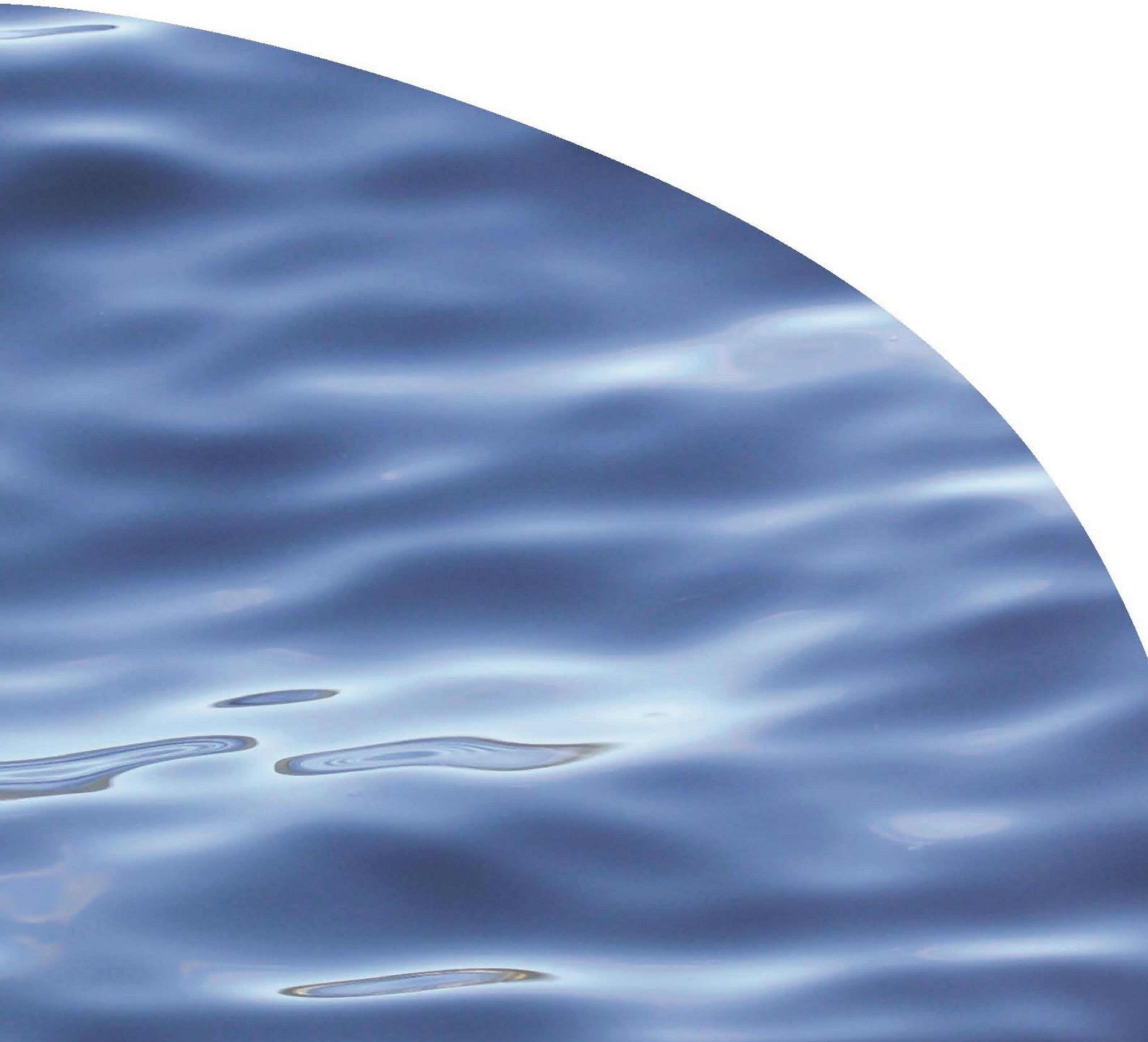
REPORT NO. 2924

OPPORTUNITIES FOR AN INTEGRATED APPROACH TO MARINE ENVIRONMENTAL MONITORING IN THE MARLBOROUGH SOUNDS



OPPORTUNITIES FOR AN INTEGRATED APPROACH TO MARINE ENVIRONMENTAL MONITORING IN THE MARLBOROUGH SOUNDS

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EXECUTIVE SUMMARY

Marlborough District Council (MDC) contracted Cawthron Institute (Cawthron) under an Envirolink Medium Advice Grant to identify data and information needs for MDC and other marine users and describe existing water quality monitoring efforts in the Marlborough Sounds. This was carried out with a view to developing a more integrated approach that capitalises on emerging technologies such as remote monitoring platforms. Our assessment included interviews with regional stakeholders and iwi to explore their views regarding needs and gaps, and the pros and cons of setting up a consortium approach to monitoring.

The following generic types of monitoring were identified:

- Consent-related environmental monitoring: This is typically local-scale monitoring (e.g. of seabed or water quality) required by councils as part of some resource consent conditions, and focuses on the immediate environs of point-source activities.
- State of Environment (SOE) monitoring: This is typically broad-scale monitoring conducted by councils. The purpose of SOE monitoring is (or should be) to capture broad-scale changes in environmental conditions, and provide a context for understanding the effects of human activities.
- Other monitoring: In addition to monitoring conducted or required by councils, other organisations may undertake monitoring for operational purposes.

People interviewed on behalf of stakeholders and iwi in Marlborough were generally supportive of a consortium approach that integrates the above types of monitoring approaches, subject to some barriers being addressed. It was recognised that some significant benefits may arise, especially where monitoring is coordinated by a single organisation. These benefits include:

- More efficient and 'fit-for-purpose' monitoring, with the potential for cost-savings to stakeholders. For example, SOE monitoring could provide regional reference sites against which the effects of point-source activities were assessed.
- Improved scientific consistency and quality control of monitoring design, methods, data analyses and evaluation, contributing to a consistent management response and an improved understanding of cumulative effects.
- Centralised storage for monitoring data, enhancing the potential for data sharing and increasing stakeholder collaboration and trust.

Knowledge gaps identified during interviews included long-term datasets for establishing environmental 'baselines', improved understanding of the cumulative effects and sources of different stressors arising from marine and land-based activities, and appropriate spatial and temporal data to facilitate management decisions.

Marlborough District Council has already made some progress in the development of a coordinated regional approach via a memorandum of understanding with New Zealand King Salmon Company Ltd, to facilitate sharing of data from regional SOE water quality monitoring and site-specific salmon farm monitoring. However, there is scope for further improvement in MDC's water quality monitoring in several respects, including the following:

- There is a need to broaden the suite of existing indicators and approaches to better address issues relating to key stressors that are poorly understood. A particular issue for the Marlborough Sounds is sediment inputs and related impacts from adjacent land-based activities.
- There may be opportunities to enhance MDC's existing SOE monitoring by coordinating activities with stakeholder-led programmes that have some common purposes or overlap in terms of information needs. Examples include the ongoing Marlborough Shellfish Quality Programme and Harbour Master needs for meteorological, wave and tide information.
- Emerging technologies such as moored monitoring platforms and satellite data provide an opportunity to overcome some of the existing shortcomings; for example, with respect to the limited temporal resolution of SOE sampling. Specific information is provided on the pros and cons of monitoring platforms that would likely meet MDC's needs.

The considerable long-term benefits that could arise from a well-integrated regional monitoring programme are likely to far outweigh the initial effort involved in developing and setting up the approach. We describe what an integrated programme might look like by comparing two hypothetical scenarios; a 'typical' existing monitoring situation that is heavily focused on consented point sources, and an 'improved' monitoring approach with an SOE component that integrates synoptic surveys, real-time monitoring and forecasting tools. However, it was beyond the scope of the report to make specific recommendations for MDC regarding the details of an integrated monitoring approach; at this stage further investigation and consultation is required to resolve some of the issues and barriers identified.

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1. INTRODUCTION

1.1. Background

The Marlborough Sounds (Sounds) coastal marine area (CMA) is a nationally significant water body subject to a range of pressures from sea-based activities and adjacent land uses. Increased pressure on the CMA in recent years has resulted from activities such as new aquaculture developments and exotic forestry operations. Coupled with these developments have been emerging community concerns regarding issues such as eutrophication from salmon farm nutrients, plankton depletion from mussel farms, and coastal sedimentation impacts from forestry. Collectively these types of activities can have cumulative effects on the water quality and ecological values of the CMA, and its associated commercial and non-commercial uses and values (e.g. aquaculture, fishing, tourism).

Marlborough District Council (MDC) has a coastal monitoring strategy that identifies the need to collect high quality data to assess the state of the marine environment and the effects of human activities (Tiernan 2012). For example, the Council currently funds monthly State of the Environment (SOE) water quality monitoring throughout the Pelorus and Queen Charlotte sounds (MDC 2016), and funds various synoptic or ongoing biological monitoring studies, such as estuary SOE surveys (e.g. Berthelsen et al. 2015; Stevens & Robertson 2015). As MDC is in the process of developing its new regional coastal plan, the council wishes to evaluate the extent to which existing monitoring meets (i) stakeholder aspirations relating to the uses and values of the Marlborough Sounds, and (ii) is fit-for-purpose in light of current and future pressures on the system. MDC also recognises that the recently passed Environmental Reporting Act 2015 makes environmental reporting mandatory for the first time in New Zealand.

MDC has contracted Cawthron Institute (Cawthron) under an Envirolink Medium Advice Grant to evaluate existing monitoring efforts and discuss the scope for improvements, with a primary focus on the water column environment and marine water quality issues. Of particular interest to MDC is the identification of information needs of key stakeholders and the evaluation of existing monitoring activities and data sources for the region, with a view to developing a more integrated approach that capitalises on the benefits arising from new monitoring technologies; for example, remotely moored monitoring platforms and satellite data (Ellis et al. 2012; Barter 2013; Knight & Jiang 2014).

1.2. Context and scope of report

Cawthron has undertaken recent studies on integrated coastal monitoring for the Waikato region (Forrest & Cornelisen 2015; Keeley et al. 2015) and for the Nelson Bays region (Newcombe & Cornelisen 2014), which have illustrated that:

- Coastal monitoring is often conducted in a fragmented way in which there is poor alignment of consent-related environmental monitoring (undertaken by consent holders), State of the Environment (SOE) monitoring undertaken by councils, and monitoring undertaken by other stakeholders (e.g. industry).
- Regional monitoring efforts typically fail to adequately reflect the full range of potentially significant stressors that may impact on the CMA, and do not measure their cumulative effects nor necessarily target the values most at risk.

More importantly, the studies show there is the potential to greatly improve on existing approaches to achieve considerable gains in the efficiency, efficacy and transparency of monitoring for all stakeholders, along with potential cost savings. Realising such outcomes first requires an evaluation of the scope for collaborative and integrated monitoring approaches.

This report, therefore builds on this previous groundwork, and forms the foundation for initiatives involving MDC, other stakeholders and iwi, to develop and implement an integrated monitoring programme for the Marlborough Sounds. To some extent MDC has already made steps in this direction, as a response to regional monitoring needs that emerged following the 2011 Board of Enquiry (BOI) hearing on the development of new salmon farms in the region (see Box 1). However, this Envirolink project enables the next steps, providing MDC and other stakeholders with the rationale for making long-term decisions in environmental monitoring and information gathering. Specifically, this project aims to:

- define the purpose and types of monitoring relevant to the CMA, and describe some of the generic benefits and considerations for an integrated regional monitoring approach
- identify perceived pressures on the Marlborough Sounds, available monitoring data, information gaps, and barriers to developing an integrated approach, through interviews with some key marine stakeholders and iwi
- describe existing coastal water quality monitoring and data availability, and assess the efficacy of existing monitoring in the context of actual or perceived pressures
- outline issues and options for enhancing coastal water quality monitoring through the development of real-time monitoring platforms such as moored instruments
- consider the next steps towards development of an integrated regional monitoring programme for the Marlborough Sounds.

Box 1. Need for integrated environmental monitoring: Salmon farm expansion case study

The majority of New Zealand's farmed salmon (Chinook or King Salmon, *Oncorhynchus tschawytscha*) is produced in the Marlborough Sounds by the New Zealand King Salmon Company Limited. In 2011, New Zealand King Salmon applied to the Environmental Protection Authority (EPA) to change the Marlborough Sounds Resource Management Plan to enable development of nine new salmon farms in the region. During the resulting EPA Board of Inquiry (BOI) process, issues relating to seabed and water quality effects came under particular scrutiny, and illustrated a need for a more integrated approach to environmental monitoring.

Water quality effects, especially the potential for nutrient enrichment and harmful algal blooms, were perhaps the most contentious issues. It was evident that the response to nutrient enrichment from the salmon farms could occur beyond their immediate environs (e.g. across scales of kilometres), thus the influence of the farms needed to be considered in light of the cumulative effects of other nutrient sources and sinks. A key gap was a lack of SOE monitoring data for the Marlborough Sounds that could be used to establish baseline conditions and validate models. Simultaneously, there were insufficient data to determine the trophic status of the Marlborough Sounds, and the system's ecological carrying capacity.

This situation meant that the level of uncertainty with regard to the effects of the proposal was greater than would have been the case if more extensive data had been available. According to Eccles (2013), this is reflected in the final decision of the Board of Inquiry (BOI):

> *The uncertainty about the capacity of the Marlborough Sounds marine environment to assimilate the modelled nitrogen discharges from the farms sought was a troubling factor for the Board, which bemoaned the lack of available research and monitoring data…The need to monitor and understand the capacity of the receiving environment should be heeded in other areas of the country where aquaculture expansion or intensification is sought.*

The New Zealand King Salmon example illustrates the importance of an appropriate level of regional environmental knowledge, and monitoring datasets of sufficient duration, to provide greater certainty regarding the effects of consented activities in the context of other natural and human activities that affect the CMA. The BOI eventually granted consent for three new farms, and required New Zealand King Salmon to conduct regional-scale baseline and ongoing water quality monitoring.

Simultaneously, MDC developed a broad-scale SOE monitoring programme that provides contextual monitoring data to support the consent-related environmental monitoring of New Zealand King Salmon. This ongoing programme is discussed in Section 5.

2. GENERAL CONSIDERATIONS FOR MONITORING

2.1. Scope of stressors and cumulative effects

Developing effective environmental monitoring programmes requires an understanding of how various activities lead to environmental changes in the CMA. In general, anthropogenic activities on adjacent land and in the CMA itself lead to a range of stressors that contribute to key threats to marine ecosystems, including pollution, resource use (e.g. fishing), the introduction and spread of harmful marine organisms, and habitat modification and loss (Figure 1). Stressors are factors or processes that lead to negative effects on ecosystem components, including lethal and sub-lethal effects on organisms, their populations and the communities and habitats they form. Some stressors occur naturally in the marine environment and may be influenced by episodic effects (e.g. increased sediment and nutrient inputs during floods) and longer-term chronic changes (e.g. shifts in sea-surface temperature and ocean acidification due to climate change). Natural stressors can be exacerbated by anthropogenic activities, as in the case of land use and related enhanced rates of sedimentation and nutrient delivery. The CMA is also directly affected by activities such as fishing, aquaculture and coastal discharges that disturb or modify natural habitats, and from the introduction of harmful organisms (e.g. marine pests) that can lead to irreversible regional-scale impacts.

