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USING OPTIMUM ALLOCATION ANALYSIS TO IMPROVE SEED MUSSEL STOCK ASSESSMENTS

JAMES ASA STRONG* AND MATTHEW SERVICE
Fisheries and Aquatic Ecosystems Branch, Agri-Food and Biosciences Institute, Newforge Lane, Belfast, Northern Ireland, BT9 5PX

ABSTRACT Seed mussel stock assessments rely heavily on techniques similar to those used in seabed mapping and can involve both acoustic data collection and physical ground truthing. Optimum allocation analysis has recently shown value in using acoustic data variances as surrogates of seabed heterogeneity to allocate efficiently the ground-truthing effort that minimizes survey coefficients of variance. Using acoustic data from a single-beam ground discrimination system, optimum allocation analysis was used to direct ground truthing between seed mussel strata. The resulting stock assessment values and variances were compared with actual fished quantities and were found to be highly comparable when compared with random and expert judgment scenarios.

KEY WORDS: optimum allocation analysis, seed mussel stock assessment, seabed mapping

INTRODUCTION

The effective monitoring, management, and utilization of biological marine resources relies heavily on periodic quantification or stock assessment. For sessile benthic resources, seabed mapping techniques have begun to form the core of the stock assessment methodology (e.g., videographic assessments of *Nephrops norvegicus* in the Irish Sea). Seabed mapping is an increasingly popular activity worldwide, coinciding with rapid methodological development (Clements et al. 2010) and technological advances such as multibeam echo sounders, acoustic ground discrimination systems, and sidescan sonar (Anderson et al. 2008). These technologies have allowed huge areas to be quickly insonified, with vast amounts of acoustic information collected. However, the ultimate difficulty lies in the substantial survey effort required to confirm the acoustic readings physically and to relate them to the biology or resource content of an area.

Most soft-sediment ground truthing, whether for resource or habitat mapping, still relies on the use of traditional sediment-sampling gear such as grabs and dredges. Comparing the small sample volume of grabs and dredges with the expansive area of a seabed that can be sampled acoustically means that ground-truthing methods are time-consuming, poorly replicated, and expensive. It is therefore imperative that ground truthing of large acoustic data sets is undertaken in the most effective and economically viable way possible to maximize map confidence and yet minimize the time and cost associated with resource and habitat map production.

It has become standard practice within broad-scale mapping of marine habitats and seabed resources to utilize a 2-stage survey methodology (Anderson et al. 2008). The first stage is a dedicated remote-sensing phase that produces the acoustically derived map of the area from which the acoustic classes, and hence predicted resource zones, are identified. The ground-truthing second stage focuses on the characterization of the predicted resource zones and confirmation of boundaries; this might take the form of dedicated grab, dredge, or videography cruises (Foster-Smith & Sotheran 2003).

Ground-truthing strategies have rarely been adequately addressed or even specified in published mapping literature. Precisely how the first-stage physical survey informs the ground truthing is poorly defined and occasionally complex. Most rely on expert judgment, whereas in some advanced studies the ground-truthing strategy uses identified acoustic ground types, with sampling being related to ground-type area (Jordan et al. 2005).

In the sea loughs of northern Ireland, the bottom culture of mussels (*Mytilus edulis* L.), an industry worth in excess of £10 million pa, relies on the ready availability of seed mussel from transient offshore beds. Competition for this limited resource and pressures from nature conservation have led to the assessment and allocation of this resource coming under increasing scrutiny.

It is generally agreed that any sampling of a "population" or, in this instance, a resource such as a stock of mussel seed, should use both size (area) and heterogeneity (variance) to inform the required "sample" size and hence ground-truthing sampling strategy (Cochran 1977). When considering a standard acoustic remote-sensing and ground-truthing survey, the resulting areas of identified acoustic resource zones are easy to calculate in Geographic Information Systems. In the absence of previous stock assessments or surveys for a site, measures of variance are problematic. It seems appropriate that acoustic data could provide information related to resource heterogeneity and thus facilitate optimally allocated sampling. Acoustic data, as demonstrated by Clements et al. (2010), are readily amenable to calculations of basic statistics such as means and SDs for each identified resource zone. Such data may be used as a proxy for within-resource zone heterogeneity.

