atmospheric variable (i.e. it can be measured with good accuracy) about which there is little controversy. Because atmospheric pressure is so directly related to weather and climate, there is a great deal of international collaboration in producing robust data sets (Kalnay et al., 1996; Uppala et al., 2005; Dee et al., 2011) and in comparing variations and trends. Pressure data will continue to be collected indefinitely, because it is used for weather forecasting.

One of the proposed indicators uses pressure observations at specific sites, whereas the second indicator is derived from pressure data over a wide region assimilated into weather prediction models.

3.8.3 Candidate indicators

Two indicators are suggested to provide information about climatic conditions over the New Zealand region (ocean and land). The first describes how mean conditions over the year differ from the long-term average, and the second relates to variability and extremes over the period considered.

Airflow Indices: Two airflow indices are suggested as indicators of how abnormal the prevailing winds have been over the year. These are known in the literature as the Trenberth circulation indices (Trenberth, 1976), specifically the Z1 index for west-east airflow, and the M1 index for south-north airflow. Z1 is defined as the pressure difference between Auckland and Christchurch, relative to "normal" (usually taken as the mean conditions over as long a reference period as possible given data availability); M1 is defined as the pressure difference between Hobart (Tasmania, Australia) and Chatham Island, relative to normal. The Z1 index approximates a zonal pressure gradient, such that a positive value implies more westerly airflow than normal between the latitudes of Auckland and Christchurch, and a negative value more easterly (or less westerly) flows. The M1 index approximates a meridional pressure gradient, such that a positive implies more southerly airflow than normal between the longitudes of Hobart and Chatham Island, and a negative value more northerly flows. Another index that could be added is Z2, which shows westerlies at more southern latitudes, between Christchurch and Campbell Island.

Figure 17 shows the geographic location of these Trenberth indices, and the monthly climatology of Z1 and M1. The New Zealand region experiences prevailing north-westerlies during the summer months (December to February), and prevailing south-westerlies in winter (April to August). Westerly winds are strongest in the spring (September to December). The proposed airflow indices will show how a particular period departed from this long-term average. The indices are calculated monthly, and could be presented as monthly, quarterly or annual values. The circulation anomaly being described is a vector, and so two values are required, which can be interpreted as magnitude and direction.

