Regional Council Sample Design

Proof of Concept for State of the Environment Monitoring

Planning, Monitoring and Reporting

February 2019

Executive Summary

- Regional councils and central government agencies are collaborating to implement an integrated approach to the monitoring and reporting of biodiversity indicators.
- The Department of Conservation has developed a Master Sample for biodiversity monitoring across all of New Zealand. A Master Sample explicitly coordinates monitoring by matching sites between agencies and across multiple spatial scales to keep track of effort and allow reduced costs when sampling areas and objectives overlap. The Master Sample is created from Balanced Acceptance Sampling (BAS) which is a modern spatially balanced design combining the benefits of both systematic and simple random sampling.
- The Master Sample approach should be considered as a design basis for future monitoring programmes and can augment existing monitoring programmes based on the 8-km systematic grid. Combining data from the 8-km grid and the Master Sample does not significantly impact the overall inference about the population (van Dam-Bates et al., 2018) for both sample augmentation to intensify sampling effort as well as for contiguous regions where one may implement the 8-km grid and then collaborate with a region that implements the Master Sample. The approach is flexible for both 'Status and Trend' and more intensive 'Management Effectiveness' monitoring.
- Due to the heterogeneity of forests in New Zealand and the homogeneity of productive land use types that make up a large portion of Regional Council lands, stratification may be considered to decrease cost while not negatively impacting the overall inference required for State of the Environment reporting. For example, Southland Regional Council implementing the 8-km grid would need to monitor 218 sites. Using stratification for croplands and other areas that are highly impacted by human use, we show below that a sample size of 165 (53 fewer sites) may be equally effective for monitoring birds.

Department of Conservation
Te Papa Atawhai

Based on the success of the National Level Monitoring Programme for native habitat we recommend maintaining the sampling intensity of the 8-km grid.

- The 8-km systematic grid utilised the best approaches available at the time for the monitoring of widespread ecological resources and mirrors similar programmes for monitoring biodiveristy internationally. However, recent developments in spatially balanced sample designs offer the benefits of systematic sampling with additional utility. The BAS Master Sample is flexible and can be tailored to the needs of individual agencies while maintaining design robustness. This flexibility includes dynamic adjustment of sample size in response to fluctuating resources or changes in objectives as well as objective methods for site replacement when access or safety constraints restrict measurement of a location.
- We suggest that the Master Sample is an improved platform for coordinating SOE monitoring which readily integrates with existing central and local government SOE monitoring.

Introduction

The Department of Conservation (DOC) has developed a National Level Monitoring (NLM) Programme as part of the National Biodiversity Monitoring Programme (NBMP) system, using an 8-km grid at ~1,400 monitoring sites on Public Conservation Land (PCL). The NLM programme focuses on status and trend monitoring at the national scale for key indicators of ecological integrity. DOC is then able to make statistically valid inference across the entire PCL and report on the State of the Environment (SOE).

Regional councils (RCs) are responsible for managing biodiversity off PCL within their territorial boundaries and have adopted an indicator framework for reporting on ecological integrity aligned with DOC and the NBMP. Monitoring programmes have already been implemented off PCL by Greater Wellington Regional Council (GWRC) and Auckland Council (AC). Considerable effort has gone into collaborating monitoring between agencies such as the Environmental Monitoring and Reporting group (EMAR); established to coordinate environmental monitoring and reporting efforts between central and local/regional government.

DOC has continued to develop tools and frameworks to support standardised, well designed and coordinated environmental monitoring within New Zealand. We believe RCs would benefit from these developments with the intention to establish a coordinated, adaptable and fit-for-purpose approach to monitoring ecological integrity and the effectiveness of biodiversity management in New Zealand. van Dam-Bates et al. (2018) established the rigorous design methods for coordinated terrestrial monitoring in New Zealand using a Master Sample. The purpose of this document is to introduce the Master Sample in the context of Regional Council SOE monitoring and reporting along with basic design principles to understand the benefits of implementing an integrated monitoring programme between DOC and each RC.

Principles of monitoring

For a monitoring programme to be successful it is important to provide clear, detailed documentation of the design decisions made. We recommend following the approach described in Reynolds et al. (2016) to work through the design decision making process. Articulating clear and achievable objectives is critical and drives all of the design decisions that follow. To report on SOE similar to NLM, we define it as "status and trend" monitoring focussing on large spatial scales (the entire region) and long-term trends (5-10 years). Status and trend monitoring may allow for inference about ecological integrity across an area but will not necessarily give information about short-term management effectiveness in a particular area unless there is a very significant response in the population. If a specific monitoring action is undertaken and we are interested in measuring its success, we would undertake "effectiveness monitoring". Effectiveness monitoring may result in choosing a BACI (Before-After Control-Impact) design, where a specific environmental response to a change is measured. The objectives decide what is measured, where it is measured and how frequently to return (spatial and temporal replication). Without clear objectives a monitoring programme is unlikely be successful and can be a waste of resources if it fails to provide management and stakeholders with useful information.

