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Appendix S1. Methods and Results for Benthic Faunal Status Assessment

METHODS

Relative status assessment for benthic taxa

The equilibrium relative benthic status (RBS) of three faunal taxonomic classes (Polychaeta, Malacostraca, Bivalvia) in Exmouth Gulf, in response to otter-trawling for shrimps, was estimated taking into account the distribution of dominant-sediment habitat types (Gravel, Sand, muddy-Sand and Mud) and the differing faunal trawl depletion rates D (specific to different gear-types) and logistic recovery rates R among these habitats. Initially, as an example for situations where spatial distributions of fauna may be unknown, the RBS of each cell was calculated (using eqn 2 in main text) as the ratio B/K of abundance B relative to carrying capacity K. The Gulf-wide status of taxa, accounting for their different sensitivity and exposure to trawling, was quantified by plotting the distribution of grid-cell RBS values against cumulative proportion of Gulf area (ordered by trawl effort) and by mapping their spatial distribution. The region-wide average RBS was also calculated as an indication of overall status, which in effect assumes that initial un-trawled taxa distributions were uniform (i.e. K=1 in all grid cells).

Absolute status assessment for benthic taxa

The assessment of absolute status for fauna requires information on distributions of abundance because different taxa may have different initial un-trawled abundance distributions and different exposure to trawling. Hence, absolute status will differ from relative status. To provide an illustrative example of absolute status assessment, distributions were predicted for the three benthic taxonomic classes, using data from a benthic survey of Exmouth Gulf (Kangas et al. 2007). Data for commercial shrimp species were excluded from Malacostraca, given our focus on non-target species. Variables used to predict distributions, with linear regression models, included depth, sediment grain-size fractions and trawl effort. To predict initial un-trawled distributions (representing K), trawl effort was set to 0 in all grid cells. Predictions were normalised (divided by their sum) to provide a profile distribution (sums to 1) for each taxon and mapped. Absolute status (B) was estimated by multiplying the predicted grid-cell distribution profiles (K) by the respective grid-cell RBS (i.e. B/K) for each taxon (i.e. $B=K\times B/K$). The 'absolute' Gulf-wide status was estimated by the sum of grid-cell B and (because K was normalised to sum to 1) provides a value in the range 0–1 that indicates the remaining proportion of total initial abundance in the Gulf. This is in contrast to the relative B/K results (RBS), which are proportions of initial grid-cell state. Absolute impact was estimated by subtracting the estimated grid-cell absolute status from the predicted distribution profile (i.e. $K-B$) and mapped.

RESULTS

Relative status assessment for benthic taxa

The equilibrium RBS (B/K) of each taxon, pooled for all habitats, as a function of trawling effort (Figure S1.1) shows that Malacostraca are more affected by trawling than Bivalvia and Polychaeta at all levels of effort. This reflects the higher depletion rates of Malacostraca, even though Bivalvia had slower recovery rates (see main text Tables 2 & 3). RBS differs among habitats due to differences in faunal sensitivity among habitats. The

initial assumption of uniform relative distribution of taxa is exemplified by the distribution of total and cumulative area against trawl intensity (Figure S1.1). The RBS of benthic taxa was 1 in most of the Gulf for all taxa (Figure S1.2), progressively declining to 0 for each taxon in a small percentage of heavily trawled Gravel cells (Polychaeta: 1.2%, Malacostraca: 2.6%, Bivalvia: 0.8%). The spatial distribution of RBS for taxa (Figure S1.3a) was similar to that for habitats, with differences in magnitude between taxa. For Polychaeta, the overall Gulf-wide average RBS was ~94.4% and the average RBS in trawled cells was ~88.9%. For Malacostraca, the overall RBS was ~90.6% and the average in trawled cells was ~81.4%. For Bivalvia, the overall RBS was ~95.5% and in trawled cells was ~91.1%. Malacostraca were estimated to be most affected (9.4% overall relative impact, compared with Polychaeta at 5.6% and Bivalvia at 4.5%), and relatively more impacted in Gravel than in other habitats.