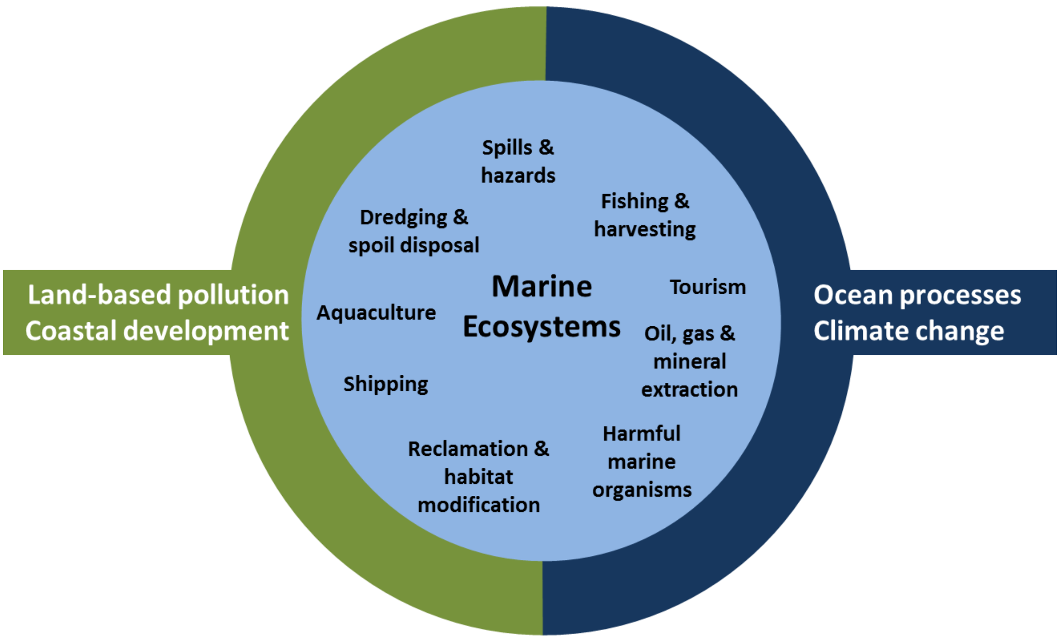


Figure 1. Generic sources of anthropogenic and natural stressors in the CMA. Human influences arise from direct activities in the CMA, and land-based sources in adjacent catchments and coastal margins. Marine ecosystems and human influences are also modified by larger-scale processes (source: Forrest & Cornelisen 2015).

Many of the human activities that give rise to stressors or effects in the CMA are managed through the resource consent process; however, some fall outside the consenting process (e.g. diffuse source[1] stressors) or lie outside the control of councils (e.g. fisheries). An important consideration with regard to environmental monitoring and management of the CMA is that multiple stressors can interact in complex ways and cumulatively degrade marine ecosystems. An example is the process of eutrophication, which is driven by nutrient loading from multiple sources and exacerbated by other stressors such as overfishing, and the loss of habitats (e.g. seagrasses, wetlands) that play an important role in nutrient retention. Cumulative effects can operate on different spatial and temporal scales, and can arise as a result of both additive and synergistic processes (MPI 2013).

Although most people broadly understand the concept of cumulative effects, widely accepted or standardised approaches to measuring and managing such effects have not yet emerged in practice (Duinker & Greig 2006). Addressing cumulative effects is inherently complex, and requires, among other things, approaches that not only consider the contribution of effects from individual developments, but also regional assessment and monitoring of wider environmental change (Dubé 2003). Addressing cumulative effects in a comprehensive manner is a significant management challenge globally. However, the development and eventual implementation of an integrated regional approach to monitoring is clearly a useful starting point that will better enable cumulative effects to be characterised and addressed in the future.

2.2. Purpose and types of environmental monitoring

Environmental monitoring can be broadly defined as a suite of activities that aim to characterise baseline conditions, track changes and establish trends in parameters used to describe or enable assessment of the status or quality of the environment or associated resources. The two types of environmental monitoring that councils such as MDC generally require or undertake are:

- Consent-related environmental monitoring: for the purpose of gauging the environmental effects of a consented activity. This type is usually limited to monitoring of effects that can be directly linked to specific activities; hence often involves local-scale surveys. Examples are water quality or seabed monitoring that focuses on the immediate environs of a point-source activity.
- SOE monitoring: for the purpose of providing a generalised indication of environmental condition and quality. Councils are required to monitor the state of the environment to the extent that is appropriate to enable them to effectively carry out their functions under the Resource Management Act 1991 (RMA s35(2)(a)).

[1] The term ‘diffuse sources’ is a catchall for stressors that don’t arise from one or a few discrete and easily managed point sources. Examples include run-off from land into the CMA (e.g. of sediments, nutrients or faecal contaminants) and diffuse sources within the CMA itself. In its broadest sense the latter includes ‘contaminants’ introduced by vessels, such as petroleum hydrocarbons, faecal bacteria and harmful marine organisms.

SOE monitoring tends to (or should) focus on broad-scale changes in select indicators that are representative of environmental conditions. Effective SOE monitoring can provide the baseline conditions and broad-scale trajectories and changes in the receiving environment alongside the pressures potentially impacting the system.

In addition to monitoring conducted by councils, other stakeholders may undertake monitoring for their own purposes to fulfil needs unrelated to immediate council requirements and obligations. Examples relevant to Marlborough include the following:

- monitoring of water quality and harmful algae species to understand production risks to aquaculture
- marine reserve monitoring undertaken by the Department of Conservation
- monitoring of fish stocks undertaken by the Ministry for Primary Industries (MPI)
- surveillance for marine pests undertaken by NIWA for MPI.

As the water quality case study in Section 5 demonstrates, there is enormous potential benefit to be gained from integrating council monitoring with some of these wider initiatives. However, it is important to acknowledge that monitoring is one component of a larger toolbox for managing the environment, and there are limitations to what monitoring can realistically achieve. For example:

- For some activities, suitable monitoring indicators (or associated environmental standards) may be unavailable or impractical to implement (e.g. due to high cost).
- Monitoring alone may be limited in its ability to attribute measured effects to a particular activity; for example, where impacts are confounded by multiple stressor sources.
- There may be a spatio-temporal 'disconnect' between a stressor and the expression of its effects. This issue of 'far-field' effects has been recognised in relation to both the water column (see Box 1) and seabed impacts (Keeley 2012) of salmon farming in the Marlborough Sounds.
- The actual or potential effects of a particular activity may simply be poorly understood. For example, the potential for negative effects arising from aquaculture due to genetic changes in wild populations, and 'escapee' effects on natural ecosystems, are well-recognised but poorly understood issues (MPI 2013).

In essence, monitoring may not always be feasible or helpful, or situations may arise where further research is needed to better understand effects. Among other things, it is therefore important that a broader framework has a process that enables knowledge gaps to be addressed, and encourages the implementation of 'best management practices' that aim to minimise actual or potential environmental effects, irrespective of known risks and uncertainties.

2.3. Context for the Marlborough Sounds

A large amount of data from environmental monitoring and assessment programmes has been collected historically in the Marlborough Sounds, and continues to be collected for a range of purposes. The many past and present initiatives provide information that will underpin or otherwise assist in the development of an integrated monitoring approach.

Outside Marlborough specifically, there are also recent or ongoing national initiatives that are pertinent to development of an integrated monitoring approach. Some of the key ones were described by Forrest and Cornelisen (2015) and are not discussed here.

In addition to ongoing coastal water quality monitoring detailed in Section 5, there are many past and present initiatives that provide key information for advancing improved approaches to monitoring in the Sounds[2]. Examples include:

- Various syntheses of historical data, which enable easier access to information that was previously dispersed (e.g. Broekhuizen 2013; Handley 2015).
- Specific studies of the effects of some key activities, such as NZKS salmon farms (e.g. Keeley et al*.* 2013) and ferry wakes (e.g. Davidson et al*.* 2010). These studies not only assist in understanding of impacts, but also provide broader geographic knowledge of environmental status and trends (e.g. via data from reference sites that are used as benchmarks against which effects have been assessed).
- Reports and studies that identify some of the most important values in the CMA (e.g. Davidson et al*.* 2011), which in turn can identify components of the environment that it may be most important to monitor. This is especially the case where there is a strong interaction between the most important values and the most significant anthropogenic pressures.

In relation to the last bullet point, a snapshot of some of the existing consented activities in Marlborough (Figure 2) highlights considerable regional pressure on the CMA. There are numerous marine farms and coastal discharges within the CMA itself, and discharges in adjacent contributing catchments. Influences from discharges to freshwater, as well as other land-based activities that impact on the quality of freshwater systems, will ultimately affect the CMA. Our limited scope has not enabled us to consider these pressures in detail, nor the monitoring that is required as part of the various consented activities. However, an in-depth assessment in these respects will be critical for further development of an integrated monitoring programme.

[2] A comprehensive listing of MDC's coastal monitoring and assessment reports can be found on the MDC website at: http://www.marlborough.govt.nz/Environment/Coastal/Coastal-Reports.aspx

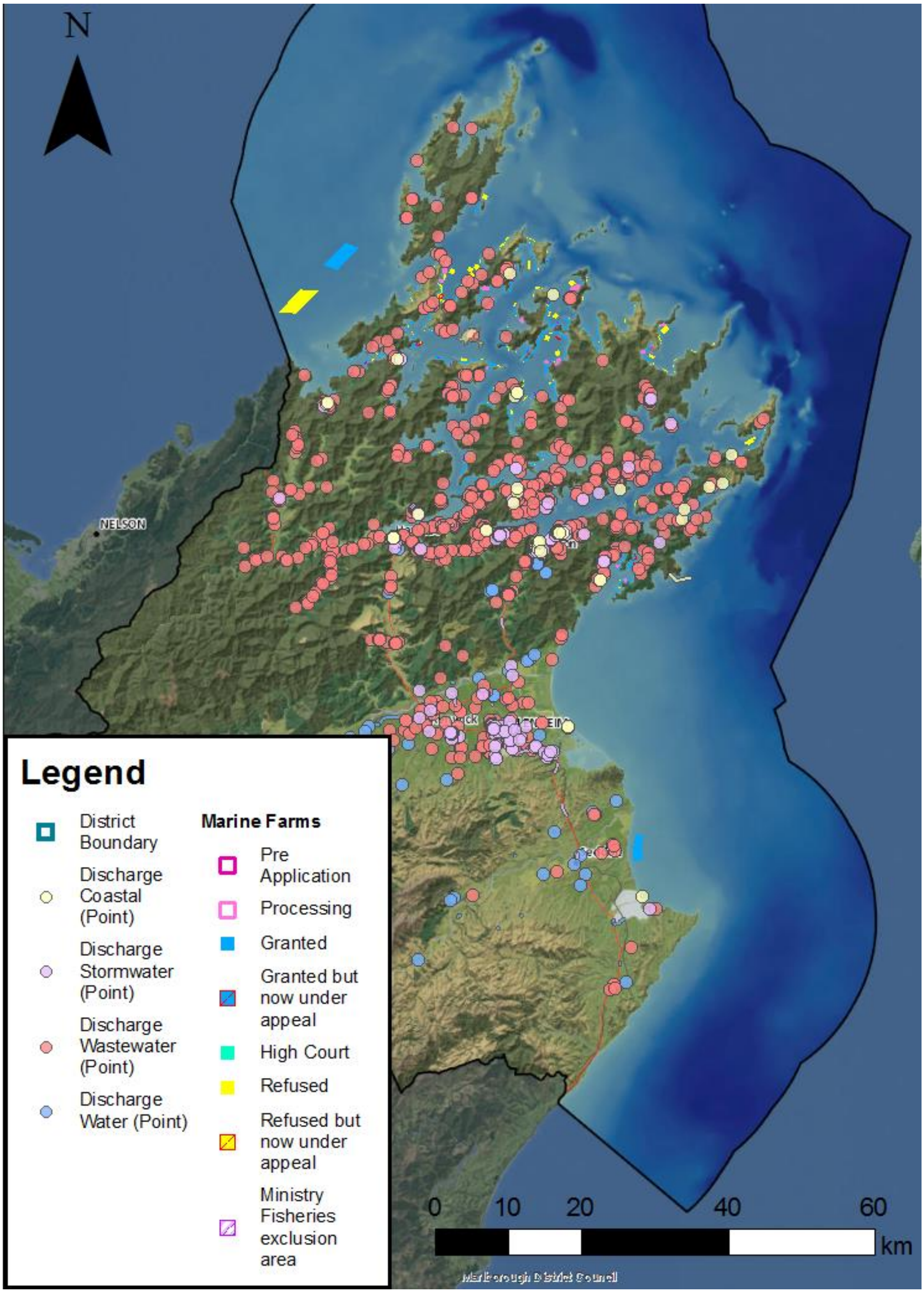


Figure 2. Discharge consents and marine farms within the Marlborough District Council region and coastal marine area. Sourced from MDC web-based GIS services (also accessible from web-based Smart Maps: https://maps.marlborough.govt.nz/smartmaps).

Our overall impression gained from experience in working on resource management issues in the Sounds, and also highlighted during the interviews described in Section 4, is that existing monitoring within the CMA is somewhat fragmented. For example, with the exception of the coordination between New Zealand King Salmon and wider SOE water quality monitoring (see Box 1 and Section 5), there appears to be no integration or coordination of monitoring efforts. Moreover, where monitoring is required it is limited in scope or lacks consistency among similar activities in terms of the breadth and depth of what is required (e.g. indicators measured, monitoring frequency).

Simultaneously, it is also arguable that the nature and extent of consent-related environmental monitoring is not always justified or commensurate with the level of actual or potential risk or the scale of the various activities or pressures. For example, existing marine farm monitoring focuses on seabed and water quality issues for salmon farming (monitoring required for mussel farms is limited), and does not account for other ecological effects that may be important for marine farming (MPI 2013). Although the benthic and water quality effects of salmon farms are more pronounced than for other types of marine farming (Forrest et al. 2007; Keeley et al. 2009; MPI 2013), only a small proportion of the marine farm space in Marlborough is consented for salmon farming (c. 1%). The remaining 99% of space (c. 2,500 ha) is consented primarily for mussel farms.

Even though the site-specific benthic and water quality impacts of mussel farms are understood generically, the broader ecosystem and cumulative effect of aquaculture alone and in combination with other pressures (consented or otherwise) are not well understood. This type of uncertainty underlies many questions that arise for MDC, some of which emerged during our interviews (see Section 4). What is the relative importance of land-based and diffuse-source stressors to point-sources? How much pressure can the Marlborough Sounds withstand? What are the tipping points for the system or some of its important values? How do we discriminate anthropogenic change from natural variability?

Finally, and most importantly in the context of this report, monitoring can be improved to: (i) help answer some of the preceding questions; (ii) track the ongoing status and trends of the Marlborough Sounds environment in a transparent, and systematic way that reflects the nature and extent of risk (i.e. according to stressors, their consequences, and the values at risk); and (iii) facilitate improved management outcomes. The present situation combined with the large coastal extent of narrow water ways within the Marlborough Sounds, creates a nationally unique and challenging environment for coastal monitoring, which points to the importance of developing an improved and integrated approach.