a

b

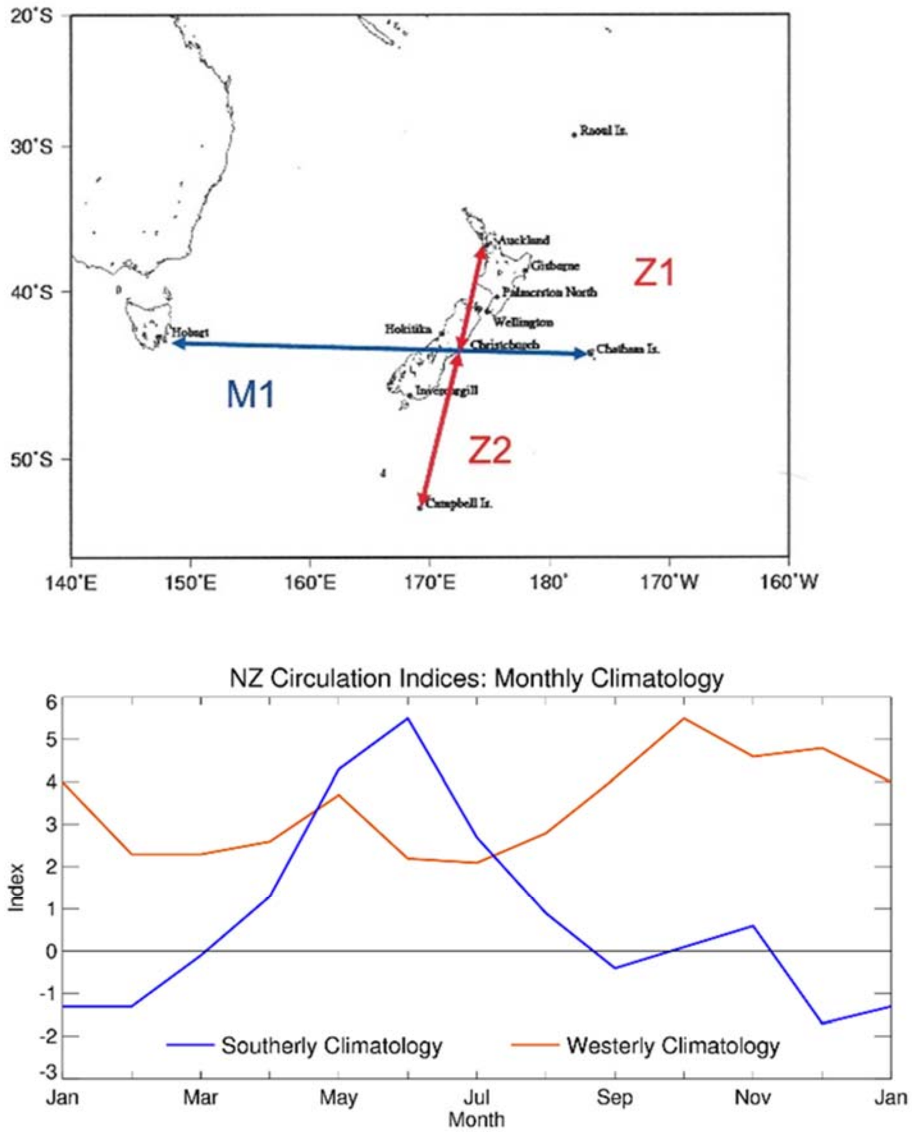


Figure 17: a: Schematic indicating the geographic span of the circulation indices M1, Z1 and Z2. b: Monthly 1971-2000 climatology of M1 and Z1 indices (blue and red, respectively).

Ocean Storm Index (cyclone counts): Cyclones are mobile low pressure weather systems about which winds circulate in a clockwise direction. These systems play a dominant role in determining the local weather, and in particular are often the underlying cause of extreme wind events. Most of the cyclones in the New Zealand region are of mid-latitude (or extra-tropical) origin, but the occasional ex-tropical cyclone can affect the region over the summer half-year (November to April).

NIWA has software which can identify cyclone centres from daily gridded pressure data (Simmonds & Keay, 2000), and a recent report to MPI described how the observed cyclone climatology was projected to change over this century, based on climate models used in the IPCC Fourth Assessment Report (Mullan et al., 2011).

One proposed Ocean Storm Index (cyclone counts) would give the number of days (by season or year, as desired) in which a deep, "closed low" pressure centre exists in one of four quadrants around New Zealand. A "closed low" is a pressure system with one or more pressure contours encircling them on the analysis charts at all levels in the troposphere. If more than one low centre is present on the same day, then both are counted. If the same low persists for several days in the same quadrant, then each day is counted. Alternatively, a more spatially-resolved map of the occurrence of cyclones could be developed, or MetService sea areas could be used to link to weather information or other Ocean Tier 1 indicators on offshore storms. This can be decided if this proposed statistic is selected.

Figure 18 shows an example, based on diagnosing low pressure centres from the ERA-40 Reanalysis data set (Uppala et al., 2005) over the period 1961–2000. Storms occur most frequently to the northwest of New Zealand, but there can be large variability from year to year (e.g., 1998 was much more active to the northwest than usual). The anomalies (changes from mean values calculated over the entire period for which consistent data exist) could be combined into a single national value.

