# Application of the Two-Term Local Quadrat Variance Analysis in the assessment of marine invertebrate populations: Preliminary findings on the sea cucumber *Actinopyga echinites*

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## Abstract

The Two-Term Local Quadrat Variance analysis (Hill 1973) has an application for quantifying spatial patterns in marine invertebrate populations. This method provides a crucial step in the process of accurately designing population surveys and monitoring programmes for fisheries that exhibit small- to medium-scale patchiness. Data from the spatial pattern analysis technique can be used to base stratification decisions upon rather than relying upon "intuition" as suggested by Andrews and Mapstone (1987). Consideration of spatial pattern in survey design can ensure that monitoring programmes are designed in a manner that can measure distribution and abundance at a scale relevant to the population. The method is readily applied in the marine setting using conventional underwater visual census (UVC) techniques. The method was used to assess populations of the deepwater redfish (*Actinopyga echinites*), a tropical holothurian that is abundant in the Indo-Pacific region on eroded limestone platforms at 0.5–7 m depth. The species was chosen for this study due to the lack of prior fishing pressure on the population.

## Introduction

Designing a sampling programme that adequately describes a population of marine organisms is a challenging task. Population surveys are commissioned for several reasons, including environmental monitoring and fisheries assessment. The process for designing a stock survey requires: 1) the consideration of the resources available for the completion of the survey, 2) the biology and potential distribution of the target organism, 3) the desired level of precision and accuracy of the estimates, and 4) the type, number and placement of sampling units to balance these aims. Often the available resources for completing a survey are restrictive and a balance needs to be struck between the conflicting goals of precision and the minimization of costs (Pitcher et al. 1992). One of the shortcomings of traditional stock assessment methods has been the failure to adequately address the localised spatial pattern of the population of interest. A population may exhibit a random, uniform or clumped distribution pattern over various scales of measurement and it is important that sampling designs take this into account. A recent shift to the use of more systematic (as opposed to random or haphazard) sampling designs has seen greater focus placed upon the usefulness of a sampling programme to map the distribution of a species (e.g. Cochran 1977; Hender et al. 2001; Skewes et al. 2000; Mayfield et al. 2004; Chick et al. 2006; McGarvey 2006; Leeworthy 2007a,b). This spatial information provides a powerful tool for monitoring programmes to assess and manage the impacts of fishing pressure or other environmental disturbances.

Several methods of spatial pattern analysis for use within the marine environment have been tested. The "point-nearest neighbour" method (Byth and Ripley 1980; Byth 1982; Officer et al. 2001) has recently been shown to be impractical to apply within the marine environment (McGarvey et al. 2005; McGarvey 2006). Quadrat-Variance methods have been shown to successfully describe spatial pattern in terrestrial ecological studies. These methods are based upon examining the changes in the mean and variance of the number of individuals per sampling unit over a range of different sample sizes (Ludwig and Reynolds 1998). Data are gained from belt transects of contiguous quadrats (i.e. a joined or continuous series of quadrats) placed in a linier manner across the population of interest. The variance of the number of individuals is calculated at different "block sizes". The block sizes are obtained by combining progressively the $N$ quadrats (therefore increasing the theoretical sample unit size) in a prescribed manner (Ludwig and Reynolds 1998). In populations displaying a patchy or clumped distribution (such as many holothurian species), the variance peak (maximum variance) can be interpreted as being equivalent to the radius of the patch.

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The Two-Term Local Quadrat Variance analysis (TTLQV) is a modification of the basic blocked quadrat variance (BQV) methods for spatial pattern analysis that are limited to powers of 2 (Ludwig and Reynolds 1988). The TTLQV uses variance data in a similar manner to the BQV method although it has a more refined "blocking scheme" in its calculation to overcome the BQV's limitation. This paper reports on the successful application of the TTLQV for the assessment of spatial patterns in marine invertebrate populations, using the sea cucumber *Actinopyga echinites*, and discusses the advantages of this relatively simple method.

