Short Communication *Mar. Freshwater Res.*, 1998, 49, 863–5

A method for sampling sandy beach amphipods that tidally migrate

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Abstract. Some sandy beach species display tidally-related, across-beach migrations. Such behaviour can produce false or misleading results when standard sampling methods are used. To address this problem, a novel method was developed for sampling migratory amphipod populations that maintain position in the swash zone. This method provides sampling repeatability at any stage of the tide by locating the water's edge, defined as the median of the upper limits of 11 consecutive waves, and thus locating the migrating population. Data to test the hypothesis of choice are then obtained via replicate core samples taken at fixed levels above and below the water's edge.

Introduction

Faunal mobility, if unappreciated, can pose problems in estimating distribution and abundance. For example, it may cause a single population to be sampled in more than one locality or not sampled at all depending on the spatio-temporal pattern of sampling. The former would occur if the temporal sequence of sampling tracked the movement of the population and the latter if sampling at a locality never coincided with the presence of the population. In both cases, the resultant estimates of distribution and abundance within the total sampled area would be seriously biased. Subsequent inferences concerning, for example, species richness or zonation patterns would be false. Even when estimates are unbiased, conclusions regarding distribution may be misleading if the spatial distribution recorded at the time of sampling is considered temporally invariant. For example, the pattern of zonation of sandy-beach fauna varies temporally with tide height (see McLachlan and Jaramillo 1995 for a review). Consequently, the comparison of different locations, a common objective, would be particularly prone to error if temporal variation associated with migration was not accommodated.

Populations living in sediments are usually sampled under the assumption that they are sedentary, and abundance estimates are therefore not subject to mobility-induced biases. However, many species inhabiting sandy beaches make regular across-beach (i.e. shore-normal) migrations associated with the tide (Brown and McLachlan 1990). The oedicerotid amphipod *Synchelidium micropleon* (Barnard 1977) migrates through the intertidal area by maintaining its position in the swash zone (i.e. the area alternately emersed and immersed by waves) by means of a combination of geo- and photo-taxes (Enright 1961; Forward 1986). Ignorance of such migratory behaviour may cause the commonly used sampling schemes on beaches (full across-beach transects or shore-parallel stratification) to produce the biases and false distributional conclusions mentioned above.

Following Dexter (1984), the exoedicerotid amphipods *Exoediceros fossor* (Stimpson 1856) and *Exoediceroides maculosus* (Sheard 1936) were studied by the present authors who discovered their migratory behaviour (Jones *et al.* 1991) which maintains the population in the swash zone. In order to accommodate this behaviour and evade the shortcomings of the above sampling schemes, a novel sampling method was developed. In addition to providing unbiased estimates of distribution and abundance, this method aimed to be efficient (i.e. to sample only sections of the beach where the species is present at the time of sampling), to be flexible (i.e. to allow sampling at any stage of the tide) and to employ a biologically relevant reference point that would guide sampling. This reference point would locate the migrating population at any time and so provide sampling repeatability independent of the tidal height.

The method

The migratory behaviour of both species became apparent because they were sampled in the swash zone but not above or below it, and because specimens were observed to move shoreward at the leading edge of flood-tide waves. Further, in closed lagoons (where *E. fossor* also occurred), specimens clustered at the water's edge, particularly when the edge was stationary in calm conditions without waves or tides. These observations suggested that the water's edge was an important reference point that could be used to guide the spatial pattern of sampling.

An attempt to standardize the position of the tidally moving water's edge at open beaches was made in the following way termed the 'median-wave technique'. At a given position along the beach, the uppermost limit of each of 11 consecutive waves was marked with stakes and the median stake (sixth from either end of the row of stakes) was considered the 'water's edge' or 'median-wave level'. Further pilot sampling for both species suggested that the migrating population was confined to the 4-m band extending from 2 m upbeach of the median wave level to 2 m downbeach, i.e. sampling both upbeach and downbeach of the 4-m band yielded no specimens. This pilot finding was confirmed, with rare exceptions, during subsequent monthly sampling (Jones *et al.* 1991).