Absolute status assessment for benthic taxa

The predicted distribution maps (Figure S1.3b) reflect the expected spatial pattern of variation in (normalized) *K* for each benthic taxon. The distribution of absolute impact (Figure S1.3c) indicates the location and magnitude of impact in comparison to the predicted abundance (Figure S1.3b). Each taxon has higher density in deeper water beyond the distribution of trawling, particularly Bivalvia, but also areas of low abundance in un-trawled or low-effort areas (compare Figure S1.3a,b,c). The greatest impacts occur in areas of the distribution of each taxon that have about, or slightly above, average abundance. Cumulative abundance curves (Figure S1.1) indicate that each taxon is partly distributed away from trawling (where the cumulative abundance curves are above the cumulative area curve at zero and low effort areas), especially for Bivalvia, and partly towards trawling (where abundance curves are below the area curve at higher effort levels).

The absolute impact maps (Figure S1.3c) differ from the relative benthic status (RBS) maps (Figure S1.3a) because they take into account the distributions of the taxa. Nevertheless, the Gulf-wide absolute status estimates (Figure S1.4) were rather similar to Gulf-wide average RBS estimates (see previous section) because the initial abundance of each taxon was about average, or slightly higher, in high effort areas (swept-ratio >2) where (like the uniform distribution) about 10% of total initial abundance of each occurred (Figure S1.1). For Polychaeta, the Gulf-wide absolute population status was ~92.6% (compared with overall RBS = 94.4%); for Malacostraca, the absolute status was 89.8% (cf. overall RBS = 90.6%); and for Bivalvia, absolute status was 94.9% (cf. RBS = 95.5%). Malacostraca were estimated to have the greatest absolute impact (10.2%) and this was slightly higher than the relative impact (9.4%). The absolute impact for Polychaeta (7.4%) was 1.3× the relative impact (5.6%) because they had higher than average initial abundance in trawled Gravel habitat. Bivalvia were least impacted; the absolute impact (5.1%) was slightly more than relative impact (4.5%).

Information on taxa distributions changes status estimates. While the differences are not large in this example for the Exmouth Gulf, they will be larger if the abundance of any given benthic taxon or species is distributed towards trawled areas. Status estimates will also be larger in regions where trawling is heavier and more extensive, because the estimates of population status would become more sensitive to distributions.

REFERENCE

Kangas, M.I., Morrison, S., Unsworth, P. , Lai, E., Wright, I. & Thomson, A. (2007) *Development of biodiversity and habitat monitoring systems for key trawl fisheries in Western Australia*. Final report to Fisheries Research and Development Corporation on Project No. 2002/038. Fisheries Research Report No. 160, Department of Fisheries, Western Australia, 334p

FIGURES

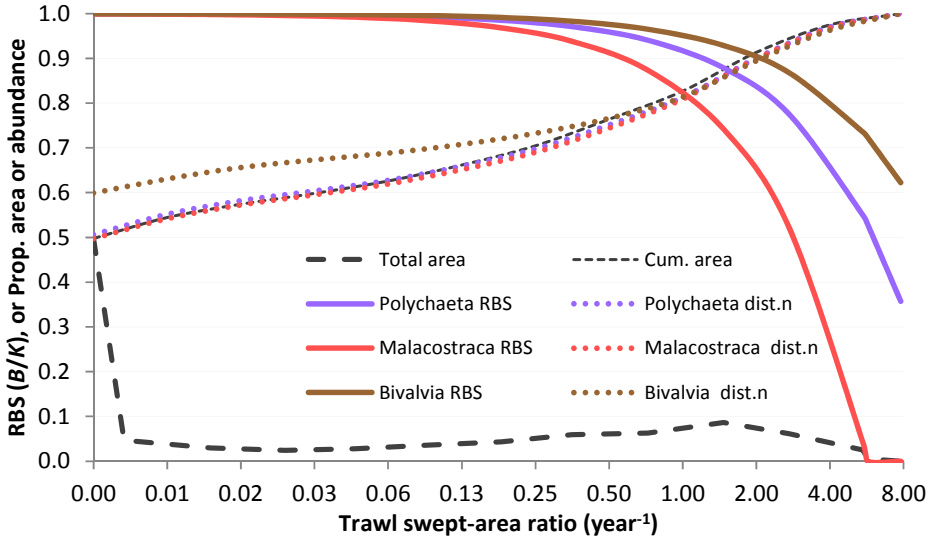

Figure S1.1. Equilibrium status (*B*/*K*) of benthic taxa (for overall *d* and *r* across all habitats) at each level of constant annual trawl swept-area ratio; with proportion of total Exmouth Gulf area and cumulative total area by trawl intensity (representing relative, uniform, distributions); and cumulative distributions of abundance for each taxon.