Conceptual models should be used to apply expert knowledge to;

1. Identify the indicators and measures that are required to report on progress and

2. Define the target population and sample frame.

The target population is defined as the population or resource of interest (e.g. all native forest in the region). The sample frame is a spatial representation of the target population (e.g. the best spatial information available representing native forests in the region). Once the target population and sample frame are defined it is important to account for any logistical constraints (such as accessibility and safe conditions for field crews) as not all areas can be visited safely. A clear definition of the sample frame is important to ensure that the scope of inference is understood. Steep unsafe areas that are not able to be sampled may exclude unique habitats from the sample. In particular for RCs, private land access may be restricted and the sample frame will be limited to areas where access is possible.

After choosing what to measure and where it should be measured, sample size/site selection is undertaken. Sample size should reflect the objectives and should be informed on the variability thought to occur in the population being measured. For example, if we assume biodiversity is reasonably consistent for bird communities on pastures in the Canterbury Plains, then a smaller amount of sampling may be required than when monitoring birds in regenerating native forest. Sampling locations should be drawn to provide an unbiased representation of the population of interest within the sample frame. A probabilistic sample ensures that what is observed represents the population as a whole. Convenience or judgement sampling generally does not allow for inference over the entire population and is not recommended for SOE monitoring.

Objectives

Regional councils have statutory responsibilities for monitoring the SOE and the effectiveness of policies and rules on the maintenance of indigenous biodiversity.

For the purposes of this document we assume the main objective is

1. To provide unbiased assessment of the SOE based on indicators from the regional council indicator framework.

However, the Master Sample framework allows for integrating effectiveness monitoring into existing SOE monitoring

2. To determine the effectiveness of policy and management interventions.

Interagency collaboration for State of Environment Monitoring and Reporting

RC's are collaborating to achieve a coordinated approach to regional SOE monitoring. An important consideration is how to effectively integrate with existing monitoring programmes such as the NLM programme. DOC also requires coordinated effectiveness monitoring across the organisation while integrating seamlessly with their existing NLM programme.

To provide for this DOC, in collaboration with the University of Canterbury (UoC), has developed the New Zealand Master Sample (van Dam-Bates et al., 2018). The New Zealand Master Sample (NZMS) utilises a spatially balanced sampling method with the advantages provided by systematic sampling (such as the 8-km grid), and extended by providing utility for dynamic adjustment of sample size and site replacement (when sample locations are unsafe, inaccessible or non-target, i.e. a built surface which precludes sampling relevant indicators). van Dam-Bates et al. (2018) demonstrate that sample designs implemented using the NZMS integrate effectively with the 8-km grid while providing enhanced flexibility. The NZMS is being increasingly used within DOC and some partner agencies for designing effectiveness monitoring programmes.

RC's are confronted with obstacles to implementing regional SOE programmes to which DOC is not subject. These restrictions include the need to sample on private land, often without guaranteed access, diverse land cover types (indigenous, productive, urban etc.) and varying resource levels as determined by rateable population. We believe the NZMS can provide solutions to these obstacles so that individual RC's can scale monitoring to available resources and replace sample locations as necessary should they occur in areas with restricted access or non-target land use types such as urban/industrial areas.

In order to integrate monitoring between the RC's and DOC, and take advantage of recent developments in statistical sample design, we recommend implementing regional SOE monitoring using the NZMS (van Dam-Bates et al., 2018).

The following sections describe the NZMS and demonstrate through case studies how the NZMS could be used as a design basis for regional and national SOE monitoring while integrating with existing monitoring efforts (such as the NLM programme).

Monitoring design for Regional Councils

We consider the NZMS and its application for SOE monitoring in contrast to the 8-km grid in the context of different monitoring programme design such as integration of legacy monitoring, stratification to optimise sample allocation and compare the scalability and adaptability of the two approaches. We then demonstrate these aspects of monitoring designs by the use of case studies.

New Zealand Master Sample

When agencies are designing rigorous monitoring programmes, the data can be aggregated with low risk of bias when the survey design is taken into account. However, it is a difficult task to aggregate data from disjoint surveys with unknown scales of inference and often uncertain probabilistic/judgement design. A Master Sample consists of a large set of sample locations that can be subsampled for different monitoring purposes. If used by different agencies and initiatives it ensures that a consistent design methodology is applied. Under this framework, data can be seamlessly aggregated at larger scales for regional/national evaluation. As a result, local monitoring efforts can be readily used to inform status and trends at regional and national scales. Through the explicit ordering of the NZMS, sites are shared at different spatial scales or overlapping regions reducing the sampling costs to the different agencies.

The NZMS was developed by DOC (van Dam-Bates et al., 2018) in order to augment existing national level programmes for the purpose of monitoring management effectiveness at multiple spatial scales. A key benefit of a Master Sample is that it helps coordinate monitoring within and between agencies. DOC required this to both coordinate monitoring between district, regional and national offices as well as externally with RCs and MfE. NZMS is a spatially balanced sample with a hierarchical order generated using Balanced Acceptance Sampling (BAS). It specifically provides a way of ensuring rigorous sample design which can readily adapt to fluctuating resource levels, changes in boundaries/area of interest while accomodating pragmatic considerations of monitoring implementation such as the need to replace sample locations due to access/logistical constraints.

While the NZMS facilitates coordination through site selection, successful implementation requires agencies communicate about their monitoring programmes and use aligned indicators, measures and methods. See the Pacific Northwest Aquatic Monitoring Partnership (https://www.pnamp.org/static-page/what-tools-do-we-offer) for an example of a Master Sample used for coordinating freshwater monitoring in Washington State, USA.

