Journal of Coastal Research	SI 39	962- 965	ICS 2004 (Proceedings)	Brazil	ISSN 0749-0208

Using the Precautionary Principle to Measure Recovery of Coastal Habitats: The Case of a Seagrass Bed

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ABSTRACT

WIDMER, W. M., 2006. Using the precautionary principle to measure recovery of coastal habitats: the case of a seagrass bed. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), 962 - 965. Itajaí, SC, Brazil, ISSN 0749-0208.

The development of sound protocols to measure recovery of coastal habitats is an important contribution that science can deliver to decision-makers. Much scientific evidence is often, however, 'uncertain'. In order to interprete this uncertainty, the precautionary principle has been developed. Bioequivalence tests are appropriate to measure recovery, due to their incorporation of the precautionary principle. The aim of this study is, therefore, to investigate the recovery of the seagrass *Halophila ovalis* in Sydney Harbour, Australia, following the experimental clearing of small patches of seagrass beds. It is hypothesised that *H. ovalis* would recover within the first two months after the initial disturbance. At each of two sites, 14 clearings were created with a corer. Sampling was done at intervals of two months after the initial clearing for each site. In the laboratory, *H. ovalis* was sorted into above-ground and below-ground material and their ash-free dry weight was calculated. Two, four and six months after the scars were made, biomass values from disturbed areas at Site 1 were not significantly larger than 85 % of the mean values from reference areas. At Site 2, however, recovery was achieved after four months for above-ground biomass. Contrary to the hypothesis proposed, bioequivalence tests used in this study suggested that *H. ovalis* may take more than 6 months to recover. For this reason, regulatory agencies should carefully define, in advance, statistical protocols to assess ecological recovery.

ADDITIONAL INDEX WORDS: *Anchor scar; bioequivalence test; recreational boating; Sydney Harbour.*

INTRODUCTION

Seagrasses are important primary producers of coastal areas. They also stabilise soft sediments, provide food and shelter for a variety of organisms and are often considered to be important nursery areas for juvenile fish (MANN, 2000). In Australia, there has been a growing concern about the conservation of these flowering plants, because people became aware that there has been a significant reduction in the area covered by seagrasses over the last 50 years (BUTTLER and JERNAKOFF, 1999). Both natural (e.g. cyclones) and anthropogenic impacts, such as dredging and pollution (SHORT and WYLLIE-ECHEVERRIA, 1996) have been identified as factors contributing to this decline.

Damage due to anchors and propellers of boats is considered one potential human impact on seagrasses (KEOUGH and JENKINS, 1995; KIRKMAN, 1997). It is of particular concern in highly populated coastal areas, where there is generally intensive boat traffic (Figure 1). There have, however, been only a few studies on the effects of boating on seagrasses (ZIEMAN, 1976; DAWES *et al.*, 1997; CREED and AMADO, 1999; FRANCOUR *et al.*, 1999), probably due to the small scale of this type of disturbance, compared to other human impacts on seagrasses.

Sydney Harbour is a busy waterway and the mooring ground for an extensive boating fleet. There are approximately 40 marinas (UNDERWOOD and CHAPMAN, 1999) and more than 35,000 recreational boats in Sydney region (DUAP, 1999). The three species of seagrasses in Sydney Harbour are *Halophila ovalis, Zostera capricorni* and *Posidonia australis*, covering an estimated total area of 1.28 square kilometres (WEST *et al.*, 1985).

Halophila ovalis is considered to be a great source of organic matter, to provide important habitat for other organisms and to stabilise soft sediments (WILLIAMS, 1988; ERFTEMEIJER and STAPEL, 1999). Although suggested rates of colonisation into cleared areas differed considerably, *H. ovalis* is also considered to be a pioneer species, due to its great ecological tolerance and rapid growth (DEN HARTOG, 1970; KEOUGH and JENKINS, 1995). According to CLARKE and KIRKMAN (1989), *Zostera* and *Halophila* species colonise unvegetated areas within one year. SUPANWANID (1996) found that *H. ovalis* needed only two months to recover after being experimentally cleared. NAKAOKA and AIOI (1999) estimated that it would take less than 10 days for *H. ovalis* to recover to control values of biomass in a cleared area. Given its rapid growth and status as an early coloniser, the time taken to recover by *H. ovalis* can, therefore, be considered (for managerial purposes) the minimal time of recovery of seagrass in Sydney Harbour, when compared to the other species of seagrass present.