Objective methods that use remotely sensed data to direct ground truthing are currently not used, and are likely to be valuable and well received by marine scientists for routine resource mapping and stock assessments. Clements et al. (2010) recently introduced the use of optimum allocation analysis (OAA) statistics for seabed ground-type mapping. OAA may be defined as a procedure used in stratified sampling to allocate numbers of sample units to different strata either to maximize precision at a fixed cost or to minimize cost for a selected level of precision; precision in this sense means both closeness to a true value and

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*Corresponding author. E-mail james.strong@afbini.gov.uk

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repeatability over time. OAA has been used in a wide variety of fields, ranging from computing (e.g., Kwon & Kim 2005) to fisheries science (e.g., Allen et al. 2002, Adams et al. 2006).

Clements et al. (2010) used acoustic parameters, derived from a multibeam echo sounder, within OAA as surrogates for ground type variance. This information was then used to allocate a limited ground-truthing effort efficiently to minimize overall survey coefficients of variance.

By integrating the resource zone areas and variances, a statistical method such as OAA (Sukhatme & Sukhatme 1970, Cochran 1977) should be able to calculate a surrogate of resource heterogeneity values to direct ground-truthing efforts. The objective of this study was to test OAA with a single-beam ground discrimination system survey to assess its utility in directing ground truthing in a seed mussel stock assessment.

MATERIALS AND METHODS

Study Site

Donaghadee Sound is situated between the Copeland Isles and the coast of northern Ireland (Fig. 1), approximately 8.5 km east of Bangor and 5 km north of Donaghadee. The Donaghadee Sound seed mussel bed is situated less than 800 m from the Copeland Isles, in a small topographic depression in the seabed. This area has an infrequent settlement of seed mussel. During the March 2010 seed mussel stock assessment, the site was judged to have received enough settlement for a stock assessment and commercial extraction of the seed mussel.

Acoustic Data Collection and Processing

A RoxAnn (Sonavision Ltd., Aberdeen, UK) ground acoustic discrimination system was mounted onto the fisheries protection vessel (FPV) *Ken Vickers*. The FPV *Ken Vickers* then completed a survey grid with 50-m track spacing. Tracks were run at 6 knots (Fig. 2). All RoxAnn ranges and gains were optimized at the beginning of the survey and subsequently fixed for the rest of the survey.

Processing of RoxAnn

Erroneous data and values missing positional data were removed. RoxAnn collects 3 parameters—namely, E1, E2, and depth. E1 is an integration of the tail of the first seabed echo and is taken to indicate seabed roughness. E2 is an integration of the whole of the second return echo and provides an index of seabed hardness. The raw E1, E2, and depth data were standardized by dividing each variable by the 95th percentile of each data range.

E1 and E2 were imported into PASW Statistics version 17 (IBM Corporation, Somers, NY) for 2-step cluster analysis to find the appropriate number of clusters (i.e., number of distinct resource zones or strata). The standardized E1 and E2 were then imported into Surfer (Golden Software, Golden, CO) for interpolation with Kriging. The interpolated values are then

