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Underwater video as a monitoring tool to detect change in seagrass cover

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Abstract

To date seagrass monitoring has involved the removal of seagrass from its environment. In fragile or highly disturbed systems, monitoring using destructive techniques may interfere with the environment or add to the burden of disturbance. Video photography is a form of non-destructive monitoring that does not require the removal of seagrass or interference with the environment and has the potential to be a valuable tool in monitoring seagrass systems. This study investigated the efficacy of video photography as a tool for detecting change in seagrass cover, using the temperate Australian species *Amphibolis antarctica* (Labill.) Sonder ex Aschers.

Using visual and random point estimates of seagrass cover from video footage, it was possible to determine the minimum sample size (number of random video frames) needed to detect change in seagrass cover, the minimum detectable change in cover and the probability of the monitoring design committing a Type II error.

Video footage was examined at three scales: transects (m apart), sites (km apart) and regions (tens of km apart). Using visual and random point estimation techniques, a minimum sample size of ten quadrats per transect was required to detect change in uniform and variable seagrass cover.

With ten quadrats it was possible to identify a minimum detectable change in cover of 15% for uniform and 30% for variable seagrass cover. Power analysis was used to determine the probability of committing a Type II error from the data. Region level data had low power, corresponding to a high risk of committing a Type II error. Site and transect level data had high power corresponding to a low risk of committing a Type II error.

Based on this study's data, managers using video to monitor for change in seagrass cover are advised to use data from the smaller scale, for example, site and transect level data. By using data from the smaller scale, managers will have a low risk of incorrectly concluding there has not been a disturbance when one has actually occurred.

Keywords: Disturbance; Monitoring; Video photography; Seagrass

1. Introduction

Seagrass cover fluctuates over time and at different spatial scales (Clarke and Kirkman, 1989). Variation in cover is due to natural disturbance created by wind, wave action, storms (Birch and Birch, 1984; Kirkman, 1985; Williams, 1988; Tilmant et al., 1994) and animals (Dirnberger and Kitting, 1988; Anderson, 1994; Valentine et al., 1994; Preen, 1995), and as a result of anthropogenic disturbances, including diffuse and point source pollution, dredging, displacement and habitat destruction (Coles et al., 1989; Walker et al., 1989; Zieman et al., 1994; Hastings et al., 1995) or a combination of both natural and anthropogenic disturbance events (den Hartog, 1987; Neverauskas, 1987; Marba et al., 1994; Manzanera et al., 1995; Kendrick et al., 2000; 2002). Fluctuations in seagrass cover resulting from disturbance may vary in magnitude and in duration, with some populations exhibiting partial or full recovery from disturbance (Duarte and Sand-Jensen, 1990). There are, however, seagrass habitats that do not recover and continue to decline in cover, leading to localised extinctions. Over the last 30 years in Australia alone more than 45,000 ha of seagrass have been lost, with the majority of the loss attributed to anthropogenic impacts (Walker and McComb, 1992). Monitoring to detect loss of seagrass is therefore of primary importance for seagrass preservation.

The most important criterion in monitoring for change in seagrass cover is to find a methodology and experimental design capable of identifying changes caused by disturbances, and distinguishing these changes from natural spatial and temporal variability. If the site of a disturbance is small relative to natural variability, then disturbance will be difficult to detect

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with any degree of confidence. Statistical power is an important tool for selecting environmental parameters and sampling intensity for the monitoring programme (Osenberg and Schmitt, 1996). Ensuring adequate statistical power is an important feature of most ecological monitoring programmes, as financial limitations and time constraints often restrict the number of variables that can be measured and the number of samples collected.

Monitoring programmes must produce statistically interpretable results in order to understand why the organism or community responds in a particular way, at a specific time, to an anthropogenic disturbance (Littler and Littler, 1985). Two possible conclusions can be drawn from any monitoring programme: that there has or has not been a change (Fairweather, 1991), with conclusions either correct or incorrect. The combination of these conclusions gives the error table for statistical tests. In two situations conclusions may be correct (i.e. concluding there has been a change when one has occurred or concluding there has not been a change when there has not been one). Making correct conclusions is obviously the desired outcome of a monitoring programme. The first type of incorrect conclusion can be made when it is falsely concluded that there has been a change. This is termed a Type I error (Fairweather, 1991). The probability of committing a Type 1 error is determined by the significance level (α) that has been used for the test (e.g. the conclusion is wrong 1 in 20 times for an $\alpha=0.05$). In contrast, a Type II error, the second incorrect outcome, concludes that there has been no disturbance, when one has actually occurred. This often provides researchers with a false belief that the habitat/organism being monitored has not undergone any change (Underwood, 1997) and can be more detrimental than a Type I, particularly when monitoring endangered habitats or species. The statistical power of a test is $1-\beta$, where β is the probability of a Type II error (Gerrodette, 1987). Statistical power should be at least 0.8 according to the biological convention of acceptable power size (Cohen, 1977).