3. FRAMEWORK FOR INTEGRATION AND ASSOCIATED BENEFITS

Some of the considerations for developing an integrated regional monitoring approach were discussed by Forrest and Cornelisen (2015) as part of a series of related projects undertaken for Waikato Regional Council. Although that work focused on the integration of SOE monitoring and consent-related environmental monitoring (i.e. it excluded consideration of wider stakeholder initiatives), the six-step framework that was developed is directly relevant to integration of monitoring in the Sounds and is reproduced in Figure 3. Some of the key issues discussed in the Waikato report formed the basis for interview questions described in Section 4.

The initial two steps advocated by the framework involve the definition of clear goals for monitoring (Step 1), based on policy and coastal plan objectives, and determining sources of risk to the CMA so that monitoring priorities can be determined based on actual or potential effects (Step 2). For the latter, collation of existing information, and identification of key information gaps or uncertainties, is the first stage in process of determining monitoring priorities. This needs to be followed by identification of values at risk, and actual and potential effects on those values. Various regional risk-based assessment methods are available that can assist in this type of undertaking (e.g. Landis 2005).

The purpose of Step 3 is to identify the linkages between the different types of monitoring that were described in Section 2.2. With respect to SOE and consent-related environmental monitoring, Forrest and Cornelisen (2015) suggested that SOE monitoring in an integrated programme should:

1. **Align with, and provide a direct context for, understanding the effects of consented activities**

   Consent-related environmental monitoring may be more efficient, cost-effective and meaningful when integrated with broader approaches. For example, in a programme monitoring the seabed effects of aquaculture, local-scale effects could be monitored by the consent holder, with an SOE programme providing reference sites against which local-scale effects were assessed.

2. **Capture trends in background conditions or pressures that may be influenced by diffuse-source pollution and interact with consent-related sources**

   This broader context becomes increasingly important when consent-related effects are non-local, and have the potential to result in cumulative effects through interaction with other anthropogenic activities (the NZKS example in Box 1 is a case in point). With an increasing spatial scale of influence, there will typically be an increased need for consent monitoring to be integrated within a regional SOE programme.

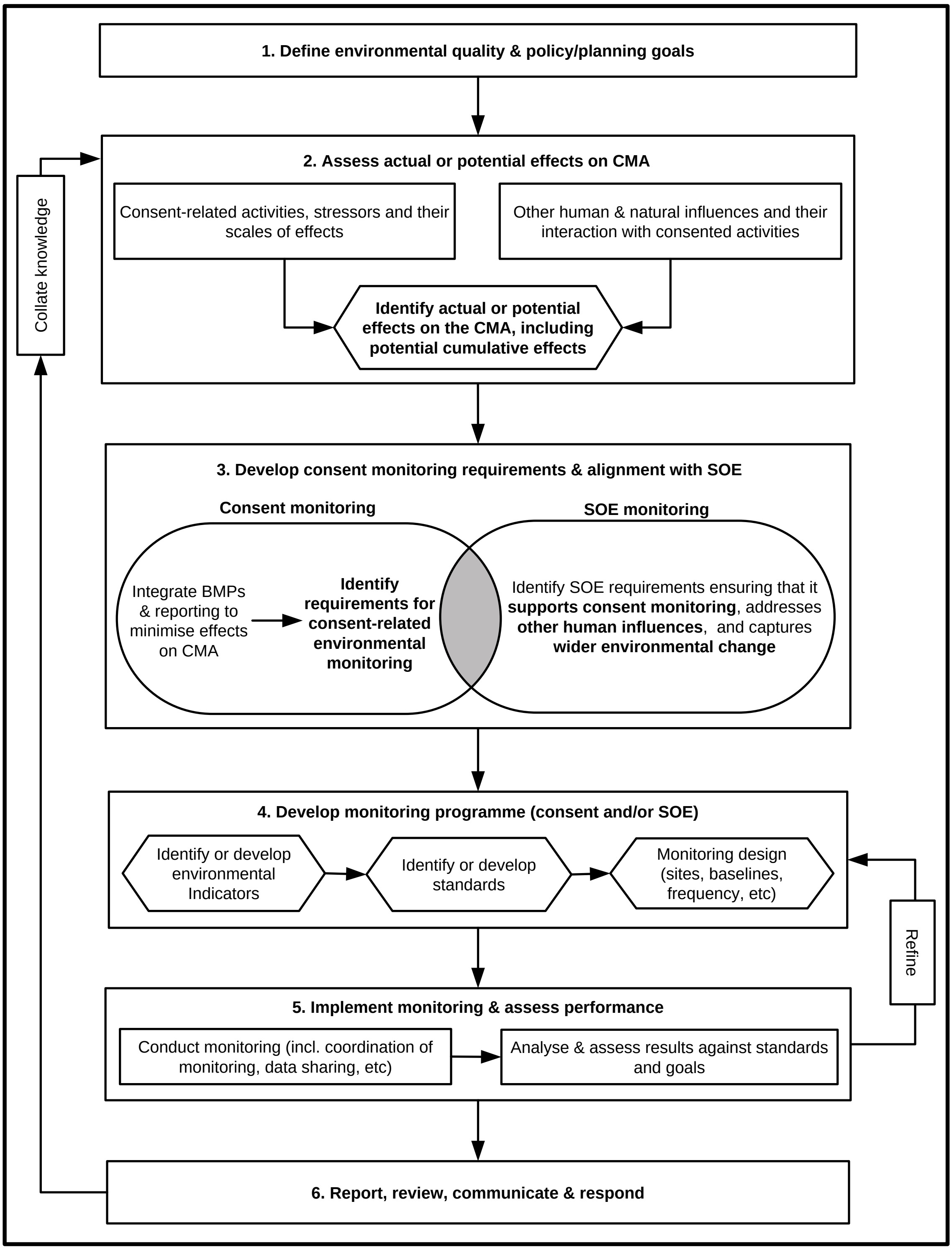


Figure 3. Regional monitoring framework developed for Waikato Regional Council, outlining key steps in the development of a programme that integrates consent-related and SOE monitoring (source: Forrest and Cornelisen 2015). For MDC it is also relevant to consider the scope for incorporating wider stakeholder monitoring into such a framework.

3. **Capture trends in background environmental conditions that may have no recognised or direct link with consented activities or other anthropogenic effects**

   The potential importance of SOE monitoring for this purpose should not be overlooked. For example, the introduction of a marine pest (e.g. as a result of vessel biofouling) could ultimately be followed by regional-scale spread and establishment, and irreversible ecological changes to the regional coastal environment. While such events may be unrelated to consented activities, they clearly have the potential to influence background or reference conditions against which the effects of consented activities may be assessed.

An additional consideration for MDC is the extent to which monitoring by other stakeholders and iwi can be integrated into a regional programme, and the barriers to achieving this, which are discussed in Section 4.

Steps 4, 5 and 6 of the Waikato Regional Council framework concern the process of development and implementation of an integrated monitoring programme, as well as the assessment of results, and subsequent actions. The process of identifying the actual requirements of a monitoring programme needs to consider many technical and non-technical aspects, the latter including iwi and stakeholder expectations. Some key technical considerations, which we explore in Sections 5 and 6, include:

- Identifying the suite of environmental indicators that reflect the key pressures
- Determining the 'nuts and bolts' of monitoring design and method. Some of the considerations for MDC in the context of an integrated approach could include:
    - Monitoring representative activities or habitats/sites to improve monitoring efficiency and reduce cost. Consent holders may be able to take a 'consortium' approach for this purpose, such as developed for aquaculture monitoring in the Firth of Thames (e.g. Taylor et al*.* 2012).
    - Identifying where existing or emerging technologies could be used to enhance efficacy or reduce monitoring costs; e.g. real-time water quality monitoring platforms as discussed in Section 6.

One of the ideas raised by Forrest and Cornelisen (2015) is the concept that the monitoring programme be managed or coordinated by a single organisation. This concept is explored with stakeholders in the next section. The benefits of a centralised approach promoted by Forrest and Cornelisen (2015) include the following:

- scientific consistency in monitoring; for example in terms of methods used, and timing of monitoring (e.g. coordinated timing of SOE and point-source sampling)
- improved quality control of monitoring design and data, and perhaps increased stakeholder 'trust' in the results
- centralised storage for monitoring data, possibly enabling stakeholders to access the data or data summaries

- standardised approach to evaluation of results and assessment of environmental quality from a regional perspective, contributing to a consistent management response and facilitating an improved understanding of cumulative effects.

Finally, one of the longer-term benefits of developing a robust regional time-series of data is that it can contribute toward developing criteria or standards for environmental quality in situations where they do not exist. This was one of the outcomes from more than a decade of monitoring the seabed effects of New Zealand King Salmon's salmon farms and associated regional reference sites. The regional reference data enabled evaluation of baseline conditions, which was essential to the calculation of biotic indices that are widely used to evaluate point source seabed effects of aquaculture (Keeley et al*.* 2012b). These indices, together with other data (biological and physico-chemical) from reference and impacted sites (i.e. beneath and next to salmon cages), were subsequently used to develop a novel seabed enrichment index (Keeley et al*.* 2012a) that is now used by MDC as one of the key environmental standards against which the impacts of salmon farms are assessed (Keeley et al*.* 2014).

4. STAKEHOLDER PERSPECTIVES IN MARLBOROUGH

4.1. Background

Cawthron staff (Natasha Berkett, Chris Cornelisen) conducted semi-structured interviews with key stakeholder and iwi representatives (Table 1) to identify knowledge needs and gaps (including data and information gaps), advantages and barriers to setting up an integrated monitoring approach, willingness to participate in a monitoring consortium and opportunities for data sharing. Before the interviews, interviewees were supplied with an information sheet on the purpose of the study and a list of questions (Appendix 1), and their written consent was obtained. Each interview was recorded and transcribed for later analysis.

Table 1. Summary of the 11 organisations interviewed (14 interviewees in total) regarding data and information needs, gaps in current knowledge, and approaches to developing an integrated monitoring approach.

Organisation	Number of representatives interviewed	Interview date	Location or method
Aquaculture New Zealand	1	16 June 2016	Nelson
Marine Farming Association	1	20 June 2016	Marlborough
Marlborough District Council	3	20 June 2016	Marlborough
Marlborough Forest Industry Association	1	20 June 2016	Marlborough
Marlborough Marine Futures	1	16 August 2016	Via phone
Marlborough Shellfish Quality Programme	1	29 June 2016	Via phone
Ministry for Primary Industries	2	28 June 2016	Nelson
New Zealand King Salmon	1	22 June 2016	Nelson
Ngai Tahu Seafoods	1	20 June 2016	Marlborough
Paua Industry Council	1	5 August 2016	Nelson
Te Atiawa Trust	1	22 June 2016	Via phone

Analysis of interview transcriptions was undertaken by two of the report authors (Berkett and Newton) in accordance with the method of Cope (2010). The responses of interviewees were grouped under seven main themes; knowledge needs, knowledge gaps, willingness to participate in a consortium, advantages of consortium approach to interviewee’s organisation, barriers to participation, data storage and other. The transcribed information is detailed in Appendix 2, with a summary below.

4.2. Knowledge needs and gaps

Knowledge needs identified by interviewees centred around the need for monitoring data and information to inform policy, manage the effects of activities undertaken in the marine environment and help inform decisions on resource consent applications (e.g. SOE monitoring, consent monitoring). Needs identified also included ensuring shellfish food safety as part of the Marlborough Shellfish Quality Programme (MSQP).

Interview respondents identified the following knowledge gaps:

- long-term datasets for establishing environmental 'baselines' and determining environmental carrying capacity
- the cumulative effects of different stressors arising from marine and land-based activities and natural events (note, the source of stressors was of particular interest, for example what activities are leading to sedimentation in the Sounds?)
- the effects of climate change (e.g. on water temperature, acidification) and predictions around future consequences for ecological systems and anthropogenic activities
- appropriate spatial and temporal data to facilitate management decisions (including areas not currently monitored; e.g. Port Underwood)
- sufficient knowledge of the environment to be able to understand how ecosystems could be artificially improved
- algal bloom patterns and spatial and temporal trends for chlorophyll-*a* (a proxy for phytoplankton biomass)
- water quality information for optimum food production
- spat monitoring counts
- coastal hydrodynamics (e.g. wave action)
- cultural indicators.

4.3. Willingness to participate in a consortium

There was universal support for the idea of a consortium approach to marine monitoring in the Marlborough Sounds. Most respondents felt their organisations would also contribute financially and/or 'in kind' to the setup and running of the consortium, subject to some barriers being addressed (see below).

4.4. Advantages of consortium approach to interviewee's organisation

The benefits of a consortium approach included those described in Section 3, as well as other advantages. Respondents identified cost efficiency as a key benefit arising from an integrated approach to marine monitoring and felt that there would be a reduction in monitoring costs to individual organisations/ groups. Another key perceived advantage was the ability to integrate data collection for multiple purposes and better align it with sources of data (e.g. satellite data) not currently utilised. Respondents also acknowledged the social benefit of the consortium approach, including a shared agreement of the problems being addressed, agreement on what data should be collected and where, agreement on monitoring and analytical methods, and the generation of trust between organisations aligned to the consortium.

In addition to the above, we note that some interview respondents were unaware of the different types of information currently collected, whether it could be accessed or how they could use it. A consortium approach would assist in communicating what is available and accessible.

4.5. Barriers to participation in a consortium

Barriers identified to participating in a consortium broadly included:

- equitable distribution of costs
- commercial sensitivity of data
- whether trust could be generated and maintained between members
- difficulties in reaching agreement on what needed to be monitored, who would be responsible for that monitoring, and what would happen if monitoring exposed problems with industry practice.

These barriers are both real and significant, but with appropriate design and goodwill could be overcome. We suggest that the learnings from collaborative planning literature and experience could be utilised to establish a successful consortium model (see Ansell & Gash 2007; Innes & Booher 2010).

4.6. Data sharing

Most, but not all, interview respondents thought that MDC would be an appropriate agency to coordinate an integrated monitoring programme, and facilitate and 'host' a data sharing platform. Key requirements were that the data interface is user-friendly and that data is in a format that is useful to everyone. Land, Air, Water Aotearoa (LAWA) was frequently mentioned as a model for online data sharing that could be adopted, although we note that this is a federated system used primarily for communicating and sharing results rather than a storage system *per se*. The data are held and retained by the owner in their system and as long as it is discoverable on the web it can be made available through the LAWA portal.

4.7. Other

Interview respondents supported the installation of monitoring platforms, or 'buoys' for the collection of water quality data. However, most interview respondents stated that 'timely' data was more important to their organisations than real-time data.

5. WATER QUALITY CASE STUDY

5.1. Overview

In this section we undertake the following:

- provide a broad overview of existing water quality monitoring activities in the Marlborough Sounds
- evaluate the efficacy of existing monitoring in relation to the:
    - the appropriateness of monitoring indicators, sampling methods, and the scales (spatial and temporal) of sampling
    - the extent to which existing monitoring addresses the pressures on the Marlborough Sounds, in particular the concerns and knowledge gaps identified by stakeholders in the previous section
- outline considerations for addressing deficiencies and improving monitoring.

The focus is on ongoing monitoring programmes. Although our assessment was not exhaustive in presentation of all data sources relevant to the Marlborough region, it aimed to ensure that the key sources are represented. Historical data have not been considered at this stage, as it would be a significant undertaking to source and describe all such information. Notwithstanding this comment, we gave examples in Section 2.3 of previous efforts to synthesise some of the historical data, so these represent useful information sources that are already available.