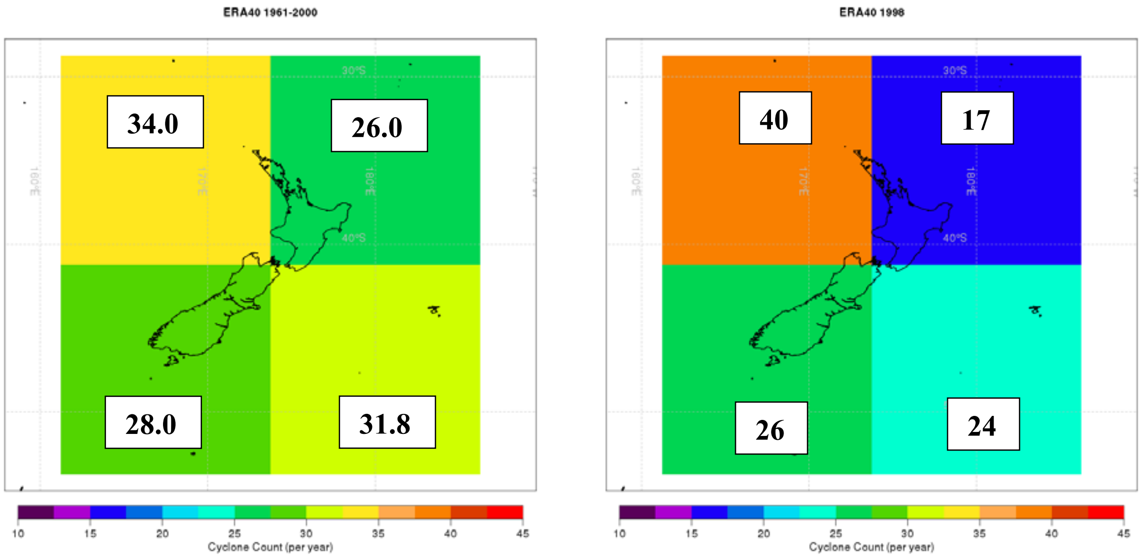


Figure 18: (Left) Climatological annual average number of storms (closed low pressure centres) in each of four quadrants around New Zealand, based on the ERA-40 reanalysis pressure data over the period 1961–2000. The information could alternatively be provided with higher spatial resolution or using MetService sea areas. (Right) Storm count for the calendar year 1998. The anomalies (changes from mean values calculated over the entire period for which consistent data exist) could be combined into a single national value.

3.8.4 Assessment against Tier 1 principles and protocols

The two proposed climate-related indicators are assessed against Tier 1 principles and protocols in Table 30.

Table 30: Airflow index: scoring the key criteria for selection.

Title:		Airflow index
Brief description:		Two circulation indices, derived from pressure gradients, which show how west-east and south-north airflow varies in the New Zealand region, compared to the long-term average.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Medium/low. The indicator describes in a general way the prevailing winds, and can be interpreted in terms of impacts. For example, more persistent onshore winds may lead to increased coastal erosion; a year with more southerly winds would help the public understand why that year was colder than normal.
	Business/economic relevance?	Low/medium. Year-to-year variations may affect offshore shipping, but likely to be more relevant to terrestrial businesses.
	Government strategy/policy?	Medium. Long-term changes can be used to support regional policies (e.g., why a specific coastline is eroding or accreting).
	Scientific or intrinsic importance?	High. The New Zealand indices proposed are known as “Trenberth indices” and have been widely used in analyses of regional climate (although to date the analyses have focussed on land-based impacts).
	Will people be able to understand it?	Low/medium. The indices should be generally understandable in terms of, say, “a more westerly year” or “a more southerly year”. The one complication is that the index is a vector average (so positive and negative values may cancel).
Quality	Are base data reliable?	High. Air pressure is a standard measurement.
	Are base data open-access / freely available?	High. NIWA-archived station pressure data are currently freely available.
	Analyses robust? Does it “tell the story”?	High. The analysis is very straightforward, and therefore quite robust. The southerly index, in particular, tells a simple story as the public can relate a positive value to a cold year, and vice versa (See Note 1).
	Similar overseas example?	High. Circulation indices and storm statistics widely used.
Longevity	Will data still be collected in 5, 10, 20y?	High. Long term commitment to collection of base data.

Note 1: The Trenberth Index for south-north airflow (M1) is formally defined as the anomalous pressure difference between Hobart (Tasmania) and Chatham Island. As such, a positive value implies more southerly airflow between those two end-points, and thus colder-than-normal temperatures. If this is thought confusing, then the index could be reversed, so a positive value means more northerly airflow and warmer temperatures.

Table 31: Ocean storm index (cyclone counts): scoring the key criteria for selection.

Title:		**Ocean storm index (cyclone counts)**
Brief description:		Number of deep low centres (cyclones) in four quadrants covering the New Zealand region.
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	High. The indicator describes well the public perception of storminess within the EEZ.
	Business/economic relevance?	High. Year-to-year variations could be used to help explain fluctuations in delays in utilising ocean resources (e.g., days fishing).
	Government strategy/policy?	High/medium. Long-term trends in storminess in the New Zealand region may in future be attributed to global warming, which may affect government policy/strategy.
	Scientific or intrinsic importance?	High. There is scientific interest in long-term trends of cyclone numbers, and in case studies of specific extreme events.
	Will people be able to understand it?	High/medium. 'Storminess' is difficult to define at a technical level, but is conceptually very simple.
Quality	Are base data reliable?	High. A number of analysis sources are available, but will agree well at the broad scale being assessed by this indicator.
	Are base data open-access / freely available?	Medium. Global gridded pressure data are currently open-access, but require technical proficiency to analyse.
	Analyses robust? Does it "tell the story"?	Medium/high. Identification of low pressure centres is technically complex, since different mathematical techniques and thresholds are possible for characterising a specific event. However, provided the same software and specifications are used throughout, the results will be reproducible. Different pressure data sets are expected to give only slightly different answers.
	Similar overseas example?	High. Cyclone tracking is widely used overseas, although there is no international protocol on defining thresholds of occurrence.
Longevity	Will data still be collected in 5, 10, 20y?	High. Long term commitment to collecting underlying daily pressure data.