Of key importance in correct statistical interpretation is sample size: sample size must be sufficiently large for adequate statistical analysis. Large sample size allows easy and efficient application of the methodology, whether it is destructive or non-destructive. If a large number of samples are indeed required for a study, it is preferable to use a non-destructive monitoring technique. In this way, the study will not create additional disturbance, if one has occurred.

Ideally monitoring must be non-destructive to reduce interference with the system studied. Video photography is a form of non-destructive sampling that does not require the removal of organisms or interference with the environment. This technique also has the advantage of allowing researchers to gather data quickly from remote or inhospitable places. It also provides a permanent record of organisms in situ that can be analysed at a later date or by numerous researchers. Video photography has been used to good effect for studies of terrestrial plant biomass (Everitt et al., 1995), distribution and abundance of seagrasses (Orth and Moore, 1983), seaweeds (Klöser et al., 1996), corals (Aronson et al., 1994; Christie et al., 1996), fish length (Harvey et al., 2001; 2002) and fish abundances in kelp forests (Davis and Anderson, 1989). The application of video to seagrass monitoring, however, needs further assessment.

The aim of this study was to investigate the efficacy of video photography as a tool for detecting change in cover of seagrass, using a temperate Australian species *Amphibolis antarctica* (Labill.) Sonder ex Aschers., across a range of spatial scales. Within this study the specific aims were to: (i) determine the minimum sample size required to detect a change, (ii) determine the amount of change in seagrass cover that could be detected, and (iii) use power analysis to determine the probability of arriving at a correct conclusion that change has or has not occurred on the basis of this data.

2. Methods

2.1. Collection of video footage

Video footage of *A. antarctica* was recorded along 27 transects within Shark Bay, Western Australia at nine sites, within three regions (Fig. 1). Each of the 27 transects measured 50 m in length and was marked at the beginning and end with a star-picket. A tape measure was stretched between the star-pickets marking the centre line of each transect and providing a reference point for subsequent analyses. Surveys were then conducted by a diver travelling along the transect keeping the camera at a constant speed and a constant distance from the substratum.

2.2. Video analysis methods

Analysis of seagrass cover from video footage was conducted at three scales: transect (m), sites (km) and regions (tens km). A nested design was used to test for differences in estimates of seagrass cover at each scale. At each transect (nested within a site, within a region), ten replicate quadrats of $0.04\ \mathrm{m}^2$ ($20\times20\ \mathrm{cm}^2$) were randomly sampled for video analysis, giving a total of 270 quadrats.

Two methods were used to estimate percentage seagrass cover from video footage of quadrats. Video footage of seagrass along transects was played and frames selected for analysis using a random number table. The two estimation techniques used were visual (VIS) and random point estimates (RPE). Video footage was paused for the VIS method, and the seagrass cover determined by overlaying a transparency with a $0.04\ \mathrm{m}^2$ quadrat (relative to the tape measure transect on the footage) onto the television monitor. Percentage seagrass cover within the quadrat was then estimated. For the random point method a transparency containing one hundred random points was placed over the same randomly selected video frames. The presence or absence of seagrass underlying each point was then recorded. Both these techniques are commonly used in the analysis of still and video photographic imagery (Dethier et al., 1993).