## Methods

The study site was a 3–5 m deep eroded reef platform in the Montebello Islands in Western Australia. The population of interest was the holothurian *Actinopyga echinites* (Fig. 1). A hip-chain device and sampling station were used to complete the transects of contiguous quadrats in a similar fashion as described by Leeworthy and Skewes (see article on p. 5). The main difference was that a count (number of *A. echinites*) was made for each 1 m traveled and recorded on the data sheet. The sampling station was only 1.25 m wide due to the cryptic nature of the species in weed beds. One quadrat represented an area equal to 1 m x 1.25 m. Three replicate transects of 200 contiguous quadrats each were completed in an area where a high abundance

of *A. echinites* had been previously located or where the population was presumed to extend to.

The TTLQV analysis was used as per Hill (1973) and Ludwig and Reynolds (1988). The TTLQV equation for block size 1, 2 and 3 is shown below.

Block size 1

$$VAR(X)1 = [1/(N-1)]\{[1/2\,(x_1 - x_2)^2] + [1/2\,(x_2 - x_3)^2] + \ldots + [1/2\,(x_{N-1} - x_N)^2]\} \tag{1}$$

Block size 2

$$VAR(X)2 = [1/(N-3)]\{[1/4\,(x_1 + x_2 - x_3 - x_4)^2] + [1/4\,(x_2 + x_3 - x_4 - x_5)^2] + \ldots + [1/4\,(x_{N-3} + x_{N-2} - x_{N-1} - x_N)^2]\} \tag{2}$$

Block size 3

$$VAR(X)3 = [1/(N-5)]\{[1/6\,(x_1 + x_2 + x_3 - x_4 - x_5 - x_6)^2] + [1/6\,(x_2 + x_3 + x_4 - x_5 - x_6 - x_7)^2] + \ldots + [1/6\,(x_{N-5} + x_{N-4} + x_{N-3} - x_{N-2} - x_{N-1} - x_N)^2]\} \tag{3}$$

Where $X$ is the variance at the given block size, N is the total number of quadrats in a transect, $x_1$ is the number of individuals within the first quadrat in the transect, $x_2$ is the second and $x_N$ is the last quadrat. Computations analogous to Eq. 3 are made at successively larger block sizes (Ludwig and Reynolds 1988). Calculations for the TTLQV were conducted using Microsoft Excel, although the use of Microsoft Visual Basic is recommended for longer transects of contiguous quadrats.
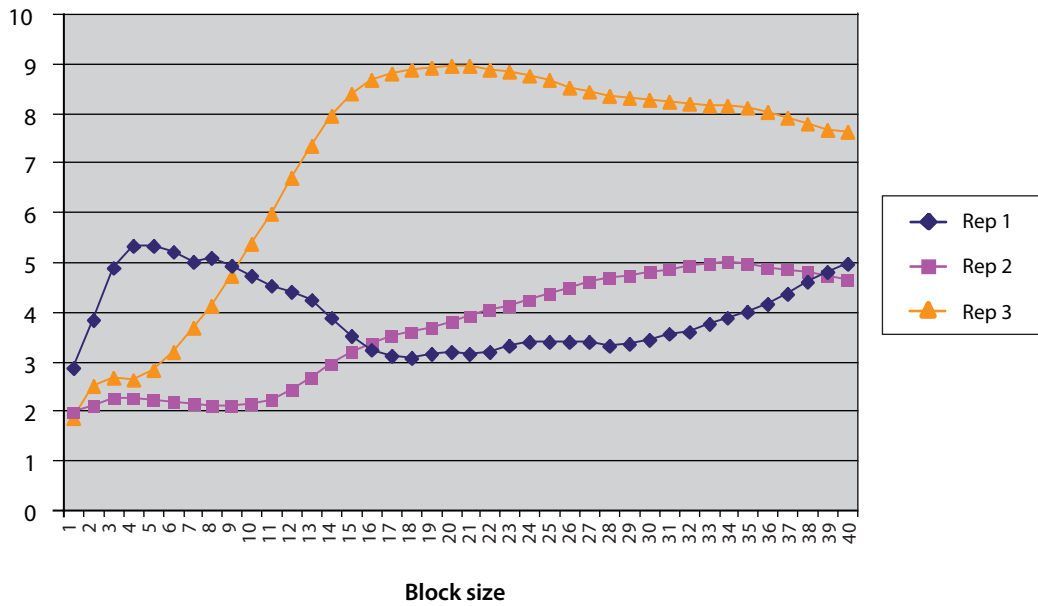


**Figure 1.** *Actinopyga echinites.*

**Figure 2.** Two-Term Local Quadrat Variance for *A. echinites* in the Montebello Islands.

## Results

The results of the TTLQV analysis for *A. echinites* in the Montebello Islands, Western Australia are shown below in Figure 2.