Existing Monitoring Programmes

The NLM is a systematic sample spread across New Zealand on an 8-km grid with a random start. It builds on the Land Use Carbon Analysis System (LUCAS) forest monitoring programme described by Coomes et al. (2002). Random-start systematic sampling is a probabilistic sample where effort is spread evenly across the landscape proportional to the survey area. The 8-km grid has excellent spatial coverage and is representative of the entire PCL. The spread of effort improves precision over simple random sampling any time there are strong spatial trends in the population. There are roughly 1,400 sites on the 8-km grid that are currently monitored for ecological integrity by DOC. Each year, 20% of the sites (randomly selected) are monitored on a non-overlapping rotating schedule. Designing the survey this way puts emphasis on capturing spatial variability versus short-term trends. The programme captures long-term trends in ecological integrity through repeated sampling every 5-years.

The 8-km grid exists across all of New Zealand and has been implemented off PCL in the Greater Wellington and Auckland Regions. Each RC has a proportion of 8-km grid locations roughly equal to their proportion of NZ land area they are responsible for. Thus for the West Coast Region , the largest proportion of Regional Council sites on the 8-km grid are on PCL and monitored as part of NLM (84% PCL). In other extremes, such as Otago, a large number of grid sites are not on PCL (497 sites off of PCL and 92 on PCL). See Table 1 for the number of sites on and off PCL for each region. Figure 1 shows the 8-km grid for the Southland region which is more balanced with 47% of the 8-km grid occurring off of PCL.

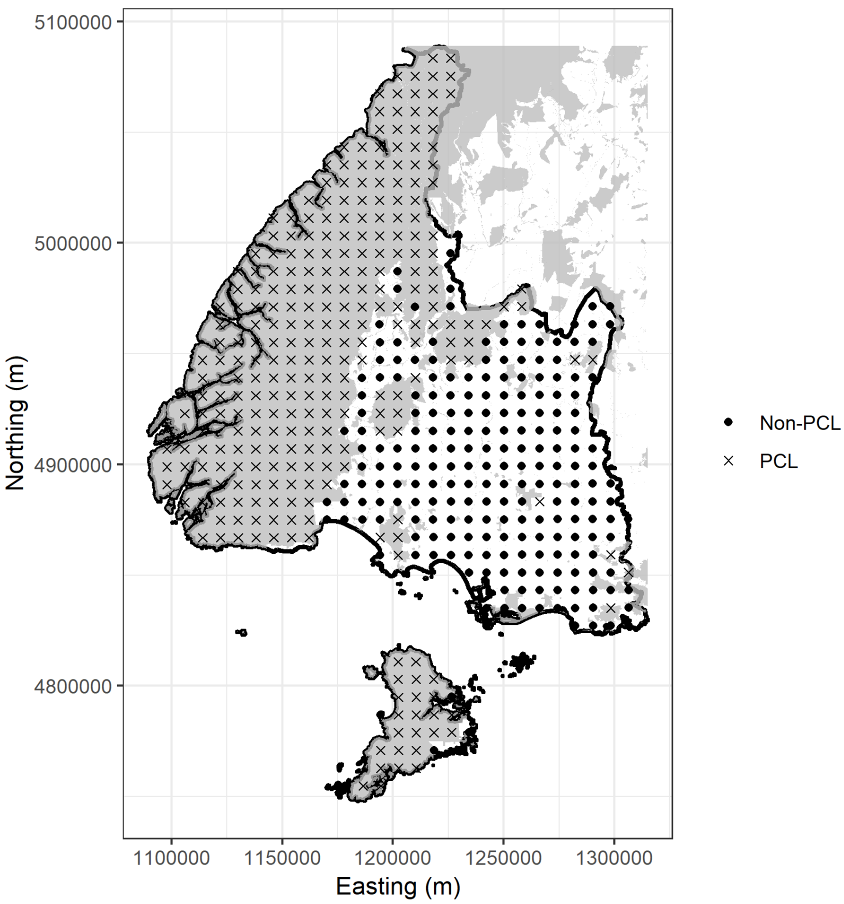

Figure 1: Southland Region Example of the 8-km grid which yields 495 sites, 277 of which are are on PCL and monitored by the NLM, and 218 which Southland Regional Council would be responsible for.

Table 1: Number of sample locations on the 8-km grid by On-PCL/Off-PCL for each region.

Region	On PCL	Off PCL	Total
Auckland	5	74	79
Bay of Plenty	38	160	198
Canterbury	205	506	711
Gisborne	8	122	130
Hawkes Bay	29	189	218
Manawatu-Wanganui	61	288	349
Marlborough	74	84	158
Nelson	2	5	7
Northland	29	173	202
Otago	92	405	497
Southland	277	218	495
Taranaki	26	89	115
Tasman	103	51	154
Waikato	63	319	382
Wellington	24	103	127
West Coast	305	52	357
Total	1341	2838	4179

Stratification

Regional Councils are specifically interested in monitoring all non-PCL in their area, consisting of a diverse matrix of ecosystems and land use types. Stratification can be used to improve precision of a sample by focusing effort in areas that are more variable. For instance, bird or plant diversity is likely to be more variable across the landscape in native forest than pasture. A bird monitoring programme that proportionally over represents forest and under represents pasture will improve precision over a programme with the same sample size which ignores the difference in variability between landcover types. Using area proportional sampling, pasture would inherently get a larger number of sites selected than is optimal for making inference on both pasture and native forest. In this case, stratification can improve the precision or maintain the same precision for estimates of the entire region at reduced cost.