3.8.5 Recommended indicator(s) for Ocean Tier 1 statistic

Both proposed indices are recommended as part of the Ocean Tier 1 statistic:

- Airflow indicator, at quarterly or annual time-scales, is a scientifically simple way of describing how the recent climate over the EEZ differed from the long-term average (Table 32), although some further work may be needed to make this understandable to the public
- Ocean storm index (cyclone counts), at annual time-scales, as a measure of extreme weather events affecting the EEZ. The index suggested here is simply a count of the number of low pressure centres over a year, but it could be augmented with an intensity index, quantifying how intense the cyclones were (Table 33).

Table 32: Airflow index: Recommended Ocean Tier 1 indicator.

Title:	Airflow index
Brief description:	Combination of two circulation indices, derived from pressure gradients, which show how west-east and south-north airflow in the New Zealand region compares to the long-term average.
Base data:	Monthly mean sea-level pressure data for four stations (Auckland, Christchurch, Chatham Island and Hobart). The first three are held on the NIWA Climate database, and the fourth by the Australian Bureau of Meteorology. The Z1 index (west-east) starts in 1885, and the M1 index (south-north) in 1896, so more than a century of data are available.
Update frequency:	The base indices are calculated monthly, but it is proposed to update the indicator annually (the indicator itself could be monthly, quarterly or annual, as desired).
Meaning:	The sign and magnitude of the two Index values is a measure of how the prevailing winds differed from the long-term average: e.g., a negative Z1 and negative M1 means more persistent airflow from the northeast, which is typically experienced during La Niña events; positive Z1 and M1 means more southwesterly, as typical of El Niño periods.
Summary method:	The Airflow indicator is derived from: a north-south pressure gradient (Auckland minus Christchurch pressure anomaly) which gives a measure of westerly wind strength, and a west-east pressure gradient (Hobart minus Chatham Island pressure anomaly) which gives a measure of southerly wind strength.
Technical method:	• Calculate the monthly mean pressures at the four observing stations (Auckland, Christchurch, Chatham Island, Hobart). • Calculate the monthly anomalies by subtracting the climatological monthly pressure (currently uses the 1971–2000 period). • Difference the anomalies to determine Z1 (Auckland minus Christchurch) and M1 (Hobart minus Chatham Island). Average monthly values to get an annual average if desired.
Example picture	Figure 19

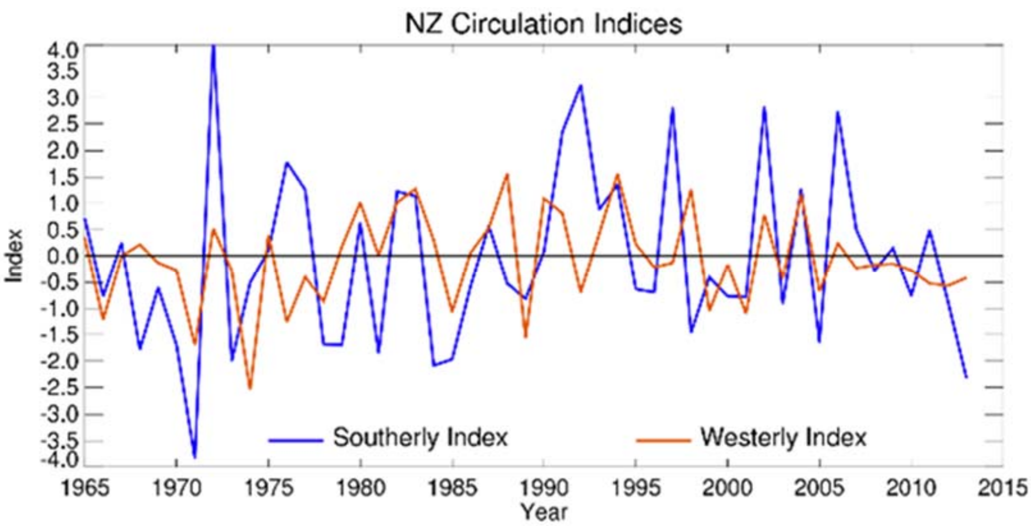


Figure 19: The Airflow Index is made up of a westerly (Z1 Trenberth Index, red – positive indicates more westerly winds) and southerly index (M1 Trenberth Index, blue – positive indicates more southerly winds) describing the prevalence of wind direction (and related weather types). Here, the figure shows the annual southerly and westerly airflow indices, 1965 to 2013.

Table 33: Ocean storm index (cyclone counts): Recommended Ocean Tier 1 indicator.