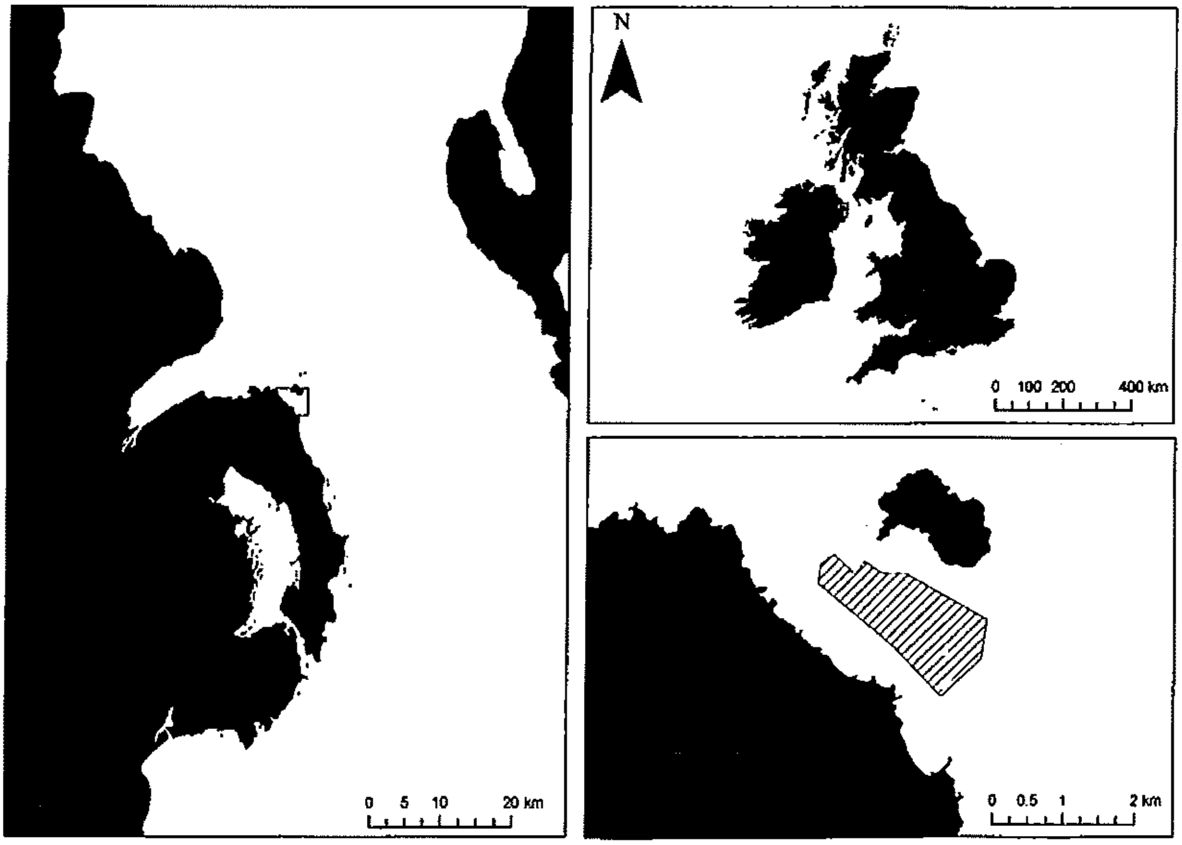

Figure 1. Location of Donaghadee Sound seed mussel bed (hatched polygon) in northern Ireland, UK.