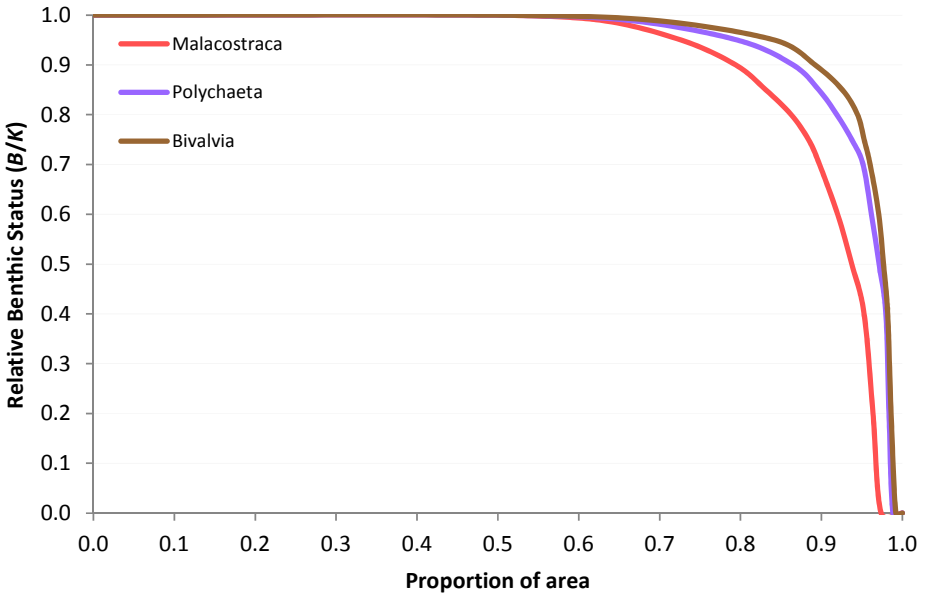

Figure S1.2. Relative benthic status (RBS) of benthic taxa by proportion of Exmouth Gulf area, accounting for their differing sensitivity in different habitats with different trawl exposure.

(a)

(b)

(c)