Title:	Ocean storm index (cyclone counts)
Brief description:	Number of deep low centres in four quadrants covering the New Zealand region.
Base data:	Global gridded pressure data currently go back to January 1948, although it is considered more reliable from the satellite era from the late 1960s. Some institutions require payment for their data, if used for other than research purposes. The cyclone tracking software is the Intellectual Property of the University of Melbourne.
Update frequency:	It is proposed that the indicator be updated annually.
Meaning:	This indicator gives a very simple and readily understandable measure of storminess and associated extreme weather during the year. By recognising that winds circulate clockwise around low pressure centres, one can understand how different coastal regions or parts of the EEZ are affected. It is proposed that the index consist of four values, one for each quadrant around New Zealand.
Summary method:	Diagnose low pressure centres from mean sea-level pressure data, and count the number of days when deep lows occur in the four quadrants.
Technical method:	• Begin with 6-hourly reanalyses of gridded mean sea-level pressure data in the New Zealand region. • Scan the gridded data to identify local maxima in the Laplacian (spatial second derivative) of pressure. An iterative search is then carried out for a pressure minimum in the vicinity of the Laplacian pressure maximum. If this is found the low is classified as a “closed” system. • If the Laplacian has a value exceeding 0.7 hPa per degree latitude squared, it is defined as a “strong’ or “deep” low. • All the deep lows identified within each quadrant around New Zealand over a year are counted. The quadrants are each 12.5 degrees wide (longitude) and high (latitude), with the quadrants centred at: 35S, 167.5E; 35S, 180E; 47.5S, 167.5E; 47.5S, 180E. • For further technical details, see Simmonds & Murray (1999) and Simmonds & Keay (2000).
Example picture:	Figure 18 (annual update) and Figure 20 (time-series view)