For the case studies described in this document we examined which land use cover types do not occur frequently on PCL based on the LUCAS Land Use Map and and where stratification could improve precision for reporting when compared to an unstratified systematic sample. We defined two classes for stratification; Stratum 1 - Native and Stratum 2 - Impacted. Impacted includes Settlements, Annual and Perennial Cropland and High producing Grassland land cover types. Native is defined as the rest such as Forest, Shrubland etc and is not truly "native" as it incorporates planted forest and other introduced land covers. Table 2 shows how many samples in the NLM programme occur in each of these two Strata. Table 3 breaks down what proportion of each Region is made up of each potential strata.

Varying sample effort in each strata can be accommodated when using the 8-km systematic sample, but sample size can only be adjusted by halving or doubling the grid size, i.e. to intensify sample effort a grid size of 4-km would be needed, to reduce sample effort a 16-km grid size would need to be employed.

In contrast, stratification within the NZMS is simpler and more flexible. Once strata are defined for the design, the sample size (see below) or number of sites in each stratum required for a set level of precision are chosen.

Traditional statistical theory recommends that strata should be chosen that are constant through time (e.g. not subject to change). Using forest and non-forest can be an issue when some non-forested areas are recovering habitat and may at some point become defined as forested. The NZMS can account for changing ecosystems but the spatial extent may need to be adapted in the long-term, adding more complexity to the survey. Both the 8-km grid and the NZMS can accommodate varying sample effort by strata, however the NZMS provides for greater flexibility in dynamic adjustment of sample size.

Although we suggest that stratification may improve precision or reduce the costs of the programme, it is necessary to note that it can negatively impact the sample if applied incorrectly. If all key indicators being measured at a site are correlated then stratification is likely to be successful. However, if there are important and complex vegetation changes occuring in the Impacted stratum, this may be missed by the reduced sampling effort and could result in a poor understanding of the complexity of those ecosystems.

Table 2: Number of sample locations if 8-km grid implemented. Seperated by strata, sampled by DOC already versus those that require sampling by Regional Councils.

		Stratum 1 = Native*			Stratum 2 = Impacted†	
Region	Total	Total native	DOC sampling already	Requires RC sampling	Requires RC sampling	Total number of 8-km that would require RC to sample‡
Auckland	79	34	5	29	45	74
Bay of Plenty	198	160	38	122	38	160
Canterbury	711	516	205	311	195	506
Gisborne	130	115	8	107	15	122
Hawkes Bay	218	132	29	103	86	189
Manawatu-Wanganui	349	256	61	195	93	288
Marlborough	158	147	74	73	11	84
Nelson	7	7	2	5	0	5
Northland	202	110	29	81	92	173
Otago	497	407	92	315	90	405
Southland	495	389	277	112	106	218
Taranaki	115	68	26	42	47	89
Tasman	154	143	103	40	11	51
Waikato	382	219	63	156	163	319
Wellington	127	95	24	71	32	103
West Coast	357	351	305	46	6	52
Total	4179	3149	1341	1808	1030	2838

* Strata 1 = Native which includes Forest, Shrubland, Planted forest and other introduced land covers.

† Strata 2 = Impacted which includes Settlements, Annual and Perennial Cropland and High producing Grassland.

‡ DOC complete no sampling of 8-km sites in the Impacted strata (Settlements, Annual and Perennial Cropland and High producing Grassland.

Determining sample size

Choosing a sample size is frequently one of the most complicated parts of designing a survey. We consider that the NLM programme has been successful for SOE monitoring on the PCL. For this reason, in our case studies below we have used the NLM sample size as a benchmark for Native areas. Determining the level of sampling effort required for Impacted areas required a different approach.

There are many ways to choose sample size within each stratum. Commonly, a budget may define the sample size but this is risky if it doesn't resource monitoring properly, the programme can become a poor investment and fail to give useful information as a result. As described above, a better approach is to choose a sample size that meets some requirement of precision based on the study objectives. For this, pilot data or expert opinion may be used to inform how many locations to sample from (and how frequently).

In the case of the existing NLM programme, the collected data can be used in the place of a pilot study to investigate the variability of different indicators that are selected for SOE reporting. As an example presented here, we consider bird abundance for as a key indicator of ecosystem health and use data provided by Greater Wellington Regional Council (GWRC) to provide an estimate of required sample size. We investigated Bellbird, Fantail, and Grey Warbler bird abundance to see how the different species varied between the two strata (Native vs Impacted).

We observed that the standard deviation of these bird's abundance metrics were roughly twice as large for Native habitats vs Impacted. Using the Neyman Allocation (Dalenius and Hodges Jr, 1959) we can assign a sample size for the Impacted stratum. The Neyman Allocation calculates sample size by combining the proportion of the sample frame of each stratum with its variability. For standard deviation $s_{Impacted} = 1$ and $s_{Native} = 2$ and $n_{Impacted}$ unknown but n_{Native} equal to the number of 8-km grid sites on Native habitat in each council we can define the total sample size as

$$n = n_{Native}/(2 \times P_{Native}/(2 \times P_{Native} + 1 \times P_{Impacted})).$$

P_{Native} and $P_{Impacted}$ are the proportion of area in the Region are Native or Impacted. This result is intuitive because sample size depends on area (the 8-km grid) and heterogeneity (how much bush or farmland is in the Region).