5.2. Overview of existing water quality monitoring

5.2.1. Marlborough District Council monitoring

As part of its monitoring role, MDC identified the importance of ecologically relevant water quality data for the Marlborough Sounds around the time of the New Zealand King Salmon Board of Inquiry (BOI) process (Zeldis et al. 2011). This led to the formation of a monthly SOE monitoring programme for water quality in the Sounds. The programme began in Queen Charlotte Sound in 2011, with Pelorus Sound added in 2012. The programme involves collection of both 15 m surface-integrated and deep water samples from seven sites in Pelorus Sound and five sites in Queen Charlotte Sound (Figure 4).

Key indicators in the MDC programme include those relevant to understanding nutrient enrichment and productivity issues, namely: phytoplankton species/biomass (including harmful algal bloom [HAB] species), chlorophyll-*a* (a proxy for phytoplankton), turbidity, Dissolved Oxygen (DO) and various nutrients. A conductivity-temperature-depth (CTD) instrument is also used to profile the water column at 11 sites in each sound. Such data assist in understanding the degree of water column stratification (mixing) and vertical patterns in key indicators. This work has added significantly to the pool of knowledge of temporal and spatial trends in water quality in the Marlborough Sounds. The present monitoring effort has been well-considered and provides a strong basis for building on the 'knowledge bank' of regional water quality. However, there is scope for improvement, as we discuss in subsequent sections.

In addition to the above, MDC undertakes weekly surveys in summer to assess the suitability of bathing beaches and other areas for contact recreation. The programme is based on water sampling and analysis for faecal bacteria (enterococci), the levels of which are in turn used as an indicator of human health risk.

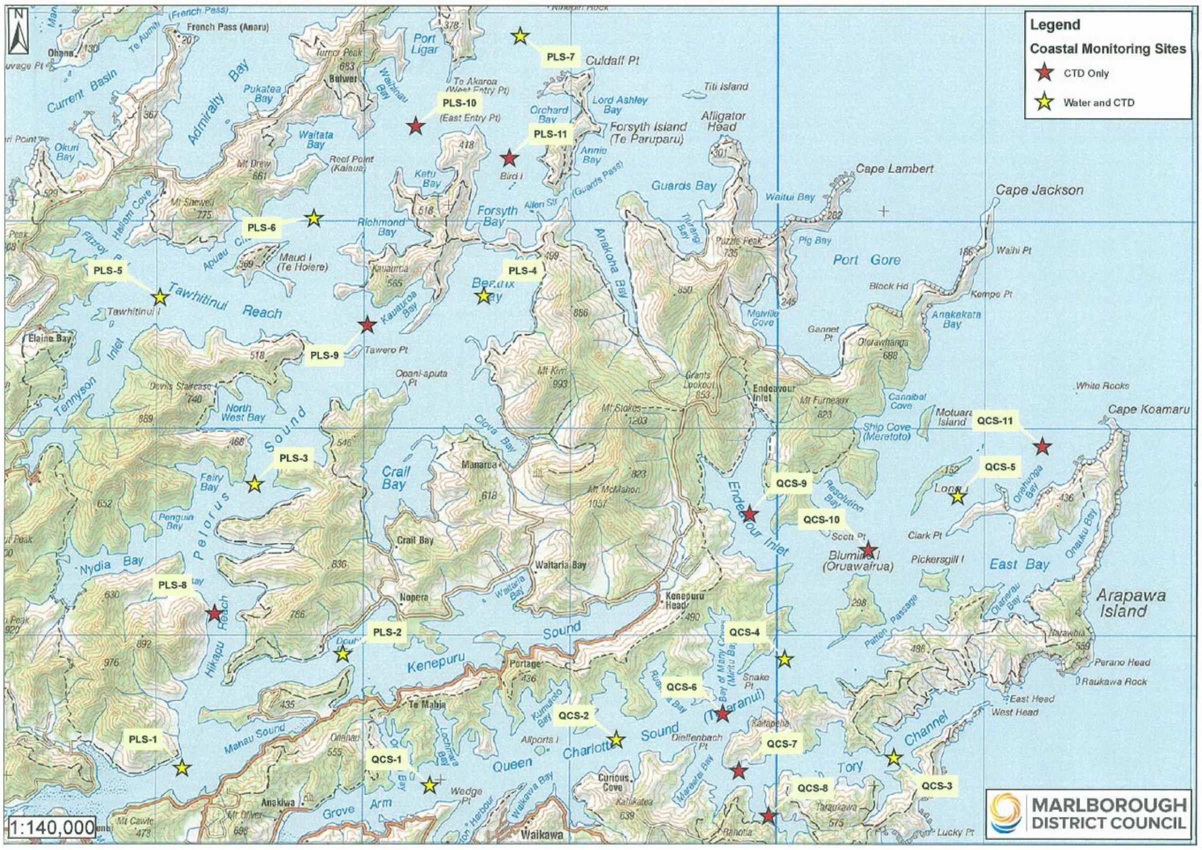


Figure 4. MDC's water quality sampling and conductivity-temperature-depth (CTD) instrument measurement sites in the Pelorus and Queen Charlotte sounds.

5.2.2. Overview of other water quality monitoring

A range of other water quality monitoring programmes are undertaken by regional stakeholders, and certain types of monitoring data are available from remote (satellite) sources. In addition, some stakeholders have undertaken biological monitoring that directly relates to water quality or water column issues, with examples in Box 2. Ongoing water quality monitoring programmes are summarised below. With the exception of New Zealand King Salmon, we have not evaluated water quality monitoring in the CMA required as part of other resource consents (e.g. periodic monitoring for point-source discharges such as a wastewater outfalls).

New Zealand King Salmon

New Zealand King Salmon monitors water quality around their farms based on the same indicators used in the MDC programme. These data are shared with MDC under a memorandum of understanding. New Zealand King Salmon also undertakes additional production-related monitoring (e.g. of DO, temperature, fish health) that are also relevant to understanding water quality more broadly.

Marlborough Shellfish Quality Programme (MSQP)

MSQP is an industry-funded initiative that involves weekly sampling of surface waters throughout the Marlborough Sounds with the primary aim of ensuring the safety of harvested shellfish. Key indicators of interest include harmful phytoplankton species (e.g. species that produce biotoxins associated with shellfish poisoning in humans) and faecal indicator bacteria (faecal coliforms). A crude assessment of phytoplankton biomass is also made. Historically, MSQP have also collected a broader range of water quality monitoring data (e.g. including nutrient, chlorophyll-*a*), which were summarised by Broekhuizen (2013).

Cawthron

As part of the ongoing *Safe New Zealand Seafood* programme, Cawthron has collected water quality and harmful phytoplankton data from a site in Opua Bay near Tory Channel since 2011. Monitoring involves a mix of deployed sensors and weekly sampling over summer and will likely continue for at least the next three years. Indicators monitored include temperature, nutrients, chlorophyll-*a*, phytoplankton cell counts, and occasional data on the abundances of *Alexandrium* cysts.

NIWA

NIWA have historically collected significant long-term datasets in Pelorus Sound as part of their core-funded coasts and oceans programme and shellfish aquaculture research. Ongoing coastal water quality monitoring in the region is limited, but data are collected regularly in Beatrix Bay (Laverique and West Beatrix), which should continue until at least July 2017 (pers. comm., Niall Broekhuizen, NIWA).

Satellite imagery

Although not formally part of current monitoring programmes, satellite imagery is collected continually for the region as part of international earth observing programmes. Different types of satellite data are available; depending on the satellite, there is potential to derive information on sea surface indicators such as water colour, turbidity, temperature and chlorophyll-*a*. Regional tuning of satellite algorithms can assist in the production of reliable indicators and use of satellite imagery as a monitoring tool (e.g. Knight & Jiang 2014).

Box 2. Examples of stakeholder biological monitoring in the Marlborough Sounds that relate directly to water quality or water column issues

Marlborough Shellfish Quality Programme (MSQP): As well as monitoring of shellfish growing waters (see text), the MSQP programme directly assesses shellfish safety based on analysis of *Escherichia coli* bacteria in shellfish flesh.

Mussel Farming Association (MFA): Since 1975 the MFA has monitored weekly recruitment of green-lipped mussels (*Perna canaliculus*) and blue mussels (*Mytilus galloprovincialis*) at various sites and depths in the Marlborough Sounds. These data have recently been summarised in a web-based application described by Atalah et al. (2016). As *Perna* and *Mytilus* larvae have extended planktonic durations, their recruitment patterns could be regarded as a useful proxy indicator for zooplankton prevalence across the Marlborough Sounds. As such, these data may assist in resolving the issue of zooplankton depletion by mussel farms, and can be considered as a proxy index of zooplankton survival against a range of other stressors (e.g. ocean acidification, sediment or waterborne toxins).

Mussel farming companies: Mussel farming companies undertake extensive production monitoring (e.g. of mussel growth and condition) during the grow-out cycle, especially leading up to harvest. These types of data can be regarded as integrated measures (i.e. over the length of a harvest cycle) on the trophic state of mussel growing environments. For example, fast growth rates may be indicative of general environmental ‘enrichment’ (e.g. Zeldis et al. 2013).

5.3. Quality and efficacy of existing water quality monitoring

Table 2 summarises and evaluates the existing water quality monitoring programmes that are ongoing in Marlborough. Note that for present purposes we have presented the coordinated monitoring of MDC and New Zealand King Salmon with respect to nutrient enrichment issues as an integrated programme. In reality they are two separate coordinated programmes with MDC providing the broad regional context and New Zealand King Salmon the fine-scale sampling in and around each salmon farm. Monitoring data from sources other than New Zealand King Salmon are not currently being used to inform MDC’s own monitoring and management efforts. Potential reasons for this include the following:

- Data are known to MDC but are not easily accessed. For example, MSQP harmful algae and indicator bacteria data are not publically available. Historically, however, permission has been gained from MSQP to analyse their data for various reasons (e.g. Hopkins et al. 2004; Broekhuizen 2013).

Table 2. Sources of ongoing water quality monitoring in the Marlborough Sounds region, subjectively rated based on their usefulness to SOE monitoring in terms of reliability of the methods used, the appropriateness of the indicators, and their resolution in time and space. Ratings shown are good (☺), satisfactory (😐), poor (☹) or unknown (?). Table continues on next page.

Source (data owner/ custodian)	Publically available?	Presently used by MDC?	Location	Water column properties	Frequency (period)	Depth	Reliable methods?	Appropriate SOE WQ Indicators?	Adequate for SOE?	
									Time	Space[1]
MDC & NZKS unpublished data (MDC/NZKS)	Y	Y	All Sounds and salmon farms	Phytoplankton species/biomass, chl-*a*, turbidity, DO and nutrients	Collected monthly (20/7/2010 to present, MDC)	Surface & deep	☺	☺	☹	😐
NZKS operational monitoring (NZKS/NZKS)	N	N[2]	Around salmon farms	DO and temperature	Several times per day or continuous (farm initiation to present)	Surface & deep	?	☺	☺	😐
Satellite: USGS EarthExplorer Website (NASA/USGS)	Y	N	LandSat satellites	Water colour information (may enable derivation of turbidity, chl-*a* temperature, etc)	16 day (1980s to present)	Water surface	?	☺	☹	☺
Satellite: OceanColor Website (NASA)	Y	N[3]	MODIS and VIIRS Satellites	Water colour information (may enable derivation of turbidity, chl-*a* temperature, etc)	3 x daily (2000 to present)	Water surface	?	☺	☺	😐

1 Note that spatial resolution refers to the representativeness of the spatial coverage. For example in the existing MDC and New Zealand King Salmon monitoring very wide areas are covered; however, due to the relatively small volumes that are analysed compared to the large areas they were collected for, it is not clear that the sample results are representative.

2 Note while New Zealand King Salmon water quality monitoring data is shared with MDC under a memorandum of understanding, other less accurate but finer temporal-scale data may exist. For example, monitoring of biologically important factors such as dissolved oxygen or temperature is very important to prevent fish mortalities, so this information may be collected by farm managers during critical periods of the year.

3 This type of data is currently used informally by MDC staff through accessible satellite data portals such as CawthronEye (www.cawthron.org.nz/apps/cawthroneye).

Table 2. (continued)

Source (data owner/ custodian)	**Publically available?**	**Presently used by MDC?**	**Location**	**Water column properties**	**Frequency (period)**	**Depth**	**Reliable Methods?**	**Appropriate SOE WQ Indicators?**	**Adequate for SOE?**	
									Time	**Space**
MSQP Unpublished Data (MSQP/ Cawthron)	N[4]	N	All Marlborough Sounds	Harmful phytoplankton species, faecal indicator bacteria, crude phytoplankton biomass assessment	Weekly (2000 to present)	Integrated surface	☺	😐	😐	😐
NIWA: e.g. Zeldis et al. (2008) (NIWA)	N[4]	N	Beatrix Bay	Phytoplankton species/biomass, chl-*a*, turbidity, DO and nutrients	Previously weekly, presently monthly (1997 to Present)	Surface waters	☺	☺	☹	☹
Safe NZ Seafood Programme (MacKenzie/ Cawthron)	Y	N	Opua Bay[5]	Temperature, nutrients, chl-*a*, phytoplankton cell counts, *Alexandrium* cyst abundance	Continuous and weekly sampling – summer only (2011 to present)	Water Column	☺	☺	😐	☹
MDC	Y	Y	Bathing beaches	Enterococci	Weekly over summer	Surface	☺	☺	😐	😐

[4] Although not publically available, data access may be able to be negotiated.

[5] See MacKenzie et al. (2011, 2012, 2013, 2014). Note that Opua Bay site used in these studies may move to Port Underwood in 2017.

- Data are untrusted, perhaps requiring additional validation so that the potential benefit for MDC is clarified. For example, satellite data often requires local atmospheric correction and regional tuning to provide reliable measurements. Similarly industry data may be mistrusted regardless of the accuracy of the methods used (i.e. based on perception).
- Data may be unknown to MDC. Examples include the Opua Bay and New Zealand King Salmon operational data in Table 2, as well as data types of broader relevance (e.g. mussel industry data described in Box 2).

As indicated in Table 2, there are deficiencies in relation to the scale of monitoring undertaken, especially the temporal scale. For example, MDC's SOE programme involves monthly monitoring. Although monthly monitoring throughout the Sounds is a significant undertaking, we have subjectively graded the temporal scale as poor, as a single point-in-time measurement from a relatively small volume of water is unlikely to be representative of the larger region it is trying to monitor.

The importance of temporal scale can be illustrated by recent high-frequency chlorophyll-*a* measurements in Opua Bay near Tory Channel (Figure 5). The marked variation across short time-scales highlights the potential to miss events, even with weekly sampling, and also highlights that different method of sampling and analysis can provide differing results. Given that a key role of SOE monitoring is to capture trends in background conditions, the temporal scale of monitoring and the associated methods are a key consideration. As noted previously in this report, background water quality may be influenced by environmental attributes that occur over short time-scales; for example, spikes in diffuse-source sediment during floods or nutrient enrichment during wind-driven upwelling events. We suggest that the existing level of monthly monitoring is unlikely to reliably capture these types of background changes.