The aim of this study was, therefore, to investigate the recovery of *H. ovalis*, following the experimental clearing of small patches of seagrass beds, similar to the size of anchor scars. Based on the above published observations that *H. ovalis* recovered within two months after being cleared, the proposed model is that this is a general pattern, happening also for the *H. ovalis* population in Sydney Harbour. Therefore, it is predicted that *H. ovalis* in Sydney Harbour would recover within the first two months after the initial disturbance.

Bioequivalence tests are appropriate to measure recovery and restoration, due to their incorporation of the precautionary principle (MCDONALD and ERICKSON, 1994; CHAPMAN and UNDERWOOD, 2000). A colloquial interpretation of this principle is that it is better to give the environment the benefit of the doubt. Usually, recovery is declared to have been achieved when a variable's mean in disturbed areas is not significantly different from the mean in reference areas (generally with a large probability of Type II error). In contrast, bioequivalence tests require that, before an area is declared to be recovered, the mean of a variable in disturbed areas has to be significantly larger than a set value (defined as 'recovered') in the reference areas. The probability of inferring that recovery has been achieved when in fact it has not (Type II error) is reduced, which is sound in terms of precautionary management strategies.

It is predicted that two months after the disturbance, the mean measure of seagrass biomass from disturbed samples would be

Figure 1. Propeller scar in Rose Bay, where the reduction of biomass of seagrass is visible.

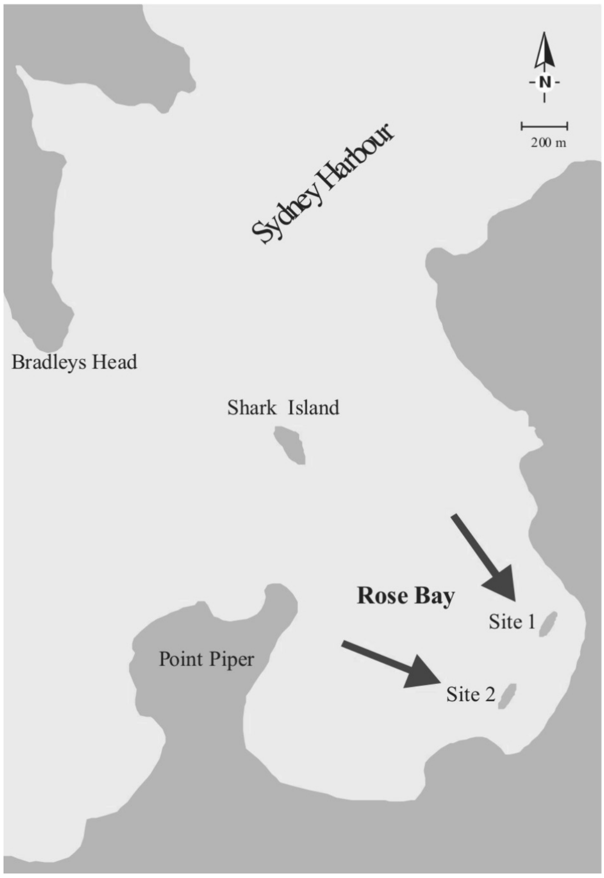

Figure 2. Study area in Rose Bay, one embayment of Sydney Harbour. Arrows point to the two ellipsoid areas, which represent the approximate location of the two sites where the experiment was performed.

significantly larger than a chosen proportion of the mean from reference samples. The chosen values are defined to represent recovery. GIBBS (1997) considered that 50 % of the original biomass and other variables was sufficient to indicate successful restoration. It is, however, reasonable to argue that this value is too small. An environmental decision-maker (representing the public interest) may not feel comfortable to declare full recovery of a damaged site using this threshold value. For this reason, a larger value (85 %) was considered to be more appropriate for this study. If the experimentally cleared patches did not indicate recovery after two months, the same hypothesis was tested after four months and, if necessary, after six months.