Using the rule of thumb variability (2:1), we estimated sample sizes in each region if we were to use stratification (Table 4). Note that for small regions such as Nelson, sample sizes in some strata are too small to be practical and minimum sample sizes will be needed. Statistically, 3 samples is the bare minimum, but we recommend a at least 5 samples in order to provide reliable inference.

Table 3: Basic breakdown the area contained within each Regions and percentage of this area that is a. On-PCL vs Off-PCL and b. Native vs Impacted

Region	Area(km^2)	%PCL	%Off-PCL	%Native	%Impacted
Auckland	4910.3	6.0	94.0	47.5	52.5
Bay of Plenty	12279.1	21.8	78.2	81.5	18.5
Canterbury	45218.6	27.0	73.0	72.7	27.3
Gisborne	8390.9	7.6	92.4	88.9	11.1
Hawkes Bay	14199.2	12.9	87.1	66.6	33.4
Manawatu-Wanganui	22224.8	17.8	82.2	73.8	26.2
Marlborough	10487.2	46.1	53.9	91.6	8.4
Nelson	423.7	13.7	86.3	88.4	11.6
Northland	12520.3	12.4	87.6	56.1	43.9
Otago	31908.0	20.2	79.8	81.8	18.2
Southland	31936.5	57.9	42.1	78.1	21.9
Taranaki	7255.0	19.7	80.3	62.1	37.9
Tasman	9643.8	64.9	35.1	91.6	8.4
Waikato	24593.2	15.2	84.8	56.2	43.8
Wellington	8118.2	17.5	82.5	75.9	24.1
West Coast	23359.7	84.1	15.9	96.9	3.1

Table 4: Estimated sample size if Master Sample implemented. Seperated by strata, sampled by DOC already versus those that require sampling.

		Strata 1 = Native		Strata 2 = Impacted	
Region	Total	DOC Sampling already	Requires RC sampling	Requires RC sampling	Total number of Master Sample that would require RC to sample
Auckland	53	5	29	19	48
Bay of Plenty	179	38	122	19	141
Canterbury	613	205	311	97	408
Gisborne	123	8	107	8	115
Hawkes Bay	166	29	103	34	137
Manawatu-Wanganui	302	61	195	46	241
Marlborough	154	74	73	7	80
Nelson	8	2	5	1	6
Northland	154	29	81	44	125
Otago	453	92	315	46	361
Southland	444	277	112	55	167
Taranaki	89	26	42	21	63
Tasman	150	103	40	7	47
Waikato	305	63	156	86	242
Wellington	111	24	71	16	87
West Coast	357	305	46	6	52
Total	3661	1341	1808	512	2320

Spatial Scales

For many RC's it will be important to have a monitoring programme that works at different spatial scales. Some monitoring objectives will include the ecological response to a specific management action. The 8-km grid was designed for broadscale status and trend monitoring and is unlikely to provide sufficient information at a local level. Increasing the sample size of the grid by reducing the grid size is possible and would allow for localized monitoring. However, as discussed above it would no longer integrate with the larger DOC monitoring program and would then simply be a systematic sample. Although systematic sampling is an effective way to spread effort evenly, modern methods of generating probability designs with spatial balance add flexibility to the systematic design and are an overall improvement.

The NZMS is able to integrate with the different spatial scales of a monitoring programme making use of the fact that it is dense (infinite sites at any scale) and has a hierarchical ordering to ensure that sites selected at the larger scale are matched with the localized monitoring reducing overall effort at the different spatial scales.

Legacy Monitoring

Often, there are existing monitoring networks that have historical information and/or are currently monitored. Incorporating these sites into new monitoring programmes improves estimation of trends and can reduce costs if the sites are already resourced. Criteria for explicit inclusion of legacy sites are consistent methodologies and sampling with a probability based method (not chosen for convenience). The NZMS has been designed with the intention of augmenting existing legacy monitoring. If legacy monitoring in an area is adequate, then no NZMS site needs to be selected. The NZMS is just used to ensure that as a whole, the region is sampled at the intensity required by the programme. If a catchment has a historical programme of 10 sites and that catchment makes up 10% of the monitoring area, then an area proportional number of those sites will be randomly selected to be included into the program and the NZMS is then used to augment areas with no existing effort.

Adaptability

Heterogeneity in ecosystems/land cover means there are many sites which may be rejected due to denial of access to private land or, for example, the randomly selected site lands directly on top of a built surface. Objective, statistically robust methods must be set up to allow for establishing sites in feasible areas when the original sample has to be rejected. The NZMS has an explicit method using the hierarchical ordering to relocate sites that fail to fall onto accessible areas. If a site is rejected, a new site, in order, is available to replace it maintaining overall spatial balance and design robustness. Instead of the user needing to re-establish the site randomly, they move down the list of available sites adding the new one and removing the missed ones. The procedure is simple and requires nothing more than identifying that a site is not able to be sampled using defined criteria.