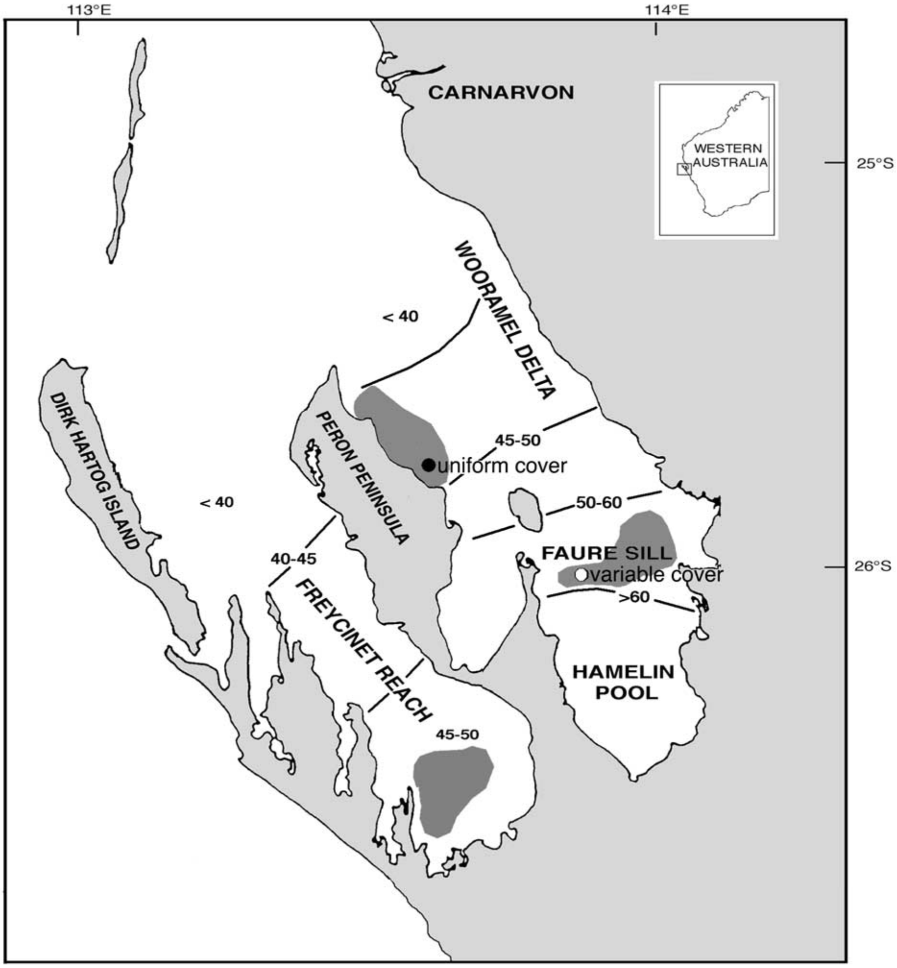

Fig. 1. Map of Shark Bay Marine Park showing salinity haloclines present within the bay. (Note: locations are shaded dark grey; • and ○ represent sites used for analysis of uniform and variable seagrass cover, respectively).

2.3. Within transect analyses

2.3.1. Determination of minimum sample size

Power analysis was performed on the data to determine the minimum number of replicates (quadrats) to examine in each transect. Determining minimum sample size is important in order to ensure a sufficient number of samples are collected. If the sample size is too small, the power of the test is likely to be insufficient. In contrast, if the sample size is too large, the power of the test will be good, but time and effort may have been wasted in collecting unnecessary samples (Bros and Cowell, 1987). Minimum sample size was determined for a transect with relatively uniform seagrass cover and a transect with highly variable seagrass cover. Seagrass cover (%) was estimated using VIS and RPE methods. Fifty quadrats selected randomly from each transect were analysed following the procedure outlined by Bros and Cowell (1987). This procedure uses standard error (SE) as a measure of resolving the statistical power associated with an increasing sample size. The first step in this process was to generate the mean, maximum and minimum SE with an increasing sample size (number of quadrats) using a Monte Carlo randomisation procedure. This randomisation procedure permitted repeated estimates of the SE for any sample size (range 2–50), as well as the mean, minimum and maximum SE. Using this procedure, the SE was estimated for each sample size. The number of quadrats was calculated as the point where the range between the maximum, mean and minimum standard errors was reduced and considered acceptable. Ten random percent cover estimates from uniform and variable seagrass cover were selected for all sample sizes examined (range 2–50). When plotted, these provided curves of the SE against increasing numbers of quadrats.