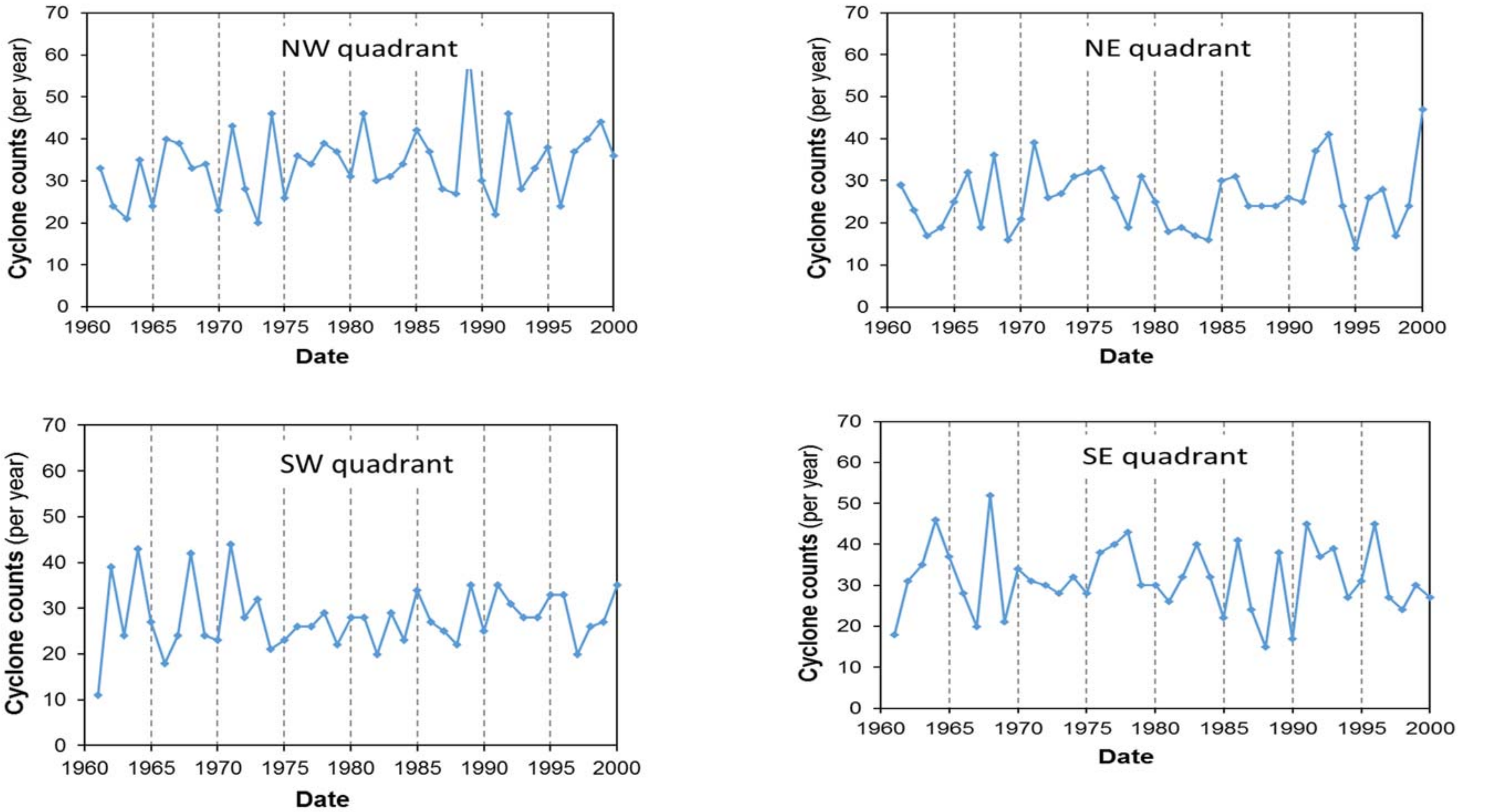


Figure 20: The time-series view of the Ocean Storm Index (cyclone counts) shows the annual frequency of deep closed low centres in four quadrants around New Zealand, from 1961 to 2000. The annual updates would be presented as shown in Figure 18.

3.8.6 Future steps

For the Airflow Indicator:

- No further work is required, apart from any documentation which may be needed. The Trenberth circulation indices are already routinely calculated by NIWA.
- The sign of the north-south index (M1) could be reversed if this makes for a more intuitive public interpretation; i.e., a positive value will then be associated with warmer than normal temperatures. Further discussion could be had about the best way to represent a vector, since this indicator describes variations in both magnitude and direction.

For the Ocean Storm Index (cyclone counts):

- The analysis of low pressure centres would need to be brought up to date with the appropriate data set (there are several to choose from). Additional documentation would be required (e.g., comparing results from different pressure data sets).
- The main issue is obtaining an appropriate gridded data set. NIWA currently accesses operational weather prediction products from the USA in its seasonal forecasting, which will not be identical to long-term homogeneous 'reanalysis' data sets. It is therefore possible that an annual value will be provisional, and will be updated in the following year.

3.9 Coastal water quality

3.9.1 Scientific background

Changes to coastal water quality have high public and statutory (central and local government) interest. These inshore waters and estuaries also have substantial value economically, recreationally and culturally. Coastal water quality is affected by climate variability (rainfall patterns) and is likely to be affected by climate change, as well as human activities including land use. Coastal water quality is often substantially affected by local change, such as due to land-use and coastal harvesting/fisheries. The complexity of factors affecting coastal water quality means that developing effective and interpretable indicators of coastal water quality that reflect climate change/variability is unlikely to be easy.

We note that there is a different proposed Tier 1 statistic called "Coastal and recreational coastal water quality" which is yet to be scoped and researched. Discussion would be needed on how the indicator proposed here would fit with that statistic. Also, relevant is the Environmental Monitoring and Reporting project (EMaR). This is a partnership between Local Government New Zealand, the Regional Councils' Resource Management Group and MfE. The objective of EMaR is to develop and operate environmental data collection networks that are delivered via widely accessible national data and reporting platform(s). The EMaR initiative is exploring potential metrics for coastal water quality. Another initiative is Land Air Water Aotearoa[33] (LAWA), a collaborative initiative between the 16 regional and unitary councils, the Cawthron Institute, MfE and Massey University with funding from the Tindall Foundation, to share water quality data.

3.9.2 Base datasets

There are substantial and highly varied sets of base data on coastal water quality:.(a) Regional Councils collect substantial amounts of water quality information, but the methods (in situ, laboratory analyses), amount (frequency, number of sites), purposes and management of data often vary substantially between councils; (b) aquaculture operators collect information on coastal water quality for business development, regulatory or other purposes; (c) research organisations including NIWA, Cawthron Research Institute and New Zealand universities regularly collect information relevant to coastal water quality at sites around New Zealand; and (d) data from ocean colour satellites can be used to estimate concentrations of suspended sediment and coloured dissolved organic matter (CDOM) in coastal waters (e.g. Pinkerton et al., 2006). Substantial effort is focussed presently on bringing together datasets held by a variety of stakeholders into a coherent and more usable whole. Data propriety issues are common for coastal water quality information, though not for data collected and held by Regional Councils.

3.9.3 Candidate indicators

Two candidate indicators are considered here:

- Coastal water quality (harmful algae) index – this candidate indicator is based on regulatory sampling for harmful or toxic algal species by coastal shellfish fisheries and aquaculture operators. This sampling is mandated to ensure the safety of cultured seafood.
- Coastal water quality (satellite) index – a measure of coastal water quality derived from satellite ocean colour measurements, including suspended solids and CDOM.