If a monitoring programme stratifies by forest, pasture, urban and other, then it is possible through new management regimes that the pasture is actively managed and shifts through succession from pasture to shrub and eventually to forest. These sites may have their own specific programme for monitoring progress of the reforestation. Otherwise, through the hierarchical ordering of the NZMS, that site may be reclassified and depending on the ordering of the existing sample, another site may be dropped from the sample or added in the "other" category maintaining spatial balance across all ecosystem types.

Coordinating monitoring

When the 8-km grid is effective and feasible for a regional council to implement, then it is very easily coordinated with DOC and other monitoring programmes. This has been shown by GWRC working with DOC to monitor biodiversity on the 8-km grid. The 8-km grid is the first part of any more localised monitoring on PCL where the NZMS and other legacy sites are used to augment/intensify sampling when monitoring for management purposes. The NZMS is equally effective for coordinating monitoring as the 8-km grid with the additional benefit of solving some of the obstacles the 8-km grid presents for some RC's, such as lack of resources to implement the sample size determined by the 8-km grid and issues with site replacement due to land access or land cover.

Southland Case Study

The objective of this case study is to contrast application of the NZMS using a stratified sample design versus an unstratified sample design using the 8-km grid.

There are 495, 8-km grid locations in Southland, 277 of which occur on PCL and are monitored by DOC. This leaves an additional 218 sites that would be monitored

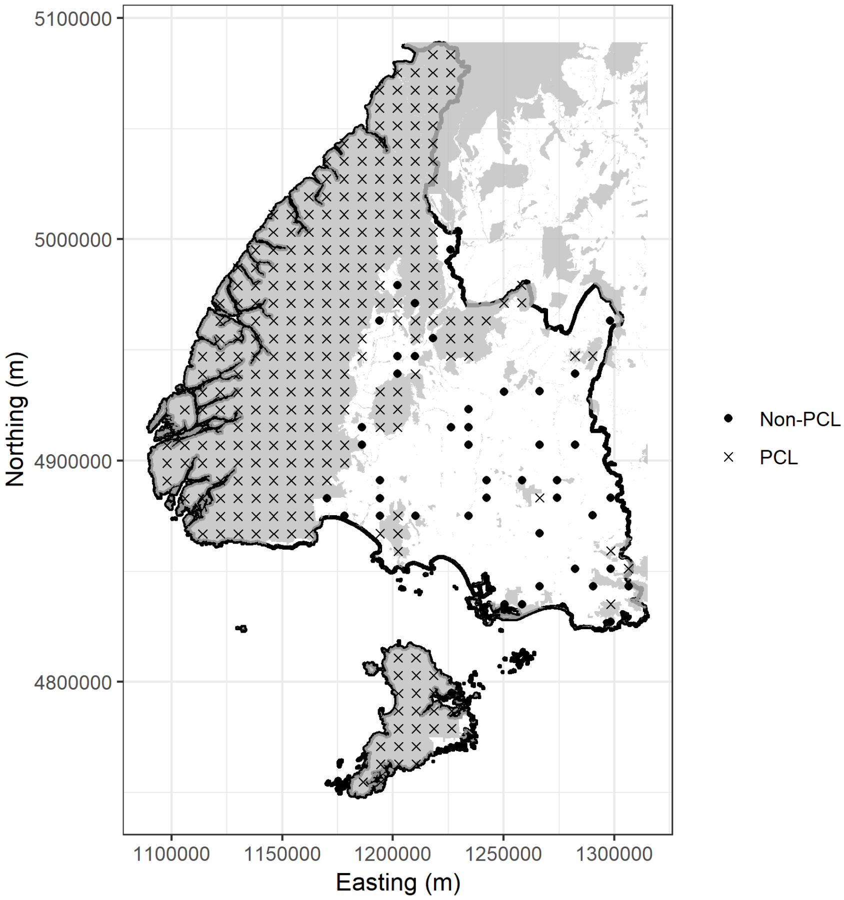

Figure 2: Southland Region Example of the 8-km grid single year of sampling, where 44 sites are monitored annually.

if Southland Regional Council (SRC) implemented the 8-km grid. DOC employs non-overlapping rotating panels on a 5-year rotation for SOE monitoring. Under this design, each year SRC would have to monitor roughly 44 randomly selected sites of the 8-km grid (Figure 2).

Given no resource constraints implementation of monitoring at each of these sample locations would be sufficient for monitoring and reporting status and trend for the Southland Region and integrating seamlessly with DOC's NBMP. However, as resource constraints are a major impediment to uptake of aligned monitoring for many partner agencies, including SRC. One approach to address this would be to reduce the sample size to match resource constraints using systematic sampling approaches the 8-km grid could be reduced to a 16 or 32-km grid. This would reduce the sample size in the Southland Region from 218 to 109 and 54 respectively.

A better approach is to use the the NZMS to derive sample locations for the Southland Region. This is conceptually simpler and more flexible than scaling a systematic sample based on the 8-km grid. For the area in Southland region not covered by PCL we stratified by Native and Impacted and applied the NZMS to derive **N** sample locations. Note that if required additional site specific monitoring can be derived from the NZMS. This means sample locations for regional status and trend monitoring overlapping with intensively managed sites can contribute to site specific estimates of monitored parameters. If more (or less) sample locations are needed in the future this can be easily accommodated without compromising the initial sample locations implemented from the NZMS.