2.3.2. Minimum detectable difference and time for processing curves

Minimum detectable difference (MDD) is the smallest change in percentage cover detectable for a given sample size (Zar, 1984). The minimum detectable difference (MDD)(at the 5% level of significance with 80% power) was based on differences in precision of the mean SE for each sample size. Using the degrees of freedom at a particular sample size, critical *t*-values were selected from *t*-value tables for both 0.05, and 0.2 (at 80% power, using 2 tailed tests). These *t*-values were entered into the following formula in order to determine MDD:

$$[(0.20 \text{ critical } t\text{−values} + 0.05 \text{ critical } t\text{−value}) \times \text{mean SE for sample size}] \times \sqrt{2} = \text{MDD\%}$$

2.4. Analysis between transects and regions

The time required to process increasing numbers of samples was recorded for visual (VIS) and random point estimates (RPE) from video footage of uniform and variable seagrass cover. The time required to process samples was overlayed against plots of MDD. Plots were used to further reinforce the number calculated for minimum sample size (number of quadrats). These plots ensured that time available to process samples was considered while still maximising the number of samples and maintaining an acceptable MDD. The time taken for each estimation technique was similar for uniform and variable seagrass cover, i.e. the time was similar for visual estimates of uniform and random seagrass cover.

2.4.1. Analysis of variability of seagrass cover

A nested analysis of variance (ANOVA) ($\alpha = 0.05$) was used to determine the degree of variability in seagrass cover existing within and between regions (tens of km), sites (km) and transects (m). Cochran's test of homogeneity of variance was performed prior to analysis to detect heterogeneity of variance within the data. Data found to be heterogenous were arcsin (sqrt) transformed. As data were percentages, an arcsin (sqrt) transformation was used (Zar, 1984).

2.4.2. A priori power analysis to detect probability of committing a Type I or Type II error

Power analysis was conducted to determine the range in mean estimates of seagrass cover that would be required to detect a difference at transect, site and region levels (where $\alpha = 0.05$ and power $(1-\beta)$ 0.80). This was conducted for both the 0.05 and 0.025 significance levels. Power analysis was performed to determine what range in the mean estimate of seagrass cover would be required to detect a difference at the level of region, site and transect at $\alpha = 0.05$ and power $(1-\beta) = 0.80$.

3. Results

Mean seagrass cover within the uniform cover transect was 78.7% (±2.32 SE; range 30–100%) and for the variable cover transect 31.1% (±5.51 SE; range 0–100).

3.1. Minimum sample size

Based upon the data examined in this study, a minimum sample size of 10 quadrats per transect ensured that the minimum number of quadrats were processed, reducing time while still ensuring that the power of any subsequent tests would be sufficient. Minimum sample size was the same when using VIS or RPE methodologies on transects with uniform and variable seagrass cover (Fig. 2).

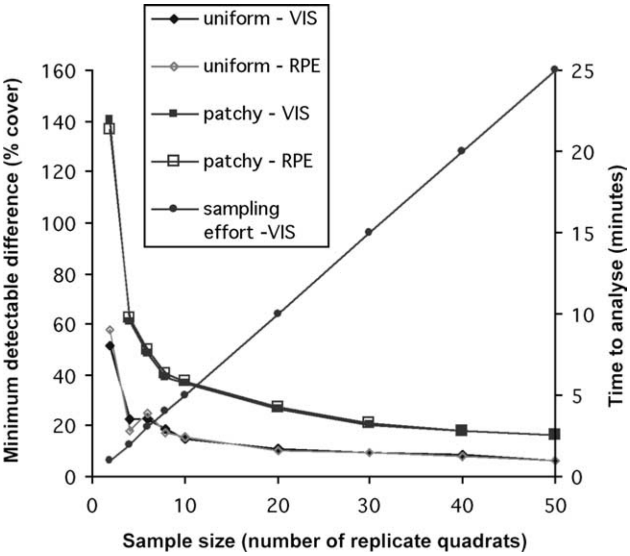

Fig. 2. Comparison of minimum detectable difference (MDD) (as % cover of seagrass) for visual (VIS) and random point estimation (RPE) from transects with uniform and patchy seagrass cover (quadrat size of 0.04 m^2, 0.05 significance level, 80% power).

3.2. Minimum detectable differences and time for processing curves

Using 10 quadrats per transect as the minimum sample size, a minimum detectable difference (MDD) of as little as 15% change in *A. antarctica* cover could be identified for uniform seagrass cover. In contrast, in variable seagrass cover, the MDD was 37%, requiring a much larger shift in seagrass cover before any change could be identified (Fig. 2).

