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Quantitative indicators of environmental sustainability risk for a tropical shelf trawl fishery

C. Roland Pitcher*

CSIRO Marine & Atmospheric Research and Wealth from Oceans Flagship, EcoSciences Precinct, 41 Boggo Road, Dutton Park, Qld. 4102, GPO Box 2583, Brisbane, QLD 4001, Australia

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ABSTRACT

Indicators of trawl exposure were developed for 837 bycatch and benthos species, assemblages and habitats on the Great Barrier Reef shelf, by analysing their spatial distributions (mapped by a previous study) in relation to management zones, overlap with trawl grounds, and the intensity of trawl effort – and estimating the proportion of their distributions exposed to trawling. Exposure to trawl intensity as a swept-coverage was a more sensitive indicator than exposure to trawled grounds or exposure as permitted by management zones. Few habitats and assemblages were highly exposed. About 33 species had high exposure to trawl effort, whereas approximately 70% of the 837 species had low exposure. The indicators for species were extended, using relative catch rates, to estimate the proportion of populations caught annually (exploitation rate). Five species had high estimated exploitation rates and 28 were intermediate, whereas most (>800) species had low exploitation rates. The productivity potential of species to counter the incidental catch was assessed using recovery scores from life history traits. This *qualitative* approach indicated species at higher relative risk due to trawling. A *quantitative* indicator of absolute sustainability was estimated using available natural mortality rates to calculate the proportion of fishing mortality at maximum sustainable yield (F_{MSY}). Three species exceeded a limit reference point ($\cong 1.0 \times F_{MSY}$), one species exceeded a first conservative reference point ($\cong 0.8 \times F_{MSY}$) and two others exceeded a second conservative reference point ($\cong 0.6 \times F_{MSY}$). While few species were assessed at high risk, there were uncertainties in the distributions, relative catch rates, and natural mortality rates that required a precautionary response, including considering additional species with high indicator values. The species identified as high risk by the quantitative sustainability indicator and by the qualitative productivity scores corresponded poorly. This raises concerns about the reliability of qualitative approaches often used to conduct risk assessments for data-poor species.

1. Introduction

Trawl fishing is among the most extensive of human activities that interact directly with the seabed (Kaiser et al., 2002). Commonly, it has long been perceived that trawling on the seabed is highly damaging due to both direct and indirect impacts (Jennings and Kaiser, 1998). However, scientifically robust empirical evidence is mixed (see meta-analyses: Collie et al., 2000; Kaiser et al., 2006; also Pitcher et al., 2009); there are demonstrated cases of severe benthic impacts and many cases where effects are negligible, or at least acceptable to management authorities. Trawling is also among the most un-selective of fishing methods, capturing many non-target species (in some cases many 100s) of no commercial value that are discarded ("by-catch"; Alverson et al., 1994) – at least in most industrialised fisheries, less so in developing countries where almost all catch is utilised.

The cases of actual benthic impacts and undoubted high proportions of bycatch, together with widespread negative perceptions, have progressively trended management of trawl fisheries (among others) towards an ecosystem-based approach (Sainsbury and Sumaila, 2003) under which the fishery is expected to assess and manage risk to acceptable levels, and gain "social licence to operate".

There have been three main approaches to assessing effects of trawling: (1) comparative surveys of areas with contrasting levels of fishing (e.g. Sainsbury et al., 1992; McConnaughey et al., 2000; Burridge et al., 2006); (2) mensurative quantitative experiments sometimes extending to model-based evaluations of management, and (3) qualitative risk-based approaches in more data limited situations. The first two typically have been used with respect to benthic impacts (experiments: e.g. Burridge et al., 2003; Pitcher et al., 2009; and see in reviews above – models: e.g. Sainsbury, 1991; Pitcher et al., 2000; Ellis and Pantus, 2001; Ellis et al., 2008;

* Tel.: +61 7 38335954; fax: +61 7 38335502; mobile: +61 0418 195 955.
E-mail address: roland.pitcher@csiro.au

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Hiddink et al., 2006), whereas the third has been applied primarily to bycatch assessments (e.g. Stobutzki et al., 2001; Hobday et al., 2011).

In principle, the assessment of risk for bycatch is essentially the same as stock assessment of target species: information is needed on the exploitation rate (incidental in the case of bycatch) and on productivity (e.g. natural mortality rate in the case of stock assessment). However, these parameters are rarely available for 100s of bycatch species, so qualitative aspects of the fishing activity, the species behaviour and life-history that influence susceptibility to exploitation and relate to potential for recovery, are considered together to represent relative risk (e.g. Stobutzki et al., 2001; Astles et al., 2006).

Hobday et al. (2011) proposed a multi-level 'triage' approach where risk is assessed in more detail (and with greater data demand and cost) only if a less detailed assessment indicates that risk is non-negligible. Level 1 may comprise a likelihood and consequence type approach (similar to Fletcher et al., 2002); Level 2 is semi-quantitative where various attributes of species behaviour and life-history are ranked with respect to susceptibility or productivity and combined in some way to indicate relative risk; Level 3 is quantitative with varying degrees of sophistication (including dynamic models and stock assessments) and represents absolute sustainability risk with respect to established biological reference points.