We determined sample size using Neyman Allocation. As described above we calculate the following: $p_{Impacted} = 21.9\%$, $p_{Native} = 78.1\%$, $n_{native} = 389$ and we still assume that variability is half on impacted than native areas. Then

$$n_{total} = 389/(2 * 78.1/(2 * 78.1 + 1 * 21.9)) = 389/0.877 = 444$$

Therefore, in the stratum defined as "Native" a sample of 389 sites (277 by DOC on PCL and 112 by SRC) and 55 "Impacted" sites are required (Table 4). Figure 4 shows the full sample with NZMS sites across Southland Region. Figure 4 shows the first year of monitoring. A comparison of the 8-km grid vs the NZMS is provided in Table 5. This is a case study to provide an example for EMAR. We recommend if RC's are interested in implementing the NZMS monitoring programme that final spatial processing is completed and the strata used are discussed and these sample sizes recalculated. As such these are a rough estimate of what stratification can look like for the SRC case study and for estimated costs.

Because an infinite number of sites make up the NZMS in Southland, all of which are ordered, we are able to move down our site list when a site needs to be replaced. For example, if one of the selected sites cannot be sampled because a farmer refuses access to their private land then that site is replaced by a new NZMS site further down the list. This keeps the site replacement completely objective and the full sample intact. Whenever this occurs the scale of inference for the entire study is reduced to "accessible" land but this is typical for these types of study and the hope is that there are not fundamental differences in these areas that bias the study.

In summary, for SRC the benefit of using the NZMS over the 8-km grid is that;

1. Stratification reduces costs.
2. Sample size can be flexibly scaled to adjust to resource constraints.

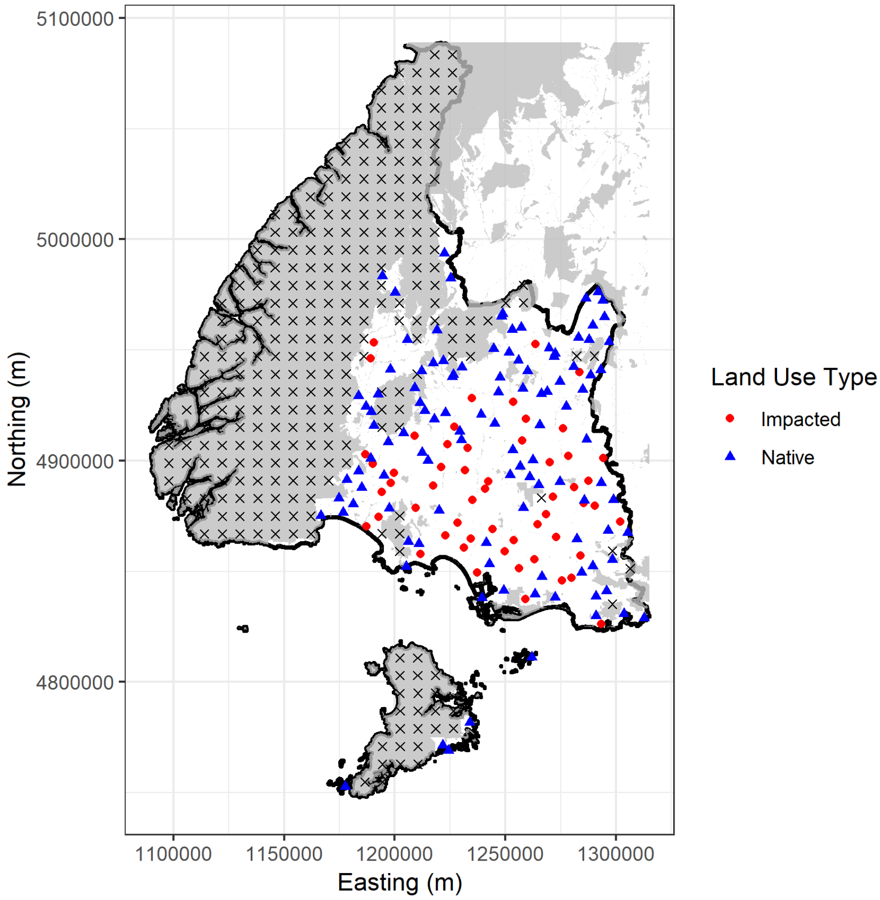

Figure 3: Southland Region Example of the NZMS with 389 sites - 277 PCL, 167 Southland Regional Council.