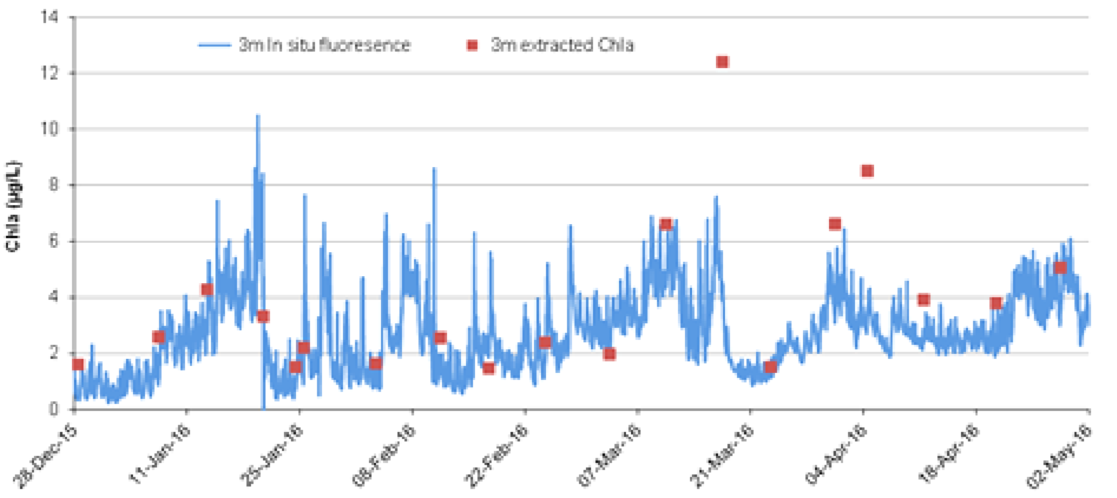


Figure 5. Chlorophyll-*a* (mg/m^3) measured from a moored sensor at 3 m depth within Opua Bay (line) and coincident weekly lab analysed extracted chlorophyll-*a* samples (squares) over January to May 2016. (Source: MacKenzie unpublished data).

We have graded the present MDC and New Zealand King Salmon monitoring as satisfactory with regard to spatial resolution, given the large number of areas that are covered and the use of vertically integrated sampling techniques. However, the small sample volumes collected (< 1 litre) may not reliably represent ambient water quality (see Zeldis et al. 2011). For many of the indicators used by MDC, pronounced variation can occur across all spatial scales (e.g. Gibbs 1993; Gibbs et al. 1991,1992). For example, in the case of chlorophyll-*a*, substantial variation occurs across scales of metres (e.g. around mussel farms; Figure 6) to kilometres (e.g. satellite images; Figure 7). A small volume of water collected monthly is therefore unlikely to provide representative information for a location, and limits the ability to extrapolate results to larger areas (e.g. bay-wide scales).

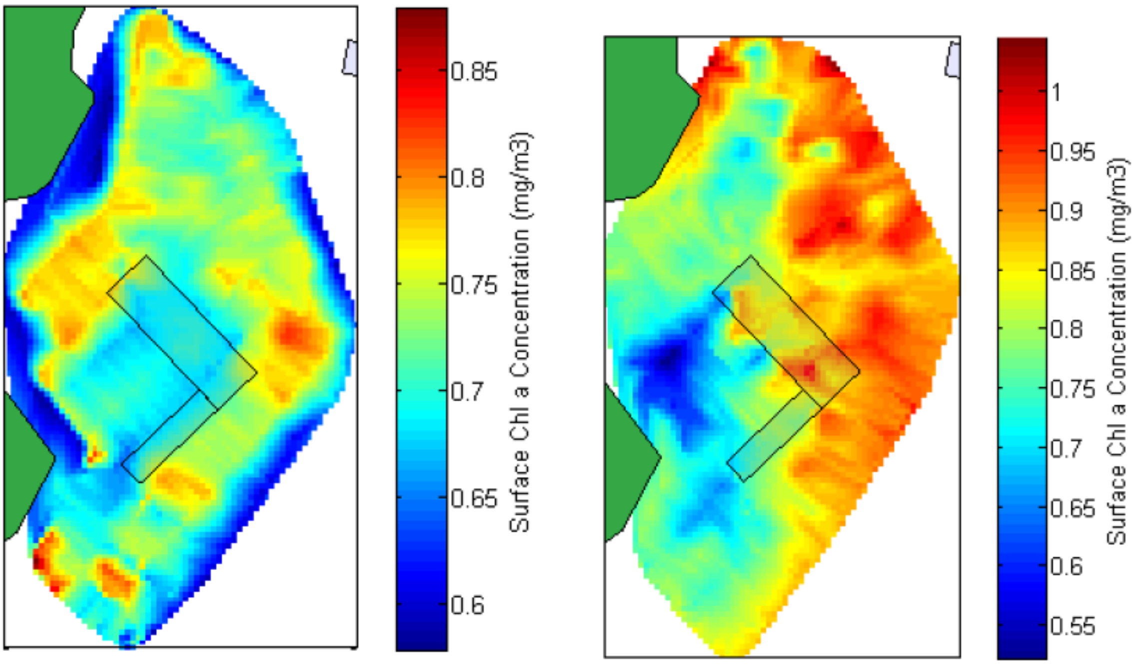


Figure 6. Fine spatial surveys of chlorophyll-*a* around a mussel farming site (mussel farms are shaded polygons) from a location in Port Underwood. Replicate surveys are shown to highlight changes through time (from Keeley et al. 2009).

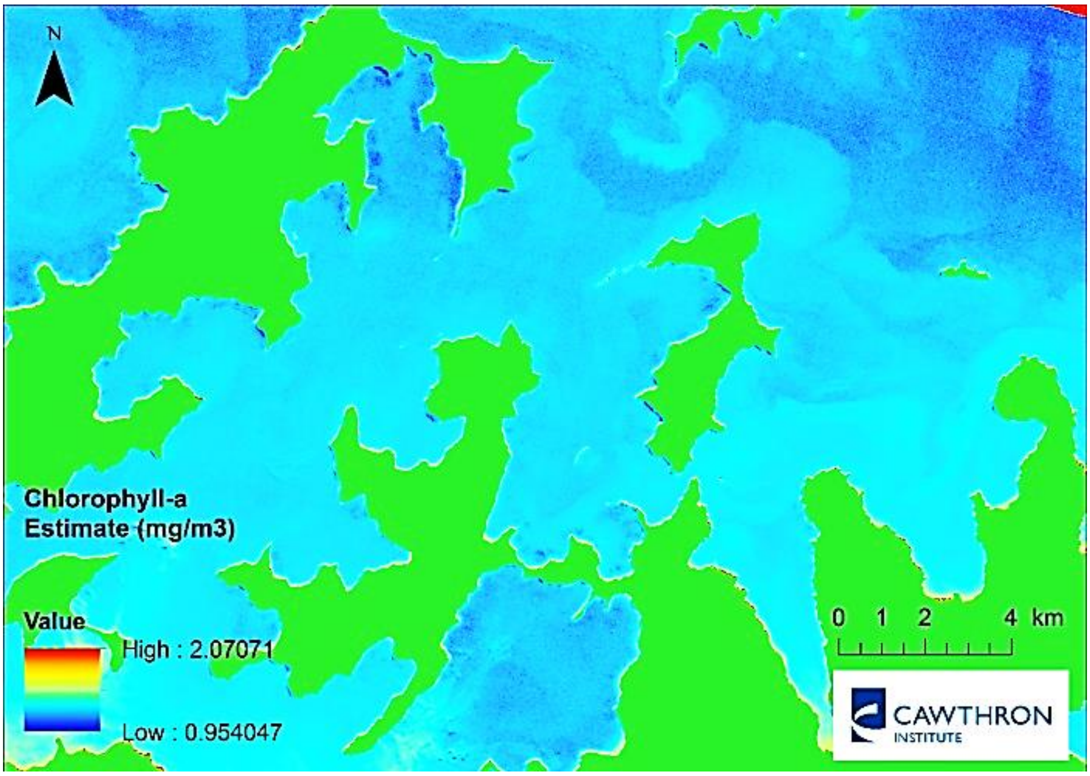


Figure 7. Chlorophyll-*a* estimates (unvalidated) from the LandSat8 satellite for the outer Pelorus Sound (20 April 2016).

5.4. Does existing water quality monitoring address key stressors?

Key stressors of interest relating to regional water quality identified during the stakeholder interviews (see Appendix 2) included:

- sediment run-off, including the importance of different sources, and the consequences for the CMA in terms of turbidity and sedimentation
- nutrient inputs, in particular the importance of different sources, and the risk of eutrophication and harmful algal blooms
- faecal contamination, especially in relation to shellfish aquaculture and recreational or customary shellfish gathering.

Note that although ‘heavy metal’ contaminants were identified as a concern (Appendix 2), no specific source or impact issues were raised. Accumulation of contaminants such as metals also tends to be more of an issue for the seabed than the water column, hence they are not considered further. With respect to factors affecting water quality, we use sediment and nutrient issues to illustrate whether (i) existing monitoring adequately addresses key stressors, and (ii) there are opportunities to better address gaps in data and information through integration. We also consider whether there are gaps beyond existing monitoring in relation to some of the key pressures on the Marlborough Sounds system. Our purpose here is not to identify and resolve every issue, but to use examples to highlight situations where there might be scope for improvement, and for which a more in-depth assessment may be useful.

Does existing monitoring adequately address key stressors?

We use a sediment run-off example to answer this question. The potential for sediment run-off from land-based activities like forestry is recognised by stakeholders as being significant in the Marlborough Sounds. The only existing monitoring of relevant water quality indicators is monthly turbidity monitoring in the MDC programme. However, as discussed above, the monthly time-scale and nature of sampling is insufficient to capture the state of the environment and the episodic events that lead to sediment inputs. Additionally, there is no measurement of other ecologically relevant water quality parameters such as total suspended solids. To improve on this situation, there exist some complementary possibilities:

- investigate the potential for acquisition of broader spatial scale and finer temporal resolution turbidity data from satellites
- investigate the potential for acquisition of near-continuous turbidity monitoring using moored instruments (also perhaps suspended sediments, see Section 6.3.4)
- use the above tools and additional ones (e.g. stable isotopes, lipid biomarkers, mass load studies) to better attribute sediment inputs to sources. MDC has already started some investigations in this respect.

Establishing relationships between turbidity and parameters such as total suspended solids may assist in placing the monitoring data in a more ecologically relevant context. A related consideration for MDC, which is beyond the scope of our report, would be to consider whether existing biological monitoring programmes adequately capture the potential consequences of enhanced sedimentation. Among other things, this would require consideration of: (i) the localities and values most at risk from increased sedimentation; and (ii) the most suitable biological indicators for measuring the ecological impacts of sedimentation.

Is there scope for improved integration of monitoring?

We use a nutrient enrichment example to answer this question. MDC's main SOE monitoring is focused on indicators relevant to nutrient enrichment and primary production. In this respect, there appears to be good alignment between the MDC and New Zealand King Salmon programmes, as described above. Furthermore, the selection of water quality indicators shared in the two programmes are appropriate for evaluating trends in nutrient enrichment status and effects (Table 2). However, key limitations of the existing monitoring as described in the previous section reflect a low temporal resolution of sampling (monthly), and small sample volume collected each month. From these perspectives, it could be argued that monitoring of concentrations of indicators such as nutrients and chlorophyll-*a* in the Marlborough Sounds is relatively poor.

On the other hand, one of the primary concerns regarding nutrient enrichment is eutrophication and the occurrence of HABs. In this respect the MSQP programme could extend the existing MDC programme, since MSQP focuses on regional HAB detection based on weekly monitoring. As such, and in terms of understanding the risk (i.e. one of the adverse potential outcomes) of nutrient enrichment, the MSQP programme has considerable untapped potential. Given some overlap in indicators used between MSQP and MDC monitoring, it would be worth also considering the extent to which there is redundancy in effort (e.g. redundancy due to sampling sites in close proximity to each other). In general, a more in-depth analysis may reveal ways in which MDC, New Zealand King Salmon, and MSQP programmes might all be better aligned to achieve a more efficient and informative monitoring programme for the Sounds.

5.5. Further considerations for water quality monitoring

While the MDC water quality monitoring programme was a step forward at the time of its conception, this report suggests that there is further scope for improvement. Several examples of cooperative data-sharing already exist, such as the memorandum of understanding between MDC and New Zealand King Salmon, and the presentation of historic data collected by MSQP and reanalysed by Broekhuizen (2013). Further efforts to overcome barriers to additional collaboration, and the development of a consortium approach, would not only be an advantage to MDC (e.g. if there were opportunities to access data accumulated from stakeholder monitoring), but also enable industry to benefit from the MDC investment in data collection. The MDC / New Zealand King Salmon collaboration is a working illustration of the potential benefits, but ideally requires an improved SOE context—the ability to determine the effects of salmon farm discharge from background conditions relies on accurately capturing background status and trends.

Difficulties in disentangling anthropogenic and natural effects can potentially be addressed by new technologies, including satellite data (see Table 2) and real-time monitoring in key locations. Such methods could help to improve the understanding of diffuse source effects or large natural changes. The feasibility of these technologies for use in an SOE context has not been fully explored for the Sounds, nor has their ability to assist consent holders in meeting their monitoring requirements. Concepts for real-time monitoring using moored platform are discussed in the next section.

6. NEW APPROACHES AND TECHNOLOGIES

6.1. Overview

The water quality case study highlights that the types of data derived from coastal monitoring programmes (and their spatial and temporal resolution) limit their ability to fully capture background conditions, including variability in the system. The Marlborough Sounds situation typifies that evident in many other regions, where SOE water quality monitoring by councils is based on point measurements of parameters that are inherently variably over small spatial and temporal scales. Largely absent from coastal monitoring programmes in New Zealand is the collection of comprehensive time-series data for basic water quality variables such as water temperature, salinity, turbidity, dissolved oxygen and chlorophyll-*a*.

There are numerous approaches for monitoring and observing ocean and coastal processes, including satellites, aircraft, ships, autonomous underwater vehicles (AUVs) and moored arrays on fixed structures (e.g. piers) or beneath surface buoys. This section focuses on monitoring platforms involving moored instrument arrays, as this is an approach that is increasingly being identified as useful to councils. Monitoring platforms that utilise buoys are well suited to monitoring in ports, estuaries and coastal waters. Many of the alternatives (e.g. AUVs) are designed for open-ocean or very large embayments, and would not be suitable in a relatively confined system like the Marlborough Sounds.

While remote monitoring using fixed platforms is not new, recent advances on a number of fronts (e.g. cellular telemetry, water quality instrumentation, miniaturisation of computer circuitry, solar photovoltaics and battery efficiency) are making these platforms more affordable. Simultaneously, the size of these types of systems is being reduced, which simplifies the infrastructure required for deployment, maintenance, retrieval and storage.

MDC has a particular interest in platform types and their pros and cons, and is looking to integrate its science monitoring with the Harbour Master's navigational safety information needs (meteorological data, and wave and tide information). The general types of moored platforms likely to be relevant to Marlborough were described by Ellis et al. (2012) and are summarised below. We also discuss issues and options relating to platform deployment, telemetry, parameters measured and sensor arrays.