METHODS

The area studied is in Rose Bay, Sydney Harbour (Figure 2). The seagrass bed is composed of *Zostera capricorni* (intertidally) and *Halophila ovalis,* which occurs mainly near the subtidal-intertidal boundary. Two randomly chosen areas were used, approximately 500 metre apart, just below the level of mean low spring tides. At each site, 14 clearings were created in November 2000 with a corer (0.23 metre diameter; area = 0.043 square metres), a size similar to that used by VERMAAT *et al.* (1995).

Rods used to mark the clearings in Site 2 were lost, so another 14 clearings were made in a slightly different location in January 2001. In each clearing, all seagrass material was removed, including rhizomes and roots, to a depth of 10 cm inside the sediment. Each clearing was numbered and plotted in a chart with relative distances to other clearings and with associated magnetic bearings, in order to locate them for subsequent sampling.

Sampling was done at intervals of two months after the initial clearing for each site (January 2001, March 2001 and May 2001 for Site 1; March 2001 and May 2001 for Site 2). At each time of sampling, four randomly-selected experimental scars and four undisturbed samples were collected from each site.

The corer was pushed 10 cm into the sediment and the material was carefully moved into a bag (net of 0.5 mm mesh) attached to the top of the corer. The samples were stored in plastic bags with salt water until reaching the laboratory, where they were sieved through a sieve (mesh size: 8 mm). Plant matter was retained on the 8 mm sieve. Organic debris (mostly decaying *Zostera capricorni*) was separated from live *H. ovalis*, which was sorted into above-ground (leaves and petioles) and below-ground (roots and rhizomes) material. The seagrass material was dried (70 ºC, 72 hours) and weighed to the nearest 0.01 gram using an electronic balance. The samples were then ignited at 520 ºC for 3 hours (VERMAAT and VERHAGEN, 1996) and weighed again, so that the ash-free dry weight, in grams per square metre, could be measured.

Mean biomass (above- and below-ground) from disturbed areas were compared against mean values from reference areas. At each time of sampling (two, four and six months) and for each site, the hypothesis that a given mean from disturbed areas is significantly greater than 85 % of the correspondent mean from reference areas was tested using the one tail Student's *t*-test.

RESULTS

Two, four and six months after the scars were made, the above-ground (Fig. 3a) and below-ground biomass values from disturbed areas at Site 1 were not significantly larger than 85 % of the mean values from reference areas (*t*-tests, 6 d.f., $P > 0.1$).

At Site 2, recovery of above-ground biomass ($t = 3.1$, 6 d.f., $P < 0.01$) was achieved after four months from the start of the experiment. Below-ground biomass did not, however, recover after four months from the start of the experiment ($t = 0.9$, 6 d.f., $P > 0.2$, Fig. 3b).

DISCUSSION

Biomasses of *H. ovalis* (both above- and below-ground) were quite variable among sampling occasions and between sites. Contrary to the hypothesis proposed, it took four months for above-ground biomass on cleared areas to recover in Site 2. In Site 1, recovery was not achieved 6 months after the disturbance. These results suggest a recovery rate slower than the two months estimated by SUPANWANID (1996) and much slower than the 10 days "…rough estimates…" from NAKAOKA and AIOI (1999, p. 102). The present results seem to be more in accordance with CLARKE and KIRKMAN'S (1989) opinion that this species recovers in less than one year and with PREEN'S (1995) finding that it took 5 months for *H. ovalis* to recover to 65 % of original biomass values after being fed on by dugongs.

Faster recovery described previously was in tropical environments. This study was done at latitude 34° S, away from the pantropical characteristic habitat of this species (LARKUM and DEN HARTOG, 1989). This is a possible explanation for the slower recovery. In addition, this experiment was done in a highly urbanized estuary exposed to different sorts of disturbances, including organic enrichment from storm-water and heavy metal contamination (BIRCH and TAYLOR, 1999). Because these disturbances have specific and additive detrimental effects on the photosynthetic efficiency of *H. ovalis* (RALPH and BURCHETT, 1998; RALPH, 1999), they may also play important roles in explaining the slower recovery found here. Another important explanation for the slower recovery is a precautionary definition of recovery used in this study (and therefore the statistical tool to test it). It requires a greater mean value of the estimates of biomass in disturbed sites in order to indicate recovery, which takes longer to be achieved.