3.9.4 Assessment against Tier 1 principles and protocols

The coastal water quality (harmful algae) index is assessed against Tier 1 statistic criteria in Table 34. The coastal water quality (satellite) index is assessed in Table 35.

[33] http://www.lawa.org.nz

Table 34: Coastal water quality (harmful algae) index: scoring the key criteria for selection.

Title: Coastal water quality (harmful algae)

Brief description: Incidence of harmful or toxic algae detected from regulatory monitoring of shellfish harvesting and aquaculture.

Component	Criteria	Score / comment
Importance	Satisfies public interest?	High. Reports of the occurrence of toxic algal blooms occur often in the public media.
	Business/economic relevance?	High. The aquaculture and coastal shellfish industries have considerable economic importance.
	Government strategy/policy?	High. Regulation of the safety of shellfish products requires information on the effect of a changing climate.
	Scientific or intrinsic importance?	Medium. The links between climate and harmful or toxic algal blooms is of scientific as well as commercial interest.
	Will people be able to understand it?	High. Frequency of occurrence of toxic algal outbreaks simple to understand.
Quality	Are base data reliable?	Medium. Because required for regulatory purposes, sampling is likely to be regular and reliable. If the monitoring is targeted to where aquaculture is occurring, combining these data could potentially give information over many areas. However, some coastal regions which are known to have outbreaks of toxic algae but have no aquaculture will not be considered (e.g. Wellington Harbour).
	Are base data open-access / freely available?	Low. Data propriety (by operators/industry tasked with data collection) may be an issue.
	Analyses robust? Does it "tell the story"?	Medium. Data likely to be collected only as mandated so likely to be focussed solely on existing shellfish harvesting/aquaculture sites.
	Similar overseas example?	Low. None known.
Longevity	Will data still be collected in 5, 10, 20y?	High. Sampling likely to continue as long as harvesting/aquaculture.

Table 35: Coastal water quality (satellite) index: scoring the key criteria for selection.

Title:	Coastal water quality (satellite)	
Brief description:	Suspended sediment concentration and coloured dissolved organic matter (CDOM) absorption derived from ocean colour sensors on satellites.	
Component	**Criteria**	**Score / comment**
Importance	Satisfies public interest?	Medium. Suspended sediment and CDOM may be of broad public interest – people recognise "muddy" or blue water near the shore.
	Business/economic relevance?	Medium/high. Suspended sediment and CDOM affect recreation (like diving, surfing, fishing), tourism and can affect coastal fisheries and aquaculture.
	Government strategy/policy?	Medium/high. Regional Councils are required to manage effects of coastal sediment and riverine run-off on coastal health.
	Scientific or intrinsic importance?	Medium. Relevant to coastal research in general and potentially affects distributions of coastal species, including fish, shellfish and primary producers (macroalgae and microphytobenthos)
	Will people be able to understand it?	Medium. Simple to explain but relevance to climate change may be difficult to establish. Likely to be linked to a combination of run-off (land-use and rainfall patterns) and coastal storminess.
Quality	Are base data reliable?	Medium. Base data (i.e. satellite observations of ocean colour) reasonably reliable but estimations of sediment concentration and CDOM absorption through New Zealand coastal zone still under development.
	Are base data open-access / freely available?	Medium. Data freely available but data volumes and processing have high IT demand.
	Analyses robust? Does it "tell the story"?	Medium. Link between changes to sediment/CDOM and climate likely to occur in conjunction with local human-use effects.
	Similar overseas example?	Medium. Satellite observations of coastal water quality used in management overseas, if not as indicator related to climate.
Longevity	Will data still be collected in 5, 10, 20y?	High. These data products are likely to improve in the future and continue for more than 10 years. Changes in ocean colour remote sensing technology and science may make it difficult to establish long-term consistency in the statistic. This can probably be overcome by "overlap" analysis between successive sensors.

3.9.5 Recommended indicator(s) for Ocean Tier 1 statistic

We recommend that the coastal water quality index (harmful algae) be considered for inclusion in the Ocean Tier 1 statistic (Table 36), although further work will necessary before this index can be produced.

Table 36: Coastal water quality index (harmful algae): recommended Ocean Tier 1 indicator.