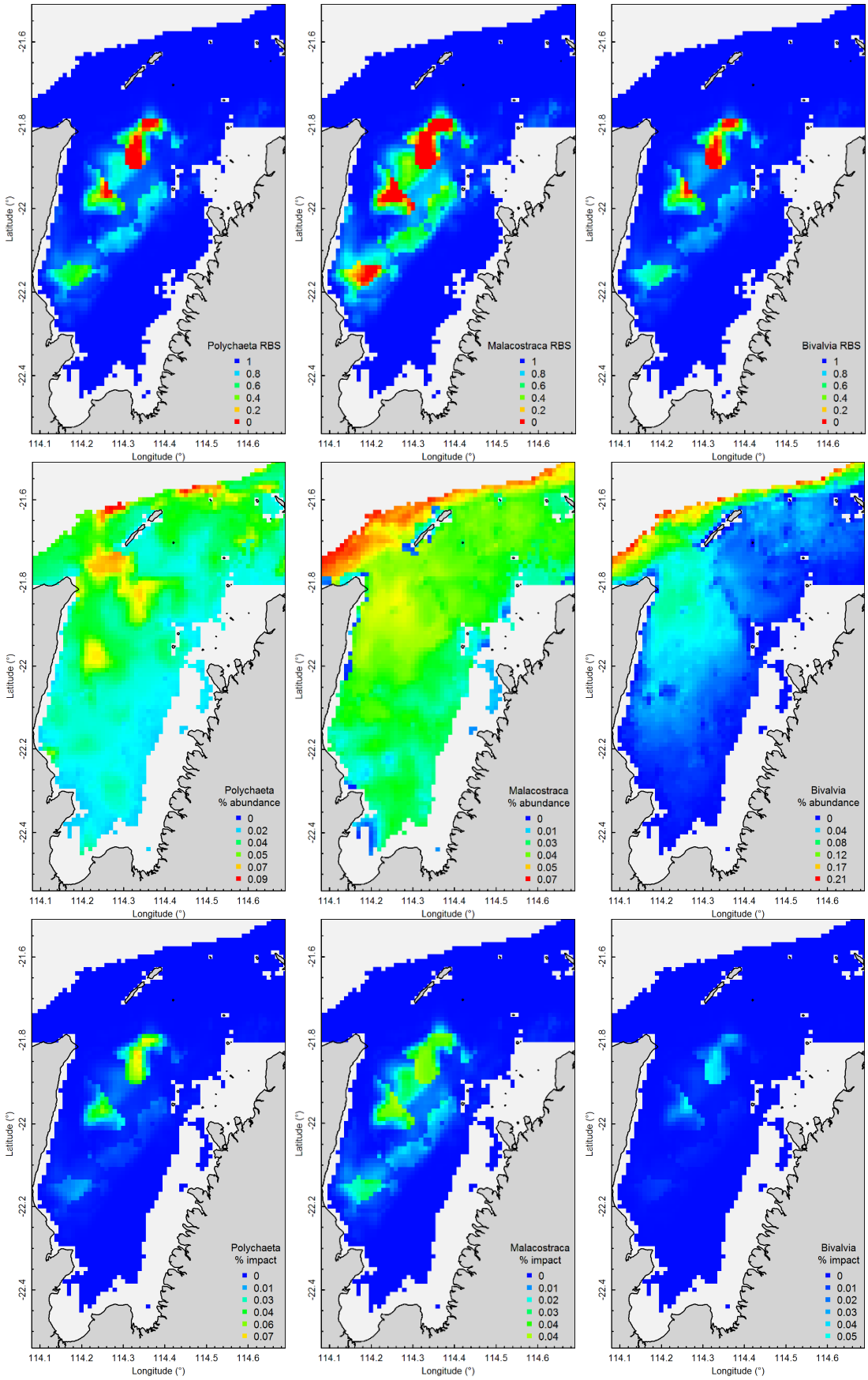

Figure S1.3. Maps of Exmouth Gulf: (a) relative benthic status (RBS) of three benthic taxa, with the same 0–1 colour ramp used for all taxa; (b) predicted taxa abundance, as a proportion of total mapped abundance, with a separate colour ramp used for each taxon, ranging from 0 to maximum abundance; (c) absolute impact on taxa, as a proportion of the total mapped abundance, with the colour ramp for each taxon matching the ramp used in (b), where red would indicate full impact on the maximum cell abundance.

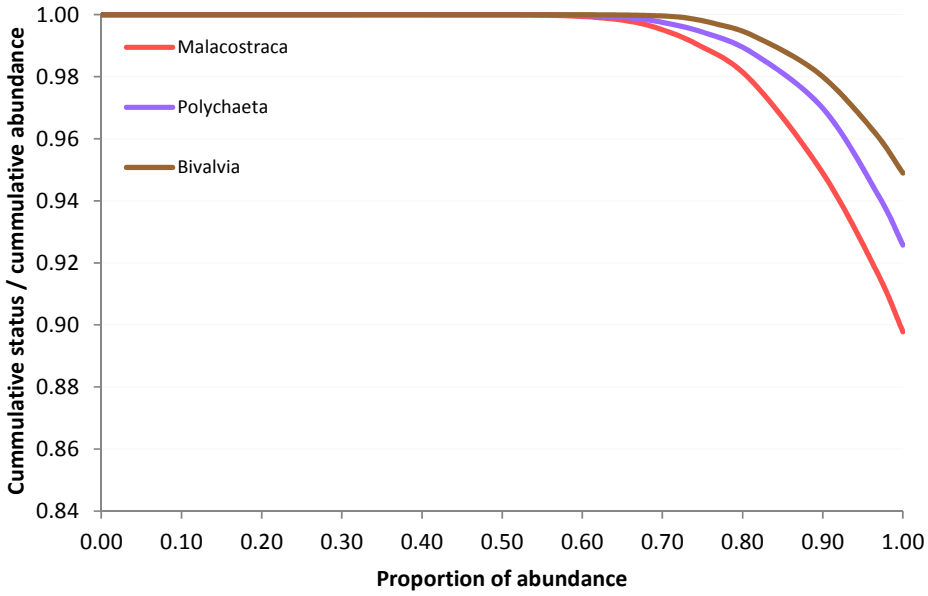

Figure S1.4. Cumulative absolute status of taxa as a proportion of cumulative initial taxon abundance, against proportion of initial taxon abundance (ordered by trawl effort). Overall regional status is indicated by the right end of the lines. Results account for differing sensitivity of fauna in different habitats and different trawl exposure of habitats.