**Table 1.** Calculation of patch diameter using peak variance results.

| Peak variance | |
|---|---|
| Replicate 1 | 42 |
| Replicate 2 | 34 |
| Replicate 3 | 21 |
| Mean variance | 32 |
| Mean patch diameter (m) | 64 |

The data presented in Table 1 suggest that sample units for an abundance survey of this population would need to be at least 84 m in length (two times the radius of the largest patch). It should be noted that while the mean patch diameter is informative to the researcher as defining the spatial pattern of the population, when using this data to design a survey of distribution and abundance, the maximum patch size should be considered to overcome auto-correlation of samples.

## Discussion

As the distribution and abundance of an organism in the marine environment is often patchy or clumped, it is important that the spatial scale of this patchiness is taken into account when designing a sampling programme. The size of a sampling unit has a marked effect on the precision of sample estimates (King 1995). For species displaying a patchy or aggregated distribution, it has been suggested that the size of the sampling unit should be larger than the distance between the aggregations, so that each sampling unit includes at least part of an aggregation (King 1995). The TTLQV analysis can be employed to quantify the size of aggregations so that decisions regarding sample size and position can be based on a quantitative process rather than relying upon "intuition" as suggested by Andrews and Mapstone (1987). For this reason, the TTLQV analysis is an extremely useful tool in making decisions regarding appropriate sampling design.

It is important to note that several scales of patchiness are observable in the populations of most marine organisms. One scale is that of the individual organism and its immediate aggregation (e.g. five abalones in a crack). The second scale of patchiness is the larger patch of high abundance (e.g. a large patch of abalone covering 600 m$^2$). The third is the environmental habitat gradient (e.g. 2 km$^2$ of reef) and the fourth is the scale of fishing pressure or environmental effect of interest, if it exists. Many larger or smaller scales of patchiness may also exist,

particularly when considering habitat complexity and details such as the specific surface area ($m^2/m^3$) or reef rugosity. If the suggested four basic scales of patchiness are taken into account when designing the size and placement of samples in the environment, an increased level of certainty can be demonstrated in the outcomes of a survey. The TTLQV analysis has the capability of quantifying these scales of patchiness in a robust manner.

It is suggested that several replicate, contiguous quadrat-transects should be placed in groups spread over the areas where the survey is planned. The decision as to where to place these transects could be based on as little *a priori* information as knowing the location of the population. Further *a priori* knowledge such as depth contours and habitat maps (once tested with the TTLQV analysis) can give enough information to make robust stratification decisions.

The TTLQV analysis gives the peak variance for the location studied. This peak variance corresponds to the radius of the aggregation; therefore the diameter of an aggregation equals two times the radius. If three replicate, contiguous quadrat transects were undertaken in a location, the largest aggregation size should be used to base sampling design decisions on. The range may also be useful for consideration. The length of survey transects could then be set at a distance equal to at least twice the largest aggregation diameter. Placement of transects could be arranged to adequately take into account the broader scales of variance for each area of interest such as habitat gradients and patterns of fishing pressure. It is important to note that precision reduces beyond a block size of N/10 for the TTLQV. For this reason it is recommended that relatively long transects are conducted in order to take into account the potential scales of spatial pattern. Three replicates of TTLQV transects, 500 m in length, have been completed for a similar population on the Great Barrier Reef, although this was the maximum length possible due to the water depth (~18 m) and associated decompression limitations (Leeworthy unpublished data).

Several extensions to the TTLQV analysis have been made (Malatesta et al. 1992; Dale and Blundon 1990; Campbell et al. 1998) and it is probable that these will be incorporated into methods for future benthic invertebrate surveys.

With regard to fisheries management, Walters and Martell (2006) have recently contended that direct surveys of abundance are less useful than estimates of fishing mortality (F). It is this author's view however that without direct consideration of the various spatial scales that a fishery operates on, it is quite possible that an estimate of F will not detect large shifts in biomass. Prince (2005) discusses the need to understand the relevant spatial scales affecting an invertebrate fishery. Use of the TTLQV analysis is a step closer to gaining a full understanding of the dynamics of such fisheries.

## Acknowledgements

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