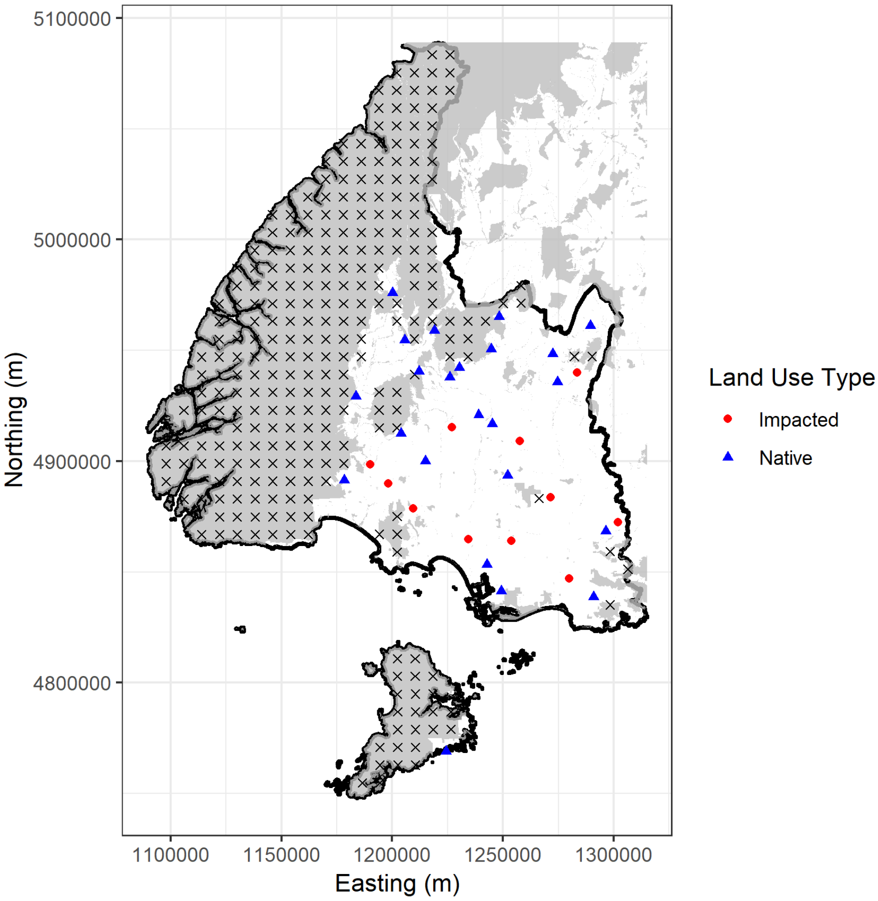

Figure 4: Southland Region Example of the NZMS showing year 1 of the sites, 11 Impacted and 23 Native.

3. Regional monitoring of status and trend contributes explicitly to monitoring of intensively managed sites.
4. The NZMS can be used to intensify regional status and trend monitoring in sites of specific interest.
5. Site replacement is built into the sampling procedure.

Stratified Analysis Example

As an example analysis using stratification, we used bird data collected by Wellington Regional Council combined with PCL 8-km grid data collected by DOC in the Wellington Region. As a result we have a combined 24 Native sites on PCL with 42 Native and 23 Impacted sites off-PCL. Grey warblers were used as an example as they are common on all habitats in the region. Count data were fit as a negative binomial mixed-effects model where a random-effect was used to deal with the 5 repeated bird counts at each site. The fixed-effect of Native/Impacted was included. Using the model we simulated data 1000 times for a full GWRC sample (95 Native and 32 Impacted) and a stratified sample (95 Native and 16 Impacted). On each iteration the mean and standard error was calculated for the GWRC region average Five Minute Bird Count of Grey Warblers. As a result, with 16 sites removed equivalent precision was achieved over monitoring with the full sample size. The full sample standard error was 0.10 (0.08, 0.14) while the stratified sample standard error was 0.10 (0.07, 0.13). To give some confidence to this result we repeated it for chaffinch and the results were similar.

We demonstrate here that stratification for at least birds has significant advantages over a more simple design. However, this result should be taken with some caution. If stratification is done poorly and variability is actually higher in the stratum that gets fewer samples, then inference/precision would be negatively impacted. For most cropland we might expect that vegetation complexity is lower than intact forests. In these cases the results above should hold. However, it is up to the group in charge of the design to choose stratification layers specific to their region that they believe will be optimal.

Table 5: Summary of plot numbers by Region for each scenario and difference if implement Master Sample programme

Region	Total number of 8-km that would require RC to sample	Total number of Master Sample that would require RC to sample	Difference
Auckland	74	48	-26
Bay of Plenty	160	141	-19
Canterbury	506	408	-98
Gisborne	122	115	-7
Hawkes Bay	189	137	-52
Manawatu-Wanganui	288	241	-47
Marlborough	84	80	-4
Nelson	5	6	1
Northland	173	125	-48
Otago	405	361	-44
Southland	218	167	-51
Taranaki	89	63	-26
Tasman	51	47	-4
Waikato	319	242	-77
Wellington	103	87	-16
West Coast	52	52	0
Total	2838	2320	-518

Conclusions

The 8-km grid was designed using the most appropriate developments in statistical sample design at the time and it remains an effective sample design for broadscale monitoring of widespread ecological resources. Since this time developments in spatially balanced designs have improved on systematical sampling to provide enhanced flexibility whilst maintaining robust design. Spatially balanced sampling methods are appropriate for broadscale and site specific monitoring. The NZMS has the same utility as the 8-km grid as the design basis for coordinating and integrating monitoring within and between agencies, with additional advantages such as dynamic adjustment of sample size and ability to accommodate changing boundaries, logistical/resource constraints and dynamic site replacement when encountering inaccessible sample locations.

We suggest the NZMS is an improved platform to coordinate and implement SOE monitoring which integrates seamlessly with existing broadscale monitoring already implemented by DOC (NLM/Tier 1) and some RC's (GWRC SOE and Auckland Council SOE monitoring). It has the added benefit of integrating with any future site specific effectiveness monitoring, thereby reducing duplication of monitoring efforts and increasing the effectiveness of any future investment in monitoring.

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