Title:	Coastal water quality index (harmful algae)
Brief description:	Incidence of harmful or toxic algae detected from regulatory monitoring of shellfish harvesting and aquaculture.
Base data:	Regulatory sampling for harmful or toxic algal species by coastal shellfish fisheries and aquaculture operators.
Update frequency:	Annual
Meaning:	The incidence of harmful or toxic algae in coastal waters is likely to be related to oceanographic conditions in complex ways that are hard to predict. Climate variability and change may affect how often conditions conducive to the development of harmful/toxic algae blooms occur in New Zealand coastal waters. Monitoring these changes may provide a biological perspective on the effects of climate change on the coastal environment.
Summary method:	Based on mandatory testing for the safety of harvested and cultured shellfish.
Technical method:	For each area of New Zealand in which shellfish are harvested or aquaculture operates, data on the testing for harmful/toxic algal species will be brought together. This will be used to give a regional and annual index of the incidence of harmful/toxic algae. The incidence rate will be compared to the long-term incidence rate to provide an annual anomaly (i.e. "were there more or less incidences of harmful algae than normal over the last year?"). The significance of this change will be summarised using information on the variance in the rate of incidence.
Example picture	No image proposed as yet. This awaits further investigation of what base data are available to produce the proposed index.

3.9.6 Future steps

Relatively large amounts of work will be needed to bring this recommended index to fruition. First, for each area of New Zealand in which shellfish are harvested or aquaculture operates, data on the testing for harmful/toxic algal species will need to be brought together. This involves identifying what data exist, gaining permission to use the data and developing methods to access and combine data from different providers. At present, it is not clear to what extent data gathered for statutory purposes (i.e. to guarantee public health) by commercial operators are in the public domain or are propriety. If the latter, permission to use the data may be variable by operators, and data may have variable formats.

4 CONCLUSIONS

This study has considered a wide variety of data that may be relevant to reporting on changes to the New Zealand marine, coastal and estuarine environment resulting from the effects of climate variability and change. The purpose was to recommend a set of indicators that together would form a new Ocean Tier 1 statistic. The indicators aim to reduce the multidimensional complexity of measuring changes in the marine environment to a level where they can be understood by policy makers, the general public, and other stakeholders with a non-technical background. The recommended indicators are designed for audit ("how are we doing?") rather than control ("what should we do in the future?") (Rice & Rivard, 2007). The indicators are designed to provide information relevant in assessing whether ocean properties are changing in a way that may be linked to climate-change, but establishing causal links between changes in the recommended indicators and the global climate system is beyond the scope of the report. More specific analysis are likely to be needed to infer causality of any observed changes in the recommended indicators.

The recommended indicators are given in Table 37 together with a preliminary (indicative) ranking. The ranking is based on whether the indicator was deemed to be: (1) of broad interest, including to policy makers, the business community, other stakeholders and the general public; (2) based on reliable data and robust analysis; (3) can be communicated effectively and can be understood (though it is not necessary to prove a causal link between climate change and the indicator for it to be useful as a Tier 1 statistic); (4) is likely to be available for the medium to long term (more than 10 years hence). Note that this ranking is somewhat subjective as it based on expert opinion (expressed at the first and second stakeholder workshops) and hence should be considered to be indicative only.

Table 37: Recommended components for Ocean Tier 1 statistic. The recommended indicators have been given a preliminary (indicative) ranking, where the 1st indicator is most likely to be useful as part of the Ocean Tier 1 statistic. This preliminary ranking will be revised following discussion with MPI, Statistics New Zealand, MfE, data providers and other stakeholders.

Rank	Indicator	Section	Table	Figure
1	Relative mean sea-level	Section 3.1	Table 7	Figure 2
2	Sea-surface temperature (satellite)	Section 3.2	Table 13	Figure 5
3	Ocean phytoplankton biomass	Section 3.4	Table 19	Figure 8
4	Sea-surface temperature (coastal)	Section 3.2	Table 14	Figure 6
5	Ocean acidity (Munida pH)	Section 3.7	Table 29	Figure 16
6	Coastal extreme wave index	Section 3.5	Table 24	Figure 13
[1]7=	Open ocean extreme wave index	Section 3.6	Table 26	Figure 15
[1]7=	Ocean storm index (cyclone counts)	Section 3.8	Table 33	Figure 18; Figure 20
8	Water masses/circulation	Section 3.3	Table 16	Figure 7
9	Airflow index	Section 3.8	Table 32	Figure 19
10	Coastal water quality (harmful algae)	Section 3.9	Table 36	None

[1] Either only one of these is likely to be selected or they will be combined into a single indicator of extreme offshore weather events.

A number of other potential indicators may be useful in the future, but were not considered in detail here because they were not thought likely to be useful for Tier 1 reporting at present. These include: (1) oxygen in bottom waters; (2) salinity; and (3) bio-indicators (e.g. do changes in the assemblages, abundances or distributions of mesopelagic or benthic organisms reflect changes to the underlying oceanic conditions?), among others. It may be useful to revisit these potential future indicators at a later stage.

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