A potential concern with level 1 and 2 assessments is that they may incorrectly indicate levels of risk (Zhou et al., 2009); in particular, they may falsely indicate a species is at low risk when a quantitative assessment would indicate the species is at a high sustainability risk. The converse is perhaps less concerning and in practice should lead to a more detailed assessment. Hobday et al. (2011) suggest that qualitative assessments are biased towards false positives, which thus are common, whereas false negatives are few.

In the Great Barrier Reef (GBR) region, the Queensland East Coast otter-Trawl Fishery (QECTF) has been trawling for Penaeid prawns for many decades. A previous study had conducted a qualitative risk assessment for 63 non-target but permitted species in this fishery (Kerrigan et al., 2004). The current study aimed to conduct a quantitative risk assessment for many 100 s of bycatch and benthic species potentially impacted by this fishery – as well as habitats and species assemblages – to support management goals of the GBR Marine Park (GBRMP) and the QECTF in maintaining ecosystem quality and conserving biodiversity, and in achieving environmental sustainability of the fishery. Earlier benthic impact studies in the region (Poiner et al., 1998; Pitcher et al., 2000) had demonstrated that information on the distribution of bycatch and benthos throughout the GBR was crucial for robust assessments, because the potential susceptibility of species is strongly dependent on their spatial exposure to trawl effort, in addition to catch (or impact) and recovery rates. The current assessment was facilitated by the provision of detailed maps of the regional-scale distribution of seabed species, assemblages and habitats from a related study (Pitcher et al., 2007a). These maps have enabled the development of quantitative indicators of exposure to trawling having a stronger distribution-based foundation than any previous bycatch risk assessment.

2. Methods

This ecological risk assessment built on a previous study that surveyed and mapped benthic species and habitat distributions, at spatial scales relevant to regional conservation and management needs, in shelf seabed areas of the GBR (Pitcher et al., 2007a). The latter survey design was stratified by environmental variables important for driving biological patterns in the region, and mapped to a 0.01° grid. Almost 1400 sites were sampled throughout the 200,000 km^2 shelf in the region (see Supplementary Appendix A, Fig. A-1), during 10 voyages between 2003 and 2006 on two vessels, which deployed towed video, epibenthic sled, research trawl and baited remote underwater video stations (BRUVS), to collect information and samples for detailed distribution and abundance data about habitats and species of plants, invertebrates and fishes on the seabed. Once the samples were sorted and identified, these data were analysed using environmental variables as predictors to produce distribution maps of species, assemblages and habitats (see Pitcher et al., 2007a for details).

Of >5300 species sampled, ~850 occurred sufficiently frequently for analyses using a two-stage generalised linear modelling approach. Model performance was good for most species, and was useful for predicting biomass distribution maps for all but a few species, which were excluded from subsequent analyses.

A map of species-assemblages was produced using a recursive algorithm to partition a Bray–Curtis dissimilarity matrix of site composition and to classify the entire GBR shelf into 16 groups, based on the decision tree splits on the environmental variables. An index of affinity-distance of each species for each assemblage was also calculated, ranging between 0 and 1, where affinity = 0 indicated that the species occurred with equal abundance at each site in the assemblage and not elsewhere and affinity = 1 indicated that the species occurred entirely elsewhere (see Pitcher et al., 2007a for details).

The broad habitat types on the GBR shelf were characterised from habitat data recorded from the towed video camera, using an approach analogous to that for assemblages, based on partitioning a Manhattan distance matrix into 9 classes representing areas of seabed having similar mixtures of habitat elements within, and different mixtures between. These predicted distribution maps underpinned several ecological assessments of the QECTF in the GBRMP.

The approach to this ecological risk assessment was to examine overlap of habitats, assemblages and species distributions with the footprint of the QECTF, using a series of exposure indicators of increasing specificity – progressively accounting for management zoning (which excludes trawling from large areas of the GBRMP), actual distribution of trawling, and intensity of trawl effort. Increasing exposure was considered indicative of increasing potential risk. Further, in most cases relative catchability of species in trawls and species productivity potential was taken into account, providing more specific indications of relative risk and sustainability. Details of these approaches are described below.

2.1. Ecological risk indicators

The series of trawl exposure estimates were based on mapped area for habitat types and seabed assemblages and on mapped biomass distributions for individual species. This series included:

1. Estimates of the percentage of the distribution of each habitat, assemblage, and individual species, located in areas open to trawling under spatial management arrangements – without accounting for the distribution or intensity of trawl effort.
2. Estimates of the percentage of the distribution of each habitat, assemblage, and individual species, located in areas where trawl effort is present – without accounting for the intensity of trawl effort.
3. Estimates of the percentage of the distribution of each habitat, assemblage, and individual species, located in areas where trawl effort is present taking into account the intensity of trawl effort.