Having developed a method of locating the population independent of tide height, it remained to decide how to locate sampling units (replicates) in the 4-m band. The latter was divided into several levels representing different heights on the beach (Fig. 1) because the population often showed

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steep across-beach abundance gradients (Fig. 2). In practice, nine levels were located at 0.5-m intervals, one at the median wave level, four levels above and four below, and their positions were staked. This created a 4-m-long, shore-normal transect in the swash zone. At each level, replicate core samples were taken randomly within 2 m of the transect line, i.e. within a 2-m-wide belt transect.

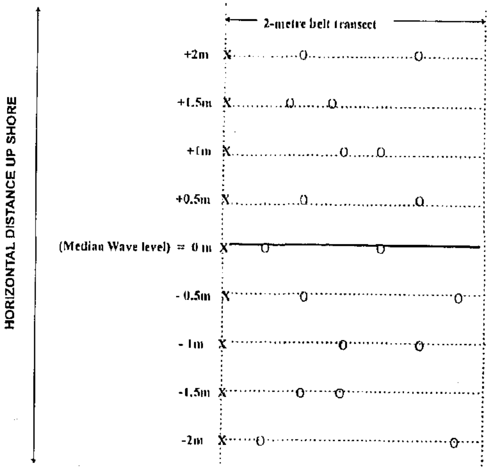

Fig. 1. Diagram showing sampling design. The median wave level is the median uppermost limit of 11 waves on the shore. 'X' marks 9 across-beach levels, as shown, at 0.5-m intervals. 'O' marks replicate cores ($n = 2$) placed randomly at each level in the 2-m wide, shore-normal belt-transect.

The core samples can be processed either immediately in the field (with specimens replaced alive) or subsequently in the laboratory. The former was chosen *(a)* because of feasibility (specimens can easily be identified macroscopically), *(b)* because sampling with replacement is preferable to sampling without replacement because the latter causes a small bias in the estimation of some parameters (Simpson *et al.* 1960) and *(c)* for efficiency; it was efficient because sieving is very fast compared with laboratory processing which requires bagging, preserving, labelling, subsequent handling etc. The speed of sieving is enhanced because these species are very shallow burrowers. Direct observation of both species on open beaches showed that they cease burrowing before complete burial, and their dorsal surface is still visible. Deeper burrowing by *E. fossor* sometimes occurred on closed lagoon beaches as shown by pilot data. When four cores were each divided by depth of sediment into 0–2, 2–4 and 4–6 cm segments, totals of 167, 5 and 0 specimens occupied the three segments, respectively.

The corer used was an open Perspex tube of 5.5 cm inner diameter. This size provided greater precision of estimate than an 11 cm corer. For example, on the basis of pilot samples of 40 × 5.5 cm cores and 10 × 11 cm cores, only 14 smaller cores were required for a precision of 20% of the mean compared with 16 larger cores for *E. maculosus* and 5 smaller cores compared with 4 larger cores for *E. fossor*. As well, the 5.5 cm corer was appropriate for the size of both amphipod species because the ratio of size of organism to size of sampling unit was less than 0.05 (Green 1979). Moreover, a 5.5 cm corer is easy to manipulate, fast to operate and needs no valve to retain the shallow depth of sand in which these species live.

Discussion

The median-wave technique was developed specifically for population studies of tidally migrating species that maintain position in the swash zone. It is thus inappropriate for other species or places. It accommodates faunal movements by locating the population at any time of the tide in an objective, repeatable way by locating the median-wave level. This method precludes inadvertent multiple sampling