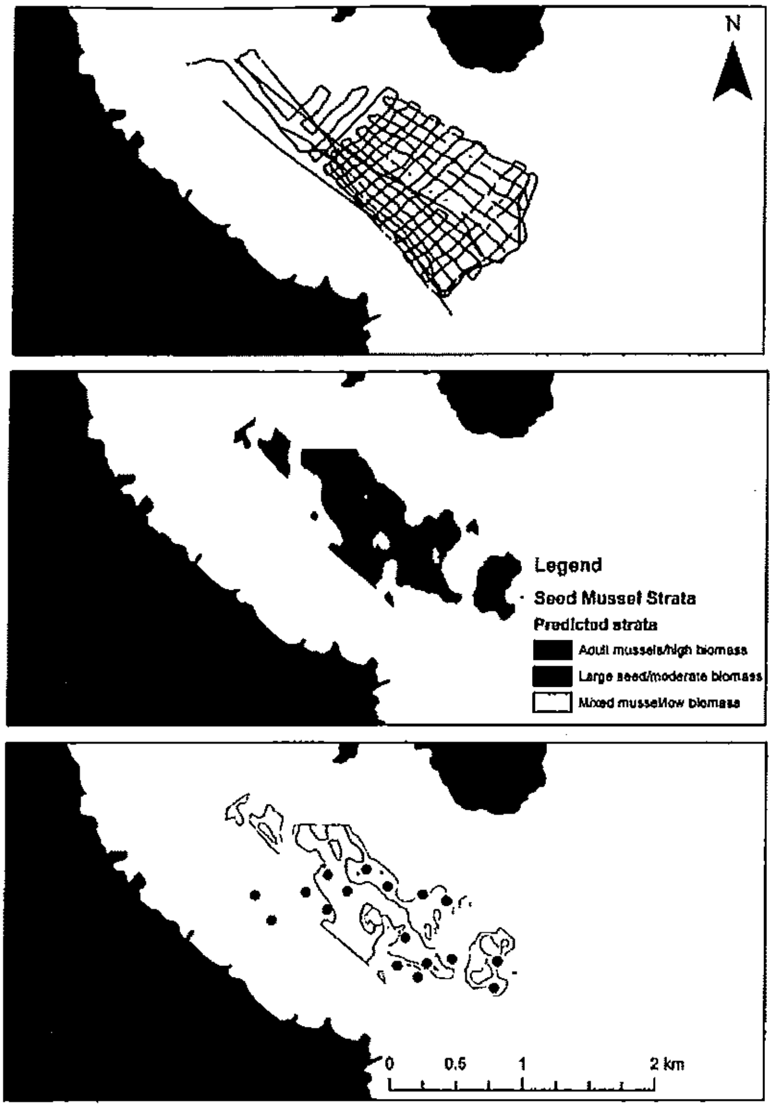

Figure 2. (A) RoxAnn tracks collected at Donaghadee Sound for the March 2010 seed mussel stock assessment. (B) Predicted seed mussel strata. (C) Location of 100-m dredge ground-truthing midpoints.

exported to AcrMap (Esri, Redlands, CA) for surface production and clustering using the Isocluster tool. The AcrMap maximum likelihood tool was then used to generate a classified surface. The resulting raster surface was then converted to a polygon and attributed with areas.

To extract the required mean and variance for E1, E2, and depth for the OAA, the standardized point data were also imported into ArcMap. The clustered surface polygons were then used to divide the raw data into the resource zones and to generate descriptive statistics that included mean and vriance.

Ground Truthing

To gather the required biomass and density data for the site, industrial mussel dredges were used to collect the ground truthing. To test the OAA recommendations and other scenarios, sampling was done in excess of that required for the ground truthing of the OAA. Dredges were towed exactly 100 m. The contents of the dredges were estimated, and samples were collected for density and size distribution analysis.

Optimum Allocation Analysis

The statistical procedure and concept of optimum (also termed *optimal* in some literature) allocation analysis as a method for stratified, random sampling design is well defined (Sukhatme & Sukhatme 1970, Cochran 1977). In a given stratum, a larger sample is required if the stratum is large, is variable, or is cheap to survey. The total number of samples required over all the strata will increase 4-fold when halving the coefficient of variation.

In the current study, a "population" refers to a population of remotely sensed data for a survey site that is thought to relate to substratum heterogeneity and type. The parameters used to define the population in this case are E1, E2, and depth, because they were the primary variables used to delineate the strata in the survey area. Subpopulations, or "strata," are the resource zones into which the remotely sensed data are classified prior to being confirmed with ground truthing.

Undertaking the Optimum Allocation Analysis

The mean and the variance of E1, E2, and depth were entered into an MS Excel macro containing embedded calculations for OAA (Clements et al. 2010). The area of each predicted resource zone was also added in square meters.

Allocation with more than one characteristic in stratified sampling is conflicting in nature, because the best allocation for one characteristic will not, in general, be best for others. Some compromise must be reached to obtain an allocation that is reflective, in part, of the 3 variables. Allocation would be simpler for all variables if they were themselves were positively correlated (Clements et al. 2010). In the case of the data used in the current study, statistically significant positive correlations were found between E1 and depth (Pearson 2-tailed correlation, $r = 0.276$ $P = 0.000$, $n = 10{,}141$), and E1 and E2 (Pearson 2-tailed correlation, $r = 0.439$ $P = 0.000$, $n = 10{,}141$), but not between E2 and depth (Pearson 2-tailed correlation, $r = 0.009$ $P = 0.352$, $n = 10{,}141$). It was therefore considered acceptable to average the recommended sampling for E1, E2, and depth to produce 1 composite value.

The coefficient of variation (CV) was set at 6% (i.e., 94% precision) and 10% (i.e., 90% precision) for calculating the optimum sample numbers per resource strata. It was not possible to run the OAA at 5% CV as a result of the loss of one dredge sample at sea. For comparison, several other ground-truthing scenarios were also undertaken (Table 1). These included scenarios needing extra ground-truthing effort in excess of the 6% OAA scenario.