The maximum power of statistical tests was acceptable and processing time was kept to a minimum when using 10 quadrats (based upon time curves calculated for time taken to process each transect). Processing using RPE required 25 min per transect at uniform and variable sites, compared to 5 min per transect for VIS from the same video imagery.

3.3. Analysis of variability of seagrass cover

A nested ANOVA was conducted to detect any significant difference in seagrass cover across a range of scales; among regions (10s km; $n = 3$), sites (km; $n = 9$) and transects (m; $n = 27$). Seagrass cover was not significantly different among regions using either VIS or RPE despite the large geographic range (Table 1 a,b). In contrast to regions, seagrass cover among sites varied significantly using VIS and RPE methods (Table 1 a,b). Variation in seagrass cover at transect level was only significant with the RPE method (Table 1b), and not the VIS method (Table 1a).

Table 1
Nested analysis of variance (ANOVA) summary table for (a) visual (VIS) and (b) random point estimation (RPE) methodologies for seagrass cover ($\alpha = 0.05$). All data was subject to Cochran's test it was arcsin (sqrt) transformed and retested using Cochran's test

Source	df	Mean square	*F*-value	*P*-value	Significance	Error term
(a) ANOVA summary table for seagrass cover using VIS ($\alpha = 0.05$)						
Region	2	0.007	0.001	0.998	n.s.	Site (Region)
Site (Region)	6	5.313	36.978	0.000	***	Transect (Region, Site)
Transect (Region, Site)	18	0.144	1.488	0.095	n.s.	Residual
Residual	216	0.097				
(b) ANOVA summary table for seagrass cover using RPE ($\alpha = 0.05$)						
Region	2	0.087	0.017	0.982	n.s.	Site (Region)
Site (Region)	6	4.965	26.675	0.000	***	Transect (Region, Site)
Transect (Region, Site)	18	0.186	1.794	0.027	*	Residual
Residual	216	0.104				

n.s. = not statistically significant; * = significant ($p < 0.05$); ** = significant ($p < 0.01$); *** = significant ($p < 0.001$).

3.4. A priori power analysis to detect probability of Type I or Type II errors

Power analysis was performed at region (tens of km), site (km) and transect levels (m), using the mean square error estimates as error variance from the nested ANOVA. Power analysis was conducted to address what range in mean estimates of seagrass cover would be required to detect a difference at region, site and transect levels (where $\alpha = 0.05$ and power $(1-\beta)$ 0.80). Visual and random point estimation of seagrass cover were used in power analysis (one-way ANOVA at 0.05 and 0.025 significance levels). The biological convention regarding power is that statistical power should be at least 0.8. In this study, the location level of the design had relatively low power using visual and random point estimates. Site (nested within location) and transect (nested within site, within location) both had a power of 1, at 0.05 significance levels for visual and random point estimates. It should be noted that it is not surprising that a significant α will have significant $1-\beta$ in an a posteriori test (Thomas, 1996).

Not surprising, power analysis revealed low power associated with region (tens km) level data as this was not significant in the nested ANOVA. The highest power at region level was 0.051 using the RPE methodology (significance levels of 0.05 and 0.025). Power curves at the region level of the design (at 0.8 power) showed that a 100% change in seagrass cover was required before a change could be detected, that is a complete loss or gain in the existing seagrass cover. At site level a 22% change in seagrass cover could be detected using the same 0.8 power, while at transect level only a change in seagrass cover of 45% could be detected.

4. Discussion

This study examined the capacity of video photography to detect change in percentage cover of seagrass, and the sampling intensity needed to detect and monitor changes in these seagrass communities, using existing video footage of *A. antarctica*. Analyses were conducted at three scales; region (tens km), site (km) and transect (m). From a cost, methodological and statistical perspective this study reports that video photography proved to be a powerful tool for monitoring seagrasses. Visual estimates (VIS) of seagrass cover were more suitable than estimates based on random points (RPE), as VIS provided comparable minimum detectable differences (MDD) to RPE but were less time consuming. Both methods have previously been used to estimate the proportion of area covered by a range of marine and terrestrial organisms (Connell, 1970; Bohnsack, 1979; Littler and Littler, 1985; Foster et al., 1991; Kendrick, 1991; Dethier et al., 1993).