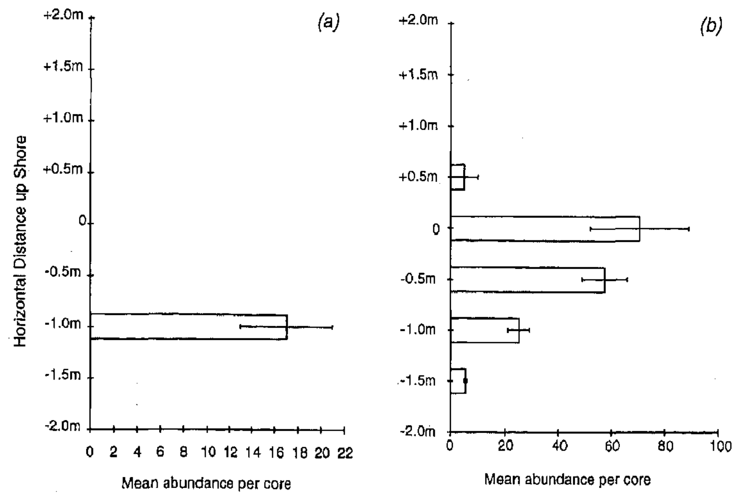

Fig. 2. Examples of patterns of abundance of amphipods in the swash zone: *(a)* abundance of *Exoediceros fossor* at Silver Beach 12, Kurnell, Sydney, on 6 March 1989; *(b)* abundance of *Exoediceroides maculosus* at Silver Beach 3, Kurnell, Sydney, on 15 September 1988.

of the same population as may happen using standard beach designs (e.g. full across-beach transects or shore-parallel stratification). For example, one may start sampling at low tide and move upbeach, remaining in the swash zone and tracking the migrating population. Such sampling would produce seriously inflated estimates of abundance, false across-beach zonation patterns and fail to reveal any tidal migratory behaviour. As well, correlations with independent factors and explanatory hypotheses would be meaningless and might divert resources into attempts to explain patterns that are merely artefacts.

Previous work on a beach faunal community, including *E. fossor* and *E. maculosus*, by Dexter (1984) stratified each beach into five tidal levels (shore-parallel strata). She described generalized across-beach patterns (zonation) for these species using kite diagrams, compared the five strata in community terms (e.g. species richness, abundance etc.) and made some inter-continental generalizations about the families dominating different tidal zones. This would be reasonable for non-migratory species but the fact of migration changes the concept of zonation from the familiar one of fixed patterns in space to one of permanent occupation of the ever-moving swash zone. The 'fixed pattern' concept does not apply to these amphipod species and Dexter's (1984) fixed kite diagrams are misleading at best.

Further, to be meaningful, comparisons among beach strata or geographical areas should exclude migratory species to avoid the confounding caused by sampling at different tide levels. Alternatively, the time of sampling could be standardized. For example, McLachlan (1990) recommended that zonation patterns be determined at low tide, thus permitting unconfounded comparisons among places.

The median-wave method is also efficient in that only the part of the beach occupied by the target population is sampled, thus freeing resources to increase sample sizes and statistical power or to incorporate nesting in space and time in order to better reveal the important scales of variation (James and Fairweather 1996; Morrisey *et al.* 1992). Further, the method is flexible in that it can be applied at any stage of the tide, an especially important practical attribute since, as demonstrated by the legendary King Canute, the tide is a difficult variable to control.

The method also permits flexibilities in sampling design depending on the primary goal of a study. For example, instead of sampling at nine fixed levels (see Fig. 1), this area could be divided into eight shore-parallel strata, each being the area between an adjacent pair of levels. Each stratum could be sampled at random. This stratification approach (combined with random, replicate transects) would give a better estimate of abundance for an entire beach or section thereof. The former (fixed-level) approach restricts inferences to the particular nine tidal heights but was chosen because it permits better discernment of differences along a gradient than stratification (Cox 1958), it is less liable to disturbance by the investigators during sampling, and it is faster to implement, speed of sampling being important as the population migrates.

Acknowledgments

The field involvement of Scott Markich and advice from Keith McGuinness on statistical design in the development of this sampling method are gratefully acknowledged as are constructive comments on the manuscript by Andrew Constable and Don Morrisey.

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Manuscript received 19 June 1997; revised and accepted 16 March 1998