It must be stressed that, although OAA recommends the area of seabed to be sampled, it does not advise where these should be placed within each strata, how they should be distributed among patches of the same strata, or what sampling equipment should be used.

TABLE 1.

Ground-truthing scenarios and required ground-truthing replication.

Scenario	Title	Resource Zone			Total
		1	2	3	
1	OAA 6%	3	2	2	7
2	OAA 10%	1	1	1	3
3	All/area	5	6	3	14
4	Equal 3	3	3	3	9
5	Equal 2	2	2	2	6
6	Random	4	4	3	11
7	Random	5	5	3	13
8	Random	3	5	3	11
9	Random	4	5	2	11
10	Random	5	3	3	11
11	Random	4	1	3	8
12	Random	2	5	1	8
13	Random	1	3	2	6
14	Random	4	6	1	11
15	Random	3	4	1	8
16	Random	2	3	1	6

Each scenario has a required level of ground truthing in each resource zone. Bootstrapping, with resampling, was used to subsample the available ground truthing randomly 1,000 times for each scenario (Efron & Tibshirani 1993, Manly 1997). For example, scenario 2 required 1 ground-truthing sample from each resource zone, yet 5, 6, and 3 samples were available for each zone. Bootstrapping randomly extracted 1 of the available values from each zone, and this was repeated 1,000 times.

Because resampling bootstrapping was used, potentially the same ground-truthing value could be selected several times in a stratum for any iteration. For each of the 1,000 combinations of ground truthing, a total site stock assessment value was calculated. After the bootstrapping, each scenario has 1,000 stock assessment values. Because the total seed mussel that was fished by the commercial vessels was reported to DARD, an actual stock biomass value was available for comparison with the estimated scenario stock assessments.

RESULTS

The results for the 16 ground-truthing scenarios are shown in Figures 3 and 4. The distribution of stock assessment values about the scenario mode was also calculated. The mean was not used after observing substantial skew in distribution for each scenario. In addition, the resampling of the same small number of ground-truthing samples resulted in stock assessment value distributions more nominal in nature. Last, because each treatment fundamentally used the same ground-truthing values, the mean values were all very similar and showed little variation.

The actual tonnage of seed mussel removed from Donaghadee Sound in March and April 2010 was 2,929 t (offset x axis in Fig. 3). The modes for scenarios 1 and 3 were within 1% of the actual tonnage. Scenarios 8, 11, 12, 13, and 16 were between 1% and 5% of the actual tonnage. Scenarios 4, 6, 7, and 9 were between 5% and 10%. Last, scenarios 5, 10, and 14 were greater than 10%, and scenarios 3 and 15 were more than 20% from the actual seed mussel tonnage. The SE for the scenarios typically fell within 1–5% of the tonnage mode, although scenarios 5, 13, and 16 were between 5% and 10%. Scenario 2 had a much greater SE and was 13% of the scenario mode.

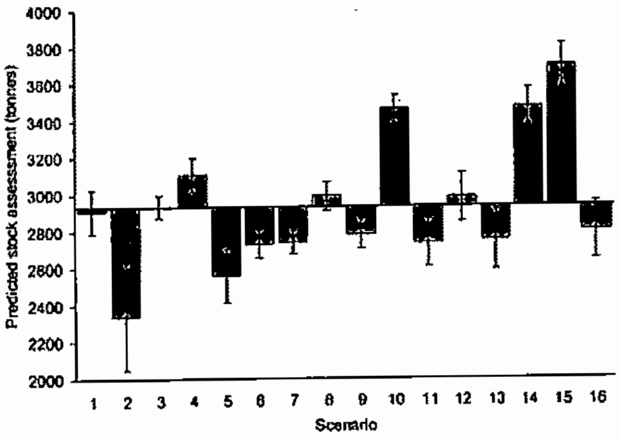

Figure 3. Scenario stock assessment predicted tonnage mode (offset x axis) shown as deviation from the "actual" fished tonnage of seed mussel (2,929 t). The vertical bars show SE ($n = 1{,}000$).