The minimum sample size of quadrats from transects level data was 10. Although differing considerably in morphology, the minimum number of quadrats required to detect change in *A. antarctica* cover is less, in relation to quadrat size, than that reported in a study by Heidelbaugh and Nelson (1996) for another seagrass, *Halodule wrightii* Aschers. Heidelbaugh and Nelson (1996) reported that using in situ percentage cover estimates a minimum sample size of six ($1\ \mathrm{m}^2$) replicate quadrats was required to detect 10% change in *H. wrightii* cover (0.9 power). Using blade counts to detect change in cover, a minimum of 247 replicate quadrats ($15 \times 15\ \mathrm{cm}^2$) was required. For *H. wrightii* the time required to conduct blade counts was 5 min per $1\ \mathrm{m}^2$. In comparison, use of video photography to detect change in seagrass cover may be considered far more time- and cost-effective. The amount of time required to analyse 10 quadrats per transect was 5 min using visual estimation and 25 min using the random point estimation technique. Given the time constraints of most monitoring programmes, this was a practical minimum sample number.

The smaller the MDD in seagrass cover that can be determined from video footage, the more quickly a disturbance can be recognised. It is essential therefore that there is prior knowledge of the MDD for a given video monitoring programme. MDD is the smallest detectable change in percent cover for a given sample size (for $\alpha = 0.05$ and $1-\beta = 0.80$). Using 10 quadrats per transect as the minimum sample size revealed that as seagrass meadows become patchy, the capacity to detect change using video monitoring declined. Percent cover of *A. antarctica* from uniform meadows had a MDD of 15% loss or gain. MDD was 37% and higher when seagrasses had a variable or patchy distribution. Similar effects of patchy distributions on MDD have been reported for change in the height of mangrove seedlings (Fairweather, 1991). Variability in mangrove seedling height influenced the minimum sample number required to detect the influence of sewage outfall on seedling growth (30 samples were required to achieve a power of 1 in seedlings of uniform height; 100 for variable seedlings). The MDD can be reduced from 39–40% to 26–27% for variable seagrass cover when the number of quadrats used increases from 10 to 20 (Fig. 3). Consequently, in areas with variable seagrass cover it is advisable to use a larger sample size to provide a more sensitive method for detecting change, a highly desirable result in any monitoring study. This would ensure that changes in seagrass cover could be detected and reported more rapidly. Toft and Shea (1983) also reported a decrease in the MDD associated with an increase in sample size. If sufficient time is available for analysis, managers may wish to reduce MDD by using 20 quadrats per transect when examining variable seagrass cover. In regions with uniform seagrass cover, a sampling regime of 10 quadrats per transect is still acceptable. The intrinsic variability presents at any level of sampling influences the power of statistical analysis. The more variable a population, the less likely it is that the sampling regime will allow for a distinction between the null and alternative hypotheses (Underwood, 1997). This should be borne in mind when making decisions regarding regions with highly variable seagrass cover.

Video monitoring was most sensitive to changes in cover at the site scale, within broad oceanographic regions. At the region level (tens of km) a MDD of 100% was calculated. From a statistical point of view, this means that a complete loss or complete gain in seagrass cover would be required before change could be detected using the current monitoring techniques. The intrinsic differences among sites may have caused such large variability in seagrass cover that any differences among locations were confounded. In contrast, at site level (km), a 22% loss or gain could be detected and at transect level (m) a change in seagrass cover of 45% could be detected. To increase the sensitivity of video photography to detect changes in cover at the level of regions, more replicates at kilometre scales (within regions) would need to be sampled.

Seagrass cover was not significantly different at the region level using either VIS or RPE, which was unexpected given the distance between regions and their different salinities. In contrast, seagrass cover among sites varied significantly using VIS and RPE methods, suggesting that the factors influencing percent cover were acting on scales among and within sites. Variation in seagrass cover at transect level was only significant with the RPE method. The ability of the RPE methodology to identify differences in cover of seagrasses at transect level reflects differences in estimations between the two techniques, and indicates that use of two or more estimation techniques may be appropriate in future seagrass monitoring programmes.