It is interesting to note the consequences of using bioequivalence tests. Considering, for example, the above-ground biomass at Site 1, a standard Student *t*-test would indicate that the means from disturbed and reference samples were not significantly different (i.e., recovery had been achieved) already at the second month after the disturbance, due to large variances associated with the means. It was not, however, realistic to consider that the mean in disturbed samples was significantly larger than that defined to represent recovery.

It is important to highlight the importance of the threshold value used to indicate recovery. Here, the value of 85 % was used. If a smaller value had been chosen (e.g. 50 %), the results of this study would have to be interpreted differently. Such different interpretations highlight the importance of carefully deciding, in advance, the critical value that will be used to represent recovery. Until there is solid ecological information to guide the selection of this threshold value, people will have to make such decisions based on their current values and ideologies.

The actual capacity of seagrass beds to recover is also dependent on the frequency of disturbances. A single scar produced by an anchor or a propeller can be seen as a pulse disturbance (*sensu* BENDER *et al.*, 1984). In such case, *H. ovalis* is a stable species, because it can recover in months. However, the press disturbance of several, frequent scars may reduce the resilience of the population, to a point of no recovery (UNDERWOOD, 1989; GLASBY and UNDERWOOD, 1996). For example, 10 new propeller scars were identified in a single observation of Rose Bay. Such observation raises concern that, at some locations, a disturbed spot may be disturbed a second time before the end of the original recovery time, potentially keeping the area in a permanent status of recovery.

The precaution used in the study presented here does not, however, seem to be widely used. In the Brazilian state of Santa Catarina, for instance, federal and state-level regulatory agencies did not request quantitative data or statistical techniques (let alone bioequivalence tests) to infer the success of past programs for recovery of vegetation on sand dunes. It is recommended, therefore, that such agencies make use of available quantitative methods to assess statistically the recovery of coastal habitats, hopefully incorporating the precautionary principle.

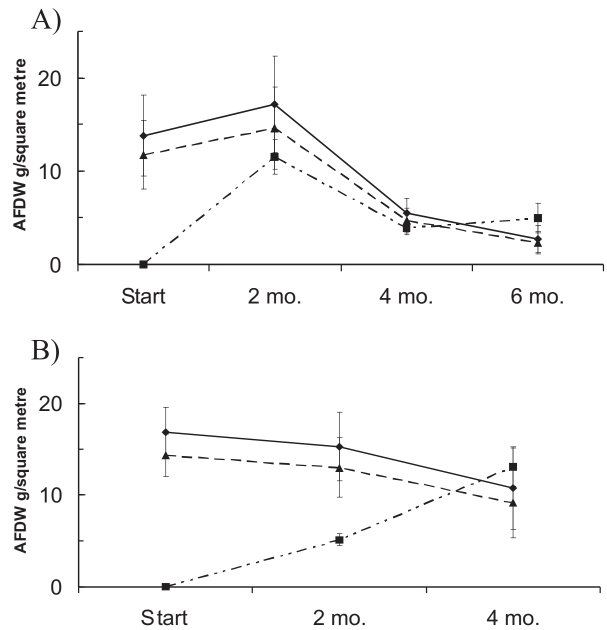

Figure 3. Recovery of *H. ovalis* after experimental clearings. (A) above-ground biomass in Site 1; (B) below-ground biomass in Site 2. Full line, • = reference; dashed line, ■ = treatment; dashed line, ▲ = recovery (i.e. 85 % reference). Data are mean (±S.E.; N = 4; except in A, "Start", where N = 2).

ACKNOWLEDGEMENTS

Marinez Scherer Widmer, José Henrique Alves and Anya Lam helped in the fieldwork. Professor A. J. Underwood, Professor C. H. Peterson and Dr M. G. Chapman provided helpful comments. This study was done with financial assistance from the Brazilian foundation CAPES Brazil (grant 1229/98-2). Author's current address is: Núcleo de Estudos do Mar (NEMAR) CCB UFSC. Caixa Postal 476 CEP 88010-970. Campus - Universitário - Trindade - Florianópolis - SC Brazil.

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