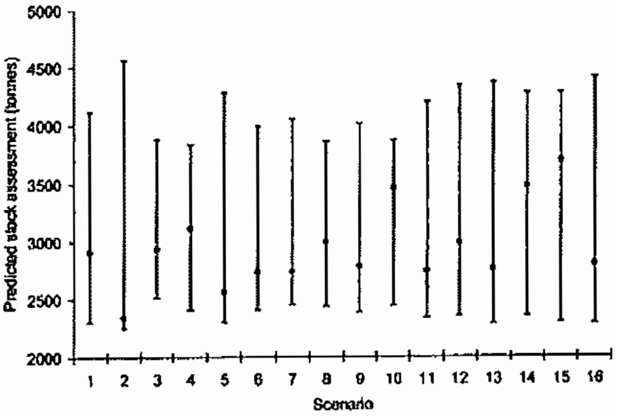

Figure 4. Scenario stock assessment predicted tonnage mode (blue point) with the minimum and maximum predicted tonnages (red lines) from the bootstrapping procedure ($n = 1000$).

The range of stock assessment values for most scenarios was great and varied from approximately 2,400–4,000 t. The range between the smallest and largest predicted tonnages was least for scenarios 3, 4, 8, and 10: between 25% and 50% of actual fished tonnage. The ranges for scenarios 1, 6, 7, 9, 11, 12, 14, and 15 were between 50% and 75% of the mode tonnage. The range for scenarios 2, 5, 13, and 16 was particularly great and was between 75% and 100% of the mode tonnage.

Based on the mode, SE, and range, it is evident that scenarios 1, 3, 8, 11, and 12 are close to the actually tonnage fished and had the smallest amount of spread about the mode, thus representing an accurate and reliable stock assessment tonnage. The total number of dredges required for these scenarios is 7, 14 11, 8, and 8, respectively.

DISCUSSION

The 6% OAA scenario (scenario 1) clearly represents a particularly good configuration of ground truthing because, of the high-performing scenarios, it has the lowest number of required dredges and yet still achieves a mode within 1% of the actually seed mussel tonnage. The SE for scenario 1 is also low when compared with other scenarios. It can therefore be concluded that OAA is effective at distributing expensive and time-consuming ground-truthing efforts in a way that maximizes the accuracy of the stock assessment while minimizing effort. A presumption that accuracy is best achieved by greater amounts of total ground-truthing effort is incorrect. The distribution of the ground truthing between strata, as specified by surrogates of variance, is also an effective way of improving stock assessments.

The 10% OAA scenario is the poorest performing scenario, but it also had the smallest and clearly the most inappropriate allocation of ground truthing. This indicates that a small CV range in the OAA has a profound effect on the required number of dredges and the quality of the predicted stock assessment values.

The use of variances from the acoustic data makes a presumption about the relationship between acoustics and seed mussel density. Because it is known that mussel beds have a distinct acoustic signature in RoxAnn, it is apparent that changes in the gross character of the seabed are reflected in acoustic values. However, subtle changes in cover and density are not as clear. It is not known what linear changes in cover and density of seed mussel generate as changes in acoustic variables. One might expect the variance of E1 (roughness) to increase as the seed mussel bed becomes more varied or patchy. Depending on the background substratum (sand, in Donaghadee Sound), increases in seed mussel cover and density will increase the E2 (hardness) value and, again, although patchy, will increase the E2 variance. At a small scale, the depth variance might also be expected to vary more with increased seed mussel patchiness (and hence heterogeneity). However, the spatial scale of the variance must also be considered.

The area insonified by a single RoxAnn "sample" may be larger than some of the variance seen in the seed mussel bed. There is a need to understand how heterogeneity within resource strata—in this case, seed mussel—relates to the response of acoustic variance over several spatial scales (as modified by working depth and resulting change in the acoustic footprint). Further work is clearly needed to substantiate and refine the original assumption linking acoustic and resource variance. Trials are required with the industry to develop this methodology as an operational tool.

CONCLUSION

We have demonstrated the early potential of OAA in objectively establishing the required effort for the ground truthing of remotely sensed acoustic data sets in benthic mapping. OAA incorporates the area for each predicted resource zone and measures of variance in each to allocate dredges efficiently among the selected strata. As a result, acoustic resource zones were effectively quantified, and generated an accurate stock assessment that closely matched the actual fished tonnage.

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