6.2. Types of monitoring platforms

There are a variety of monitoring platforms, ranging from those suited for nearshore waters to those that can withstand open ocean conditions, with three main categories shown in Figure 8. This section focuses on the nearshore and coastal platform types in Figure 8, as these systems are likely to be the most useful to MDC, especially for monitoring conditions in the relatively protected waters of the Marlborough Sounds.

Coastal Monitoring Platforms

	Nearshore	Coastal	Offshore
Description	Typically in protected inland waterways (e.g. sounds, fiords, estuaries) or ports harbours. Can be either fixed to a wharf/seabed or moored	Typically in shallow water out to the 12 mile territorial limit. Usually mid-range in size between nearshore and offshore platforms	Large moored platforms typically in deep water outside the 12 mile limit and out to the EEZ (or beyond). Need to be very robust to withstand oceanic conditions
Examples	Tide gauges, weather (met) stations, wave riders, small water quality buoys	Water quality moorings, wave/tide gauges, current meters, weather (met) stations, etc.	Tsunami early warning (DART), weather (met), global warming
Communication	Cellular or Satellite	Cellular, UHF Radio, Satellite	Satellite (Iridium, Argos, Orbcomm *etc.*)
Price Range ($ = approx $25k NZD)	$ - $$$	$$$ - $$$$$	$$$$ - $$$$$$$$
Image(s)			

Figure 8. Attributes of different moored monitoring platforms for use in nearshore, coastal and offshore waters. Price range is largely dependent on the amount and types of instrumentation deployed on the platform.

Nearshore platforms are typically the smallest and least expensive of the three types, and can be either fixed to a wharf/seabed or moored below a surface buoy. The greatest advantage to such platforms is that they are relatively easily to deploy, recover and service. For example, the small roto-formed polyethylene buoys recently developed by Cawthron (nicknamed the μWQ or 'mu dub que') are able to be deployed and retrieved manually via a davit on a small vessel (e.g. 7 m).

The disadvantage of nearshore platforms is their limited capacity for instrument configurations compared to that of larger coastal platforms (see Section 6.3.5). On coastal platforms, the possible instrument arrays are really only limited by budget; such platforms routinely include weather stations, downward looking Acoustic Doppler Current Profilers (ADCPs), single point current meters and a wide range of water quality sensors. Coastal platforms also have the advantage of being more robust (e.g. able to withstand greater swells and sea conditions), but are more expensive in terms of capital cost and the costs of deployment, recovery and servicing.

6.3. Considerations for implementation

6.3.1. Location of platforms

When considering possible locations for a monitoring platform, both the benefits of a given location and constraints on deployment need to be considered. In the context of the present report, integration with existing monitoring is clearly of primary interest. Therefore, locating platforms in a way that supports MDC's SOE programme would be appropriate. However, some of the constraints to account for include:

- **Proximity to shipping lanes:** Port and harbour approaches and ferry zones should be avoided for obvious vessel navigation and safety reasons. Several of the existing MDC monitoring sites are situated mid-channel in Queen Charlotte Sound, Tory Channel and Pelorus Sound and would not be suitable.
- **Telemetry:** Areas without cellular coverage would pose a problem for telemetry and should be given reduced priority as described below.
- **Depth range:** Within the Sounds the range should be deep enough (e.g. > 15 m) that it affords some protection from large storm surge or vessel wakes, but possibly shallow enough (e.g. < 30 m) that the mooring anchor and hardware can be serviced by divers without being lifted.
- **Distance from nearest maintenance facilities:** Close proximity facilitates repair and maintenance and should be a priority for initial deployments.

6.3.2. Telemetry

Cellular coverage provides the most cost-effective means of telemetry, especially by comparison with costs associated with satellite telemetry. Although cellular coverage in some parts of the Sounds is limited, MDC has radio coverage in areas that may fill blanks in the cell network. Figure 9 shows MDC's monitoring sites in relation to 'black-spots' in the Sounds with no (or limited) coverage that would need to be considered when siting a platform. This map suggests that cellular telemetry would not be possible for sites including: Endeavour Inlet (QCS-09); Onehunga Bay (QCS-11); and Tory Channel (QCS-08). A few of the other sites are in close proximity to areas of limited cellular coverage and may have intermittent communication problems. These include: Tory Channel (QCS-07); Pelorus Sound (PLS-03); and Outer Pelorus Sound (PLS-07).

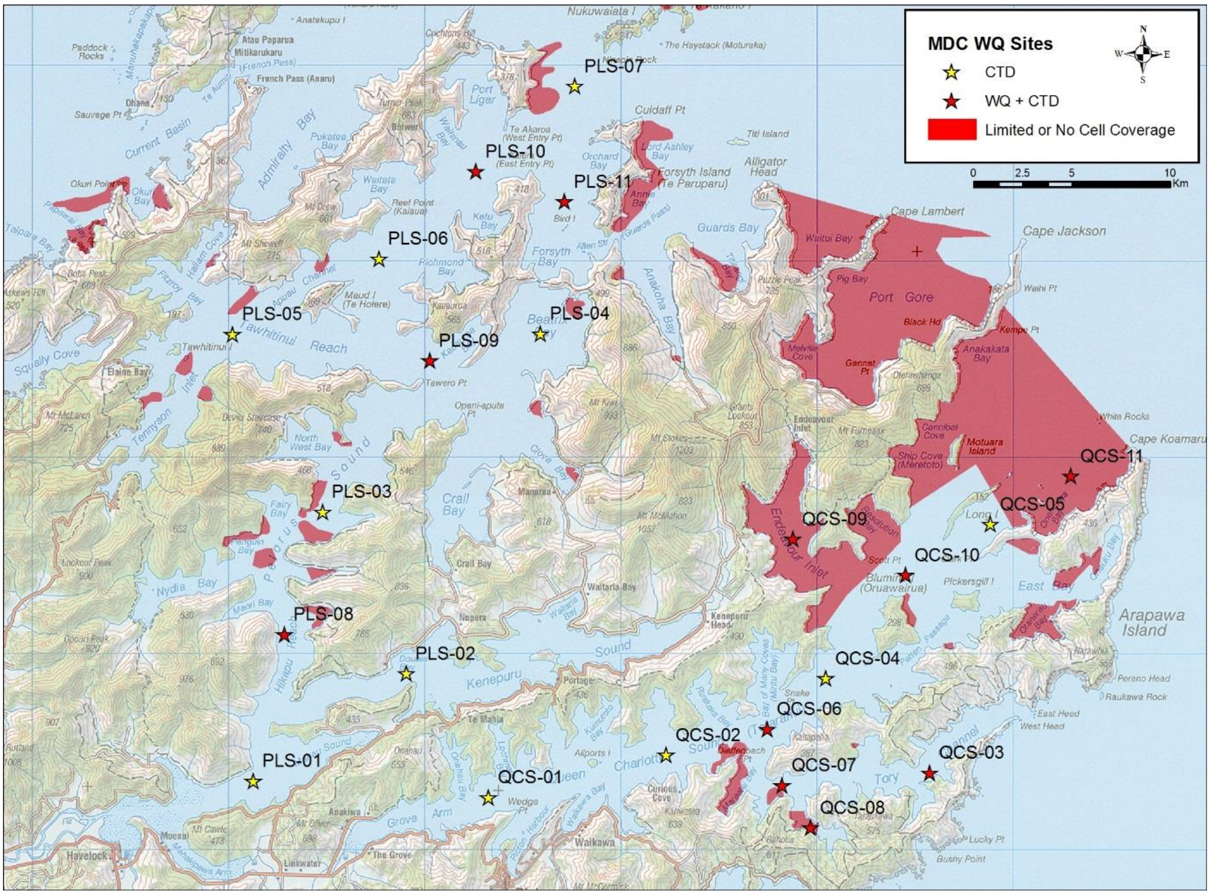


Figure 9. Map of the Marlborough Sounds showing existing MDC monitoring sites overlaid with areas of limited or no cellular coverage, as of 22 August 2016. Coverage map based on the Vodafone network (http://www.vodafone.co.nz/network/coverage/), but Spark is similar.

6.3.3. Key water quality indicators

The water quality case study highlighted some key indicators that are used in existing monitoring (see Table 2). With the exception of faecal indicator bacteria, and phytoplankton species/biomass, the following parameters are amenable to measurements by sensors that could be incorporated into a moored platform:

- conductivity/salinity and temperature
- dissolved oxygen
- turbidity and suspended sediments[3]
- chlorophyll-*a*
- nutrients (e.g. nitrate)
- pH (for monitoring ocean acidification).

In terms of measuring these parameters *in-situ* over a long timeframe (e.g. months) on a moored platform, there are several pros and cons which need to be considered. These are discussed in turn for each indicator in Appendix 3, with examples of specific trademarked and commercial instruments that measure the parameter(s) in question and which may be most suitable for MDC. Note, however, that the reference of a specific manufacturer does not, by default, mean that alternatives are not available that would or could work equally well. Future advances in technology may also lead to alternative instrumentation that may be better suited to MDC's purposes.

It is also worth noting that reference to specific equipment manufacturers is based on a few important considerations. Firstly, there are obvious advantages in having consistency between platforms, and duplicating equipment selected for other monitoring buoys throughout New Zealand ensures this. Secondly, equipment used on other buoys has a track record on similar, or larger, platforms used nationally and overseas, and therefore has proven performance. Thirdly, one of the biggest stumbling blocks with deploying myriad different sensors on the same platform is handling both firmware and software issues. By incorporating previous equipment setups, this issue can be addressed in advance.

6.3.4. Other parameters for consideration

Incorporation of GPS for location tracking is strongly recommended, given the relatively low cost of these sensors relative to the cost of a platform. There are also other supplementary data types that can be included in moored platforms, which help with the interpretation of the key water quality parameters listed above. These include weather stations, current meters, and wave sensors, which are briefly described below (see Appendix 3 for details). These data also overlap with information needs of the Harbour Master.

- **Weather/meteorological:** Inclusion of weather data, specifically wind speed and direction, can be very useful in determining general sea state and surface water movements.
- **Currents:** Understanding the speed and direction of water currents can be critical in the interpretation of water quality data, and are also important for running and calibrating forecasting models. Due to recent improvements, Acoustic Doppler

[3] It is possible to measure suspended sediments via site-specific calibration of Acoustic Doppler Current Profilers (described in Section 6.3.4).

Current Profilers (ADCPs), with proper site-specific calibration can also be used to determine suspended sediment concentrations.

- **Waves:** The measurement of waves may have relevance to MDC; for example, in relation to ferry wake studies, wave-dampening effects from different types of aquaculture, or effects of waves on resuspension of sediments.

6.3.5. Platform options for MDC

It is beyond the scope of this report to make specific recommendations on which new approaches and technologies should be pursued by MDC; however, several generic suggestions are made in Appendix 3 based on the existing water quality programme and the site-specific considerations listed above.

As part of scoping the size and type of platform that will best meet the needs of MDC, an exercise to prioritise the parameters, locations (bearing in mind cellular coverage issues) and monitoring depths should be undertaken. From this exercise, a shortlist of required equipment and parameters at specific target locations can be derived, and further refined to identify the platform and instrument array that would best meet the requirements for each site/area. It may be the case that small (< 100 kg) nearshore platforms (see Figure 8) are most suitable for MDC in that they can be deployed and retrieved easily.

However, the smaller size can constrain the size and number of instruments attached directly to the hull, and these constraints would need to be considered up front. For example, smaller platforms can be configured to measure currents using higher frequency (i.e. shallower water) ADCPs and/or single point current meters, but not heavier and larger ADCPs. Similarly, the total number of water quality sensors that can be secured to smaller platforms is space-limited but can be overcome by utilising multi-parameter instruments. In terms of the key water quality parameters listed above, the small nearshore platforms would be suitable using the combination of instruments (or some alternative arrangement) listed in Appendix 3, but this would leave less scope for future expansion and/or modification. In contrast, the larger coastal platforms leave plenty of scope for additional instrumentation and expansion but involve higher upfront and ongoing costs. One option may be to dedicate larger coastal platforms at long-term ‘sentinel’ sites, and use the more mobile nearshore platforms for shorter-term deployments in areas of interest (in a rotational capacity).

Appendix 3 provides advice in relation to solar power requirements, and discusses considerations for data management. To the extent feasible, it is suggested that MDC consider how regional data can be shared nationally (and even internationally). Note that future development of a national network of coastal observation platforms includes consideration of how the data will be managed at the regional level and secondly how it will be disseminated.

7. SYNTHESIS AND FURTHER CONSIDERATIONS FOR MARLBOROUGH

The concept of an integrated regional monitoring approach as discussed in Section 3 has a lot of intuitive appeal and some clear benefits. Furthermore, the interactions with stakeholders and iwi described in Section 4 highlight that there is considerable interest in the progression of this type of approach for the Marlborough Sounds. With respect to water quality, this report has highlighted some limitations with existing monitoring in the Marlborough Sounds; however, the coordinated approach developed between MDC and New Zealand King Salmon represents an important first step towards improving on the existing situation. There remains considerable scope for further improvement, including:

- the adoption of emerging monitoring technologies
- recognising that some of the region's stakeholders have significant datasets (e.g. long-term datasets with wide geographic coverage)
- identifying where overlapping information needs provide opportunities for integration (e.g. Harbour Master needs for meteorological data, and wave and tide information).

The various regional datasets and ongoing water quality (or related) monitoring and information (i.e. consent-related environmental monitoring, SOE monitoring, stakeholder programmes), represent a substantial repository of information for the Marlborough Sounds. It is clear that greater benefits could be realised by undertaking a more coordinated consortium-based approach to this monitoring, as long as some of the issues relating to data sharing, transparency and trust (see Section 4) can be resolved. There is the related but significant issue raised by MDC regarding the contribution of individual consent holders to a consortium model, where consent holders have legal obligations to undertake monitoring relating to individual consented activities. However, to the extent feasible, monitoring needs to be fit-for-purpose and necessary. Monitoring (especially consent-related environmental monitoring) can sometimes be perceived as 'monitoring for the sake of it' or monitoring to fulfil stakeholder expectations, without having a real benefit in terms of environmental outcomes.

Given some of the key issues to be resolved, it is beyond our present scope to make specific recommendations for MDC regarding the details of an integrated monitoring approach. The purpose of this report has been more about exploring the idea, its pros and cons, and the barriers to development. In our view, the considerable long-term benefits that could arise from a well-integrated regional monitoring programme will by far outweigh the initial effort involved in developing and setting up the approach. However, further investigation is first required to resolve some of the issues identified above. In the meantime it is worth considering hypothetically what an integrated programme might look like.