4.1. Scale of accuracy of the video monitoring methodology

Power analyses are important in allowing a degree of quality control over any inferences derived from monitoring studies (Fairweather, 1991). Strengthened inferences provide better information about changes occurring within a habitat, and provide a basis from which management decisions can be made with confidence. In this study, power analysis revealed low power associated with region level data. Low power values correspond to a high risk of a Type II error, i.e. incorrectly concluding that there has been no disturbance. According to biological convention regarding acceptable power, statistical power should be equal to at least 0.8 (Cohen, 1977). Low power

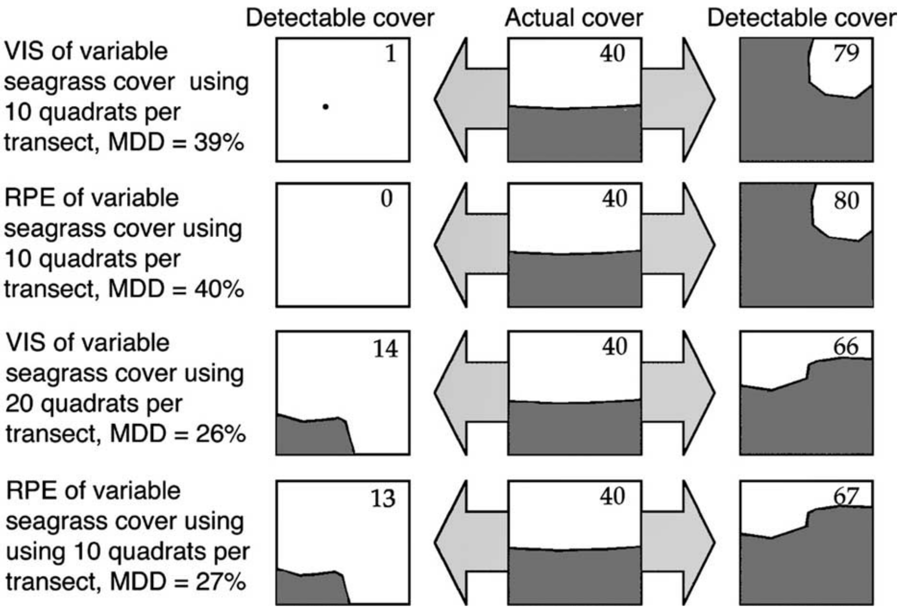

Fig. 3. Schematic representation of minimum detectable difference (MDD%) for a transect with variable seagrass cover using 10 and 20 quadrats, for both visual (VIS) and random point estimation (RPE) methods. Numbers inside each quadrat indicate the percentage cover of the seagrass. For example, if the actual cover of seagrass (shaded area) is 40% and the MDD is 39% the detectable cover may range from 1% at the lowest to 79% at the highest.

at this scale indicates that the current data and statistical tests do not permit a strong test of the null hypothesis of no disturbance. At this scale of the analysis, video monitoring did not prove to be an effective monitoring tool. Based on the video analysed in this study, management decisions regarding change in seagrass cover at region levels could not be made with any degree of confidence without a redesign of the sampling programme. The highest power at region level was from the RPE methodology. In contrast, power at site (km) and transect (m) level was high, consequently, there was low risk of committing a Type II error at these scales, providing managers with a strong testing of the null hypothesis that no disturbance has occurred to the system (Gerrodette, 1987). At high power it is unlikely that a disturbance will be assessed incorrectly and as a result management decisions for monitoring seagrass habitats can be made with confidence. Using the example outlined in this study video photography can be used as an effective tool in detecting change in seagrass cover.

5. Conclusions

Video photography is an effective monitoring tool for detecting change in the cover of the temperate seagrass *A. antarctica*. Video footage was examined at three scales: transects (m apart), sites (km apart) and regions (tens of km apart). Using the statistical approach outlined in this paper, video footage was more effective in detecting change at the site (km) and transect (m) level of analyses than at the region level (tens of km). Using two estimation (visual and random point) methods, this study determined a minimum sample size of 10 replicate quadrats was required to detect change in both uniform and variable seagrass cover. Using this sample size, there was a minimum detectable change in seagrass cover of 15% for uniform and 30% for variable seagrass cover. Power at site and transect levels was 1. This high power value corresponds to a low risk of a Type II error. Based on this study's data, managers using video to monitor for change in seagrass cover are advised to use data from the smaller scale, for example, site and transect level data. By using data from the smaller scale, managers will have a low risk of incorrectly concluding there has not been a disturbance when one has actually occurred.

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