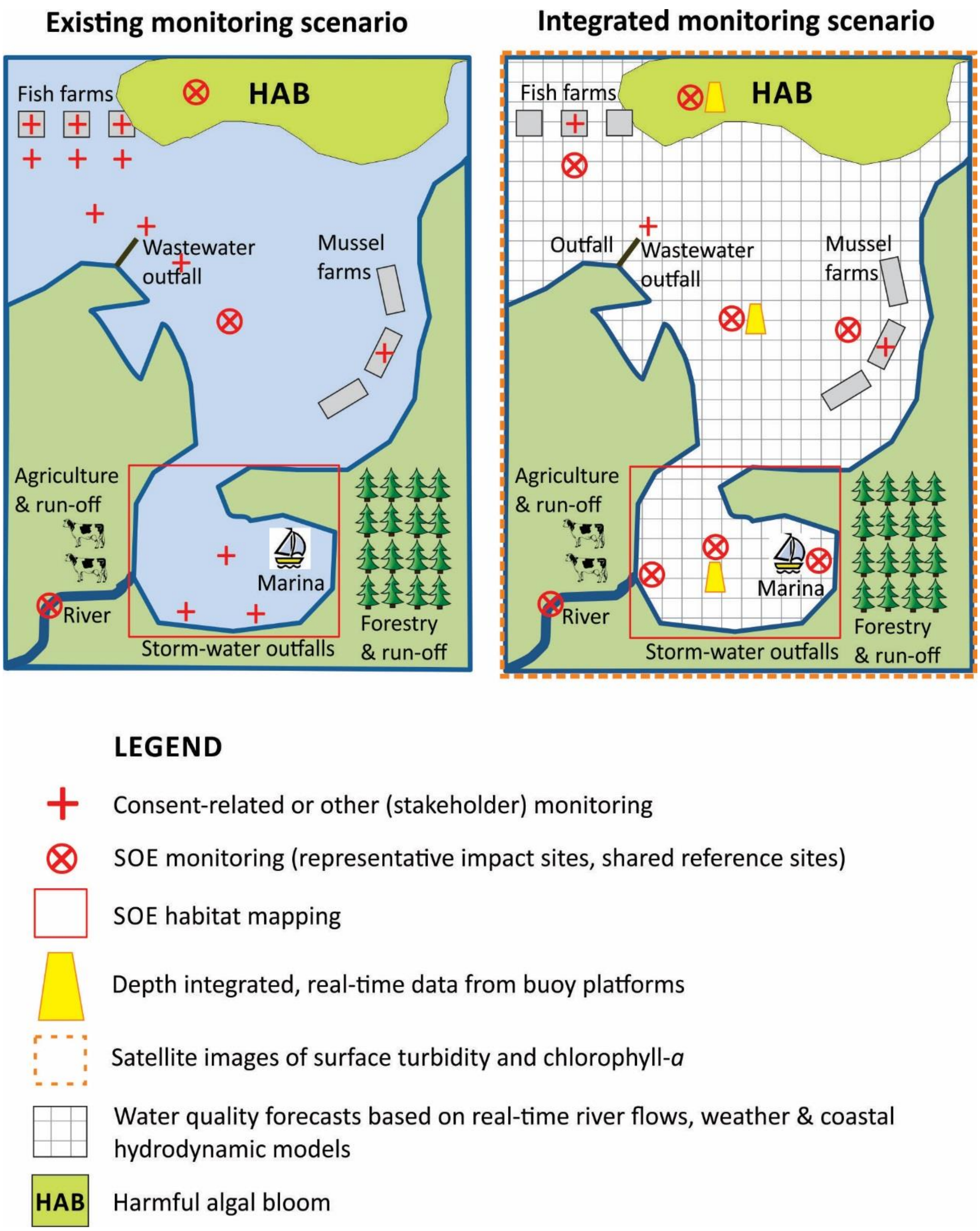
Box 3 below depicts some illustrative water quality and related monitoring approaches to highlight some of the benefits outlined in this report. In the **existing monitoring scenario**, the following is undertaken:

- Local-scale effects of consented salmon farms, wastewater and stormwater outfalls (e.g. on the seabed and water quality) are assessed for individual consents, each with adjacent reference site(s).
- There is no environmental monitoring of mussel farms, although water quality and related monitoring is undertaken in relation to industry production and harvest purposes.
- In the embayment (or estuary), monitoring focuses only on contaminants (nutrients, sediments, metals, indicator bacteria) from consented outfalls. However, the contaminant contributions from diffuse sources (catchment land-uses and associated run-off, boating marina) are far more significant but not accounted for.
- SOE monitoring is limited. Moreover, the frequency of monitoring and suite of indicators used differs to that required for some of the consented activities.
- All water quality monitoring is based on infrequent synoptic field surveys, which may not capture trends in the system or lead to timely detection of episodic events (e.g. flooding effects, harmful algal blooms).
- There is no coordination of monitoring among consent holders, and different providers and methods may be used. As a consequence, results may be inconsistent, or interpreted in different ways.

The **integrated monitoring scenario** in Box 3 includes the following improvements:

- SOE monitoring provides a suite of reference sites against which the effects of the consented point-sources or representative sites are assessed.
- Assessment is based on a common suite of indicators where feasible, and surveys are coordinated so that they are conducted at the same time using the same sampling and analytical methods. Results are interpreted in relation to environment standards that have been simultaneously developed.
- In the embayment, the monitoring focus moves from the consented stormwater discharges to the state of the embayment overall, with all key pressures and a suite of related indicators included.

Box 3. Integration of synoptic surveys, real-time & forecasting tools to improve design and implementation of environmental monitoring



- Synoptic water quality surveys are supplemented by continuous real-time monitoring for key indicators using moored platforms. Together with broad-scale satellite imagery, variation in background environmental conditions is better characterised. These improved methods provide a context for interpreting data from synoptic surveys and consent-related environmental monitoring.

- Together with targeted surveys and research, and development or applications of models, the importance of different stressor sources is determined, and management measures are implemented accordingly.
- In the longer-term, the acquisition of a regional time-series of monitoring data enables the development of forecasting tools for assessing threats to environmental or resource quality (e.g. forecasting of shellfish harvest closures due to land-derived contaminants or harmful algae).

The adoption of new technologies such as real-time monitoring using platforms, and application of higher resolution models, will clearly have increasing potential as technology advances. However, there remain questions relating to cost, and the quality and quantity of data or forecasts that need to be considered. For example, the web-based application for *Perna* and *Mytilus* described in Box 2 includes a tool to forecast spat recruitment one month ahead; however, the reliability of the forecast is far from perfect at this stage (Atalah et al. 2016). Steps towards the utilisation of new technology should, therefore, be seen as complementary to 'traditional' monitoring approaches rather than replacing them.

Collectively, the types of improvements suggested for the integrated scenario in Box 3 could lead to greater scientific consistency, and cater for a standardised approach to evaluation of results and assessment of environmental quality from a regional perspective. The concept of a nominated organisation with a coordinating role, and a central repository for monitoring data, could lead to a range of broader benefits such as discussed in the report. Overall, the development of an integrated monitoring programme can only be seen as a positive step that will benefit multiple stakeholders and iwi, and enable the effective management of the Marlborough Sounds and its important uses and values.

8. ACKNOWLEDGEMENTS

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10. APPENDICES

Appendix 1. Interview questions.

1. What is the name of the organisation you work for?
2. What is your role in your organisation?
3. What knowledge is important to your organisation? i.e. what purpose do environmental data, and in particular, data on water quality in the Sounds serve for your organisation?
4. What management decisions does your organisation make as a result of data collected on water quality in the Sounds?
5. Do you feel that the data that has and is being collected serves its purpose and meets all of your needs?
6. What are the obvious gaps? (consider temporal and spatial)
7. Do you have any trust issues around data currently being collected?
8. How could data be collected more effectively and efficiently?
9. Do you feel your organisation should/could contribute towards the collection of data/knowledge that would be openly shared, and in what ways?

Appendix 2. Transcription notes from interviews with Marlborough Sounds stakeholders and iwi.

Organisation		Theme						
		Knowledge Needs	Knowledge Gaps	Willingness to participate in a consortium	Advantages of consortium approach to interviewee's organisation	Barriers to participation	Data sharing (storage, dissemination, exchange etc)	Other
Governance:	MPI	• 'Big picture' information to manage forestry, agriculture, aquaculture, fisheries, marine protection, customary fishing etc • MSQP	• Comprehensive dataset that integrates e.g.: – Baseline information (e.g. ocean acidification, nutrients, temperature, pH) – Cumulative water quality effects – Sedimentation – Marine reserve monitoring • Standard parameters, measured using the same method at the same time every year • Spatial data	• Yes	• Cost efficiency gains • Shared costs • Better data – more statistical power over time	• Working out how individual consent holders additionally contribute to the overall benefit, as they would still be legally required to do individual monitoring under consortium model. • How to show cause and effect • Commercial sensitivity and peoples' willingness to share information	• Convenor should be council to save funds, and because they already do SOE monitoring • Data should be open access • LAWA could be used as a model for data sharing and storage • Data needs to be shared/ presented in a useful way – not just raw data	• Data currently being collected does not meet MPI needs as it is fragmented, follows different methodologies, and is largely inaccessible to other users (e.g. resource consent monitoring). • Data does not provide 'big picture' understanding of environmental changes. • Better SoE monitoring, combined with resource consent monitoring to achieve a comprehensive monitoring plan.
	MDC	• SOE monitoring for coastal waters in the Marlborough Sounds • Knowledge to inform policy and resource consent decisions • Knowledge for monitoring effects of activities such as aquaculture and forestry • Data to establish water quality limits	• An long term dataset that could be used to establish a baseline • Data that is available is spatially and temporally limited • Temporal variability exceeds spatial variability • Algal bloom patterns • Sediment effects of land use • Limited understanding of how nutrients from the four rivers impact on the Sounds	• Yes • Council would possibly invest in the consortium	• Integrated data sets (e.g. with satellite data) • 'Unlocking' data that is already being collected so it can be used more effectively • Cost effective to use instrumentation • Use of instrumentation to measure patterns in areas under pressure (e.g. Tory Channel). • Data would enable predictive modelling (e.g. productivity) • Reduction in overall monitoring costs to individual organisations	• Overcoming historical approaches to data collection between different organisations • Determining equitable distribution of costs • Confidence/ trust that the data will be of good quality • Greater transparency will expose poor practice	• Data has to be in a format that is useful to everyone • Data interface has to be user-friendly • Peer review audit of data collection is important • LAWA an obvious user interface, but there could be others (e.g. Council website)	• Analytical costs are a big component of the total monitoring costs • Measurement of nutrients including silicon, chlorophyll, pH • Links to MDC's multibeam seabed mapping project
Industry:	Shellfish	• MSQP monitoring – Biotoxins – Bacteria – Heavy metals	• Routine pest monitoring • Nutrient monitoring • The *source* of sediments and nutrients • Water quality forecasting / predictive modelling • Nutrients – attribution to activities, carrying capacity etc • Marine pests – dispersal, lifecycle trends, behaviour, survival etc • Water quality safety for food production • Sedimentation – load, composition (e.g. contaminants), and source	• Yes	• Shared costs • Increased monitoring leads to better behaviour e.g. council, industry, community • Informs better management decisions • More efficient monitoring	• Issues of trust – who holds the data? • Need transparency: What is the data for? Why are you gathering the data? For what purpose? What are the management implications of bad results for industry? • If reason for monitoring is not clear, there are potential efficiency losses by collecting more data than is needed • Funding/cost	• Open access • Need not-for-profit overarching organisation that gathers data at the right time, in the right format, maintains database, and disseminates data to all parties	• Want real-time monitoring of the water column using permanent in-situ ESP monitoring devices

Organisation	Theme						
	Knowledge Needs	Knowledge Gaps	Willingness to participate in a consortium	Advantages of consortium approach to interviewee's organisation	Barriers to participation	Data sharing (storage, dissemination, exchange etc)	Other
Salmon	• Resource consent monitoring information e.g. benthic and water quality information • Water column monitoring: harmful algae blooms	• Background environmental data to determine e.g. capacity data • Water column monitoring: harmful algae blooms • Baseline information: – Water quality – temperature • Real time, continuous data collection • Sediment information	• Yes (but see 'barriers to participation')	• Possibility of better data through continuous monitoring • Shared costs – cheaper monitoring	• Resource consent conditions would need to be reviewed • Funding/cost – needs to be shared among all stakeholders • Who runs it e.g. council, independent organisation?	• Online open access i.e. LAWA or phone app of some sort • System needs to have 'triggers' in case monitoring detects something going wrong	
Paua	• Currently the industry doesn't use any monitored data	• Future scenarios/modelling (mainly beyond the Marlborough Sounds heads) of, e.g. – Temperature – pH – Sedimentation dispersal – Macrocystis • Coastal hydrodynamics, particularly wave action	• Yes	• Shared costs	• Commercial sensitivity		
Forestry	• Baseline sediment information • The nature of sediment: sources and sinks, attribution of sediment spikes to certain events. • Sediment effects of driving vehicles through hard-bottomed streams • Historic sedimentation information	• Not all that familiar with the sort of data that is being collected in the Sounds but whatever it is, it's not really serving forestry purposes at the moment	• Yes	• Shared costs/ cost effectiveness • Social licence • Better data • More efficient	• Funding • Need an impartial convenor	• Open access	
Iwi/Shellfish/Finfish	• MSQP monitoring – Biotoxins – Bacteria – Heavy metal • Temperature	• Impact of water quality/chemistry changes on shellfish • Sedimentation • Nutrient and phytoplankton levels (e.g. chlorophyll *a* – spatial and temporal • More frequent monitoring • Predicting spat abundance	• Yes	• Good data • Shared costs	• Funding/cost	• Need four or five sites for sufficient monitoring in Marlborough Sounds • Data could be gathered using the MSQP boat • Convenor needs to be independent/trusted: e.g. MSQP model could be used for consortium • Too many strained relationships between council and industry for council to be convenor • Online information storage and sharing portal e.g. LAWA	

Organisation	Theme						
	Knowledge Needs	Knowledge Gaps	Willingness to participate in a consortium	Advantages of consortium approach to interviewee's organisation	Barriers to participation	Data sharing (storage, dissemination, exchange etc)	Other
Community	• Information on water quality • State of benthic environment • Interaction between water quality and benthos (e.g. how does turbidity affect macrocysytis) • Knowledge needed to make recommendations on management decisions	• Need more collection points (e.g. Port Underwood) • Need more information through the water column strata • Water temperature data • pH data and effects of acidification • Understanding how environment could be artificially improved	• Yes • Consortium should be made up of decision making agencies, science representatives, non-industry community, iwi, two or three key industry reps and fishing commercial and recreation • Consortium would need a mandated steering group	• Social aspect of a collaborative approach – brings people together and allows people to test each other's thinking • Have more knowledge around the table and can recognise more opportunities for efficiency and effectiveness gains	• Process could break down if actors retreated to 'their corner'	• Open platform for sharing data where everyone agrees on what has been collected, how and why it has been collected and how it has been summarised and analysed	• Data collected in the past has been for industry and focused on local effects and food safety • Timely data more important than real-time data • Consortium most likely to succeed if the people involved are actually connected to the Sounds – the community has to be involved too. • Buoys are the key but need to have built in redundancy in case of failure

Appendix 3. Options for measuring different water quality indicators and other relevant parameters using moored instrumentation.

A. Water Quality Parameters

Conductivity/salinity and temperature: This is an important set of measures, as these parameters can be used to track terrestrial run-off, diurnal and seasonal changes in water temperature, and density gradients through changes in thermocline and/or halocline if deployed at multiple depths. Temperature is perhaps the easiest and cheapest of all the measures available and should be the highest priority, followed closely by conductivity/salinity. Salinity is subject to bio-fouling of the inductive cell and drift/error so instruments with built-in antifouling measures are necessary. The SeaCat series of sensors built by Seabird are the global standard for oceanographic buoys and are presently being used on the majority of buoys known to measure salinity in New Zealand. These sensors have integrated antifouling devices, which dramatically reduce fouling in the conductivity cells, and have been deployed successfully for over 12 months in the surface waters of Tasman Bay with no substantive drift or loss of data integrity. At present MDC uses a YSI Exo-Sonde for routine CTD casts undertaken as part of the existing SOE monitoring. For an integrated monitoring programme, the recommended surface salinity instrument is a Seabird SBE-37, which also has the capacity dissolved oxygen (see next paragraph).

Dissolved oxygen: Dissolved oxygen is a priority parameter in that it represents an important component of surface water for self-purification processes, and the maintenance of aquatic organisms that use aerobic respiration. Oxygen solubility in water is governed by a complex set of physical conditions that include atmospheric and hydrostatic pressure, turbulence, temperature and salinity. Oxygen reduction is normally measured through the DO deficit of the surface waters[4], which is expressed as the percentage of the oxygen concentration below the oxygen saturation level.

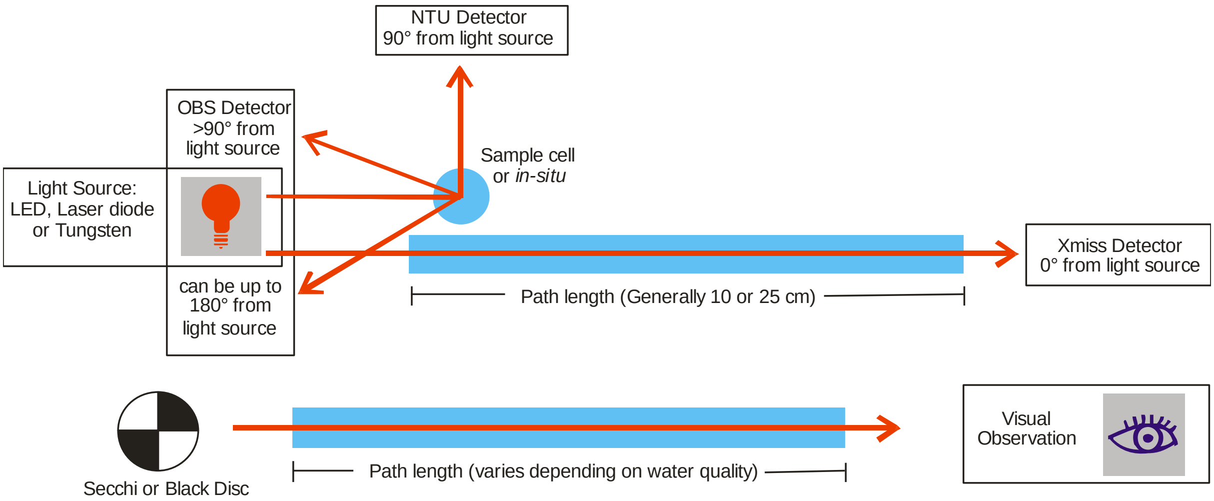
Measurement of dissolved oxygen via an *in-situ* instrument has made advances since the early 2000s with the introduction of optical DO (ODO) sensors, which are more robust and less prone to fouling than the preceding membrane style sensors. There are numerous reliable optical DO sensors on the market but all require some sort of mechanical or chemical antifoulant to function over long periods in coastal situations. The SBE-37 has recently been upgraded to include an ODO option which incorporates the existing salinity antifoulant system. Other ODO options (e.g. Zebra-Tech D-opto©, YSI-Exo©) tend to use mechanical wipers to keep the optical components clear of fouling.

Turbidity: Several different types of electronic devices have been designed to measure the relative clarity in coastal and freshwaters. The three most commonly used devices are: (i) turbidimeter (or nephelometer); (ii) optical backscatter (OBS)

[4] For example, MDC currently use oxygen saturation values of 70% and 90% as threshold concentrations in NZKS farm management protocols.

sensor; and (iii) transmissometer. While each of these instruments uses a primary light source (generally in the form of an LED, laser diode or tungsten lamp), they differ markedly in how the incident light is measured after having passed through a water sample (see figure below) with two of the instruments (turbidimeter and OBS) relying on a side- or back-scattering of light from particles in the sample. For comparative purposes, the figure below also includes a schematic representation of visual clarity measurements collected using traditional black-disk or Secchi disk. This shows that transmissivity is most closely related to these visual methods.

Schematic showing the differences in how light is measured from different clarity instruments.



Turbidimeters or nephelometers measure the relative clarity of a water sample based on the 90 degree side-scatter of a beam of light. Readings are based on the relative clarity of a sample and are expressed as nephelometric turbidity units or NTU where higher NTUs represent more turbid waters. Optical backscatter sensors are very similar to turbidimeters but rely on a back-scatter (i.e. greater than 90 degree) of the light source. Readings from these sensors are often expressed as FTU or formazin[5] turbidity units to avoid confusion with NTU. OBS sensors are more commonly used on buoys because the light source and detector can be incorporated into a much smaller sensor, which in turn is easier to keep free from fouling.

A transmissometer is akin to a nephelometer in that it measures the attenuation of a beam of light passed through a sample but with some fundamental differences. Firstly, a transmissometer, unlike a nephelometer, measures the amount of light passing directly through the sample and not the amount deflected. As such, these instruments measure clarity in the same fashion as the Secchi disk measurements

[5] Formazin is a compound standard used that appears cloudy white in solution and can be mixed in discrete concentrations, allowing for the preparation of quantifiable standards. Both these types of sensors are calibrated to a formazin standard.

collected for MDC's SOE programme, only on a much smaller scale. Transmissometers tend to be more expensive than nephelometers or OBS sensors and have two optical sensors prone to fouling, which is likely why they are not more widely used on buoys despite having obvious advantages in measurement method and direct comparison to traditional methods (e.g. Secchi disk).

For MDC, the recommendation would be to use a dual (or multi) channel optical instrument that measures OBS along with another fluorescent parameter like chlorophyll-*a* as described below; for example, a WETLabs© ECO-FLNTUs© which measures both turbidity and chlorophyll-*a.* This sensor has a proven antifoulant setup, which includes both copper cladding and a mechanical shutter that protects the optical face except during sampling.

Chlorophyll-*a*: Chlorophyll-*a* is a primary colour pigment of marine algae and is used for oxygenic photosynthesis. As such it also serves as a proxy for phytoplankton biomass. Along with nitrate and dissolved oxygen, chlorophyll-*a* is one of the main indicators used by MDC in their existing monitoring programmes. Chlorophyll-*a* is a fluorophore, meaning it absorbs light at one wavelength (about 450-470 nM) and emits light at a higher wavelength (about 650-700 nM). Thus, in terms of *in-situ* measurement, fluorometers that are tuned to these wavelengths, and properly calibrated, can effectively measure relative chlorophyll concentrations over time. Like OBS sensors, they require an effective antifouling system to keep the optical faceplate clear of obstructions. The ECO-FLNTUs mentioned above has a good track record within New Zealand in terms of long-term measurements requiring little maintenance or cleaning.

Nitrate: The newest of the emerging technologies for MDC's key parameters is the *in-situ* measurement of nitrate which, until recently, required chemical analysis. In the early 2000s the team at the Monterey Bay Aquarium Research Institute (MBARI) developed a UV method for nitrate measurement using In-Situ Ultraviolet Spectroscopy (Johnson and Coletti 2002). This technology was acquired by Satlantic© who commercialised it into an instrument called the SUNA (Submersible Ultraviolet Nitrate Analyzer). The most recent iteration of this sensor is the SUNA V2 which can be powered externally and used on moored buoys, but integration is not as straight forward as the other optical sensors mentioned above. Firstly, the SUNA V2 has a nominal power consumption of 7.5 watts (625 mA at 12VDC) which is an order of magnitude more than the combined chlorophyll-*a* and OBS sensor mentioned above. Integration would therefore require a very careful consideration of power usage and sample timing to optimise the sample frequency, which may turn out to be much less frequent than other variables. Secondly, in order to minimise drift and improve precision, real time salinity and temperature correction is required which involves communication with a separate C-T sensor in real time. Thirdly, as an optical sensor, the SUNA V2 requires an integrated bio-wiper for both lenses to reduce error from fouling. Finally, as a newly commercialised technology, the current price for this instrument is on the order of $40k NZD, making cost a significant barrier to using it routinely on moored platforms.

pH: The pH of seawater is a fundamental variable of carbon chemistry and the CO_2 / bicarbonate buffer system. Rising CO_2 dissolved in the ocean results in a lowering of pH (increased acidification), which can lead to negative effects on marine life. Advances in sensor technologies over the past decade now enable the autonomous measurement of pH in marine environments. The instrument of choice for the New Zealand Ocean Acidification Observing Network (NZOA-ON) is the SeaFET, which was created by MBARI and Scripps Insitute of Oceanography and is produced commercially by Satlantic. The SeaFET uses the ion sensitive field effect transistor (ISFET), which is also the same as the Durafet pH electrode. The SeaFET is essentially a Durafet pH electrode repackaged to operate at high pressures in the ocean. Ocean acidification monitoring also involves water sampling for instrument calibration and for analysis of acidity parameters (alkalinity and total dissolved inorganic carbon) for calculating pH, pCO_2, carbonate ion concentration, and saturation states. pH sensors can be integrated with other instruments to create a more comprehensive data suite *in situ,* which aids in interpretation of results. Examples include Sea-Bird Scientific's SeapHOx instrument, which combines a SeaFET with a Sea-Bird Scientific CTD and Dissolved Oxygen sensor. Other examples have combined a Durafet pH sensor with towed instrumentation (Bresnahan et al. 2016). As part of the CARIM (Coastal Acidification Research, Impacts & Management) programme, a SeapHOx has been deployed on the TASCAM mooring in Tasman Bay, with intentions of making the instrument transmit pH data in real time through collaborations with MBARI. SeaFETs cost about $16k NZD, and the integrated SeapHOx system is in the order of $40k.

B. Other Parameters

MDC is looking to integrate its science monitoring with the Harbour Master's navigational safety information needs (meteorological data, and wave and tide information), hence some relevant parameters and approaches to measurement are outlined below.

Weather/Met: Inclusion of weather data, specifically wind speed and direction, can be very useful in determining general sea state and surface water movements. Recent advancements in ultrasonic wind sensors have both reduced the cost and improved the accuracy/precision of these instruments to the point where they are becoming the standard for near-shore monitoring platforms. One of the biggest advantages over the more traditional rotor-style wind sensors is that there are no moving parts, hence less corrosion and problems with sea spray. These sensors also routinely collect air temperature and barometric pressure and many include integrated GPS for location tracking.

Currents (ADCP): Like the weather stations, advancements in acoustic instrumentation have recently resulted in a change in the routine measuring of water currents. The trend for coastal monitoring has seen a shift away from single-point current meters towards profiling current meters. While both generally use acoustic Doppler shift technology, the primary difference is that Acoustic Doppler Current

Profilers (ADCPs) are able to divide the water column into a series of discrete cells (or bins) and return a current speed and direction in each of these cells, whereas single point meters only measure the current at the deployed depth. Recent improvements in acoustic bottom tracking on ADCPs has made them much more reliable to mount on a buoy in 'downward looking' mode. While ADCPs generally cost more than single point current meters, the additional data makes them worth considering for sentinel monitoring sites. With proper site specific calibration, ancillary data like suspended sediment concentration can also be derived throughout the water column using the backscatter signal from the individual bins or cells.

Waves (Wakes): The measurement of waves, or ferry wakes, is a measure taken at water level (i.e. inside the buoy) using inertial sensors and accelerometers. Until very recently, inclusion of this type of measurement required purchasing a specific 'wave rider' buoy with the electronics incorporated. Stand-alone wave sensors that can be added to existing hulls have not been widely commercially available. However, Cawthron is currently collaborating with an equipment manufacturer (Seaview Systems©) and evaluating the use and efficacy of their hardware on existing hull types. Initial indications are very promising that this type of measurement will be more routinely available for a variety of different buoy configurations at much lower cost than the previously available options.

GPS: Incorporation of GPS for location tracking is strongly recommended. Given the relatively low cost of these sensors and the importance of tracking an expensive asset like a buoy, it is recommended that they be duplicated on each platform. These can be used as stand-alone GPS units, but are also routinely incorporated into existing hardware like weather stations or cellular modems. There are also recently released, low-cost, satellite-based GPS trackers (e.g. SPOT Trace) which will work independently of a buoy's main telemetry system and offers an alternative means of location tracking.

C. Suggested platform options for Marlborough District Council

It is beyond the scope of this report to make specific recommendations on which new approaches and technologies should be pursued by MDC; however, several generic suggestions can be made based on the existing water quality programme and site-specific considerations.

Before initial scoping is done on the size and type of platform which will best meet the needs of Council, an exercise to prioritise the parameters, locations and depths should be undertaken. From this, a short-list of required equipment and parameters at specific target locations can be derived, and further refined into what platform or array would best meet the requirements for each site/area. In the absence of this shortlist, from the information presented above, the general configuration that would conceivably best meet MDC's requirements is described below.

Buoy Size/Style: Ideally a small (< 100 kg) roto-formed polyethylene or small discus style buoy that can be deployed and retrieved easily. Larger hulls are not needed given the generally protected nature of the Sounds. Use of these smaller hulls has another advantage in that they can be more easily re-located or swapped if a rational policy of different sentinel stations is adopted.

Telemetry: While there are some locations in the Sounds where cellular black spots exist, coverage is generally good enough that cellular telemetry is advised as it offers the most cost-effective means of data transmission.

Power/solar: The hills and ridges of the Sounds which offer protection form the seas are disadvantageous for solar recharge because of the additional shading that exists at many coastal sites. The Sounds is also subject to cloudy and foggy conditions more so than many other coastal regions in New Zealand. Therefore care must be taken to work out a conservative power budget for any platform being considered, especially if high consumption equipment like a nitrate sensor are specified. As a minimum, it is advised that a minimum of 20-30 watts of solar cells are used with a battery capacity of 20 amp/hr or more.

Data management: These new technologies are capable of generating data at ever-increasing rates; data which in turn must be analysed, distributed, and archived. The main requirements for data management were discussed in Ellis et al. (2012) and include:

- selection of open source, well-documented methodologies to ensure consistency between datasets
- inter-regional integration
- collection, maintenance and dissemination of standardised metadata
- integration with existing data management systems
- consistency with national and international networks.

Whatever approach MDC adopts, it is prudent to consider how regional data can be shared nationally and internationally and form part of a national network. Future development of a national network of coastal observation platforms includes consideration of how the data will be managed at the local (regional) level and secondly how it will be disseminated. This dissemination will almost certainly be through an open web-based platform (e.g. LAWNZ, MOV, EDENZ, etc.).

In order to facilitate input of data within open web-based platforms, time-series datasets will likely need to follow standardised formats consistent with those suitable for the Sensor Observation Service (SOS), which is the official Open Geospatial Consortium (OGC) standard web service for simplifying access to time-series data. Currently, CRIs and LINZ are working on SOS standards for New Zealand, which will in turn help underpin regional and national initiatives. Similarly, as part of ongoing buoy collaboration with MBARI, Cawthron has implemented a data schema which conforms to the Integrated Ocean Observation Service (IOOS) SOS standards for all of the platforms Cawthron runs.