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Quantitative ecological risk assessment for fishing effects on diverse data-poor non-target species in a multi-sector and multi-gear fishery

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ABSTRACT

Assessment of ecological sustainability for all species impacted by fishing is one of the most important and practical steps towards an Ecosystem Approach to Fisheries. We extend methods for Sustainability Assessment for Fishing Effects (SAFE) to assess diverse bycatch species in a multi-sector and multi-gear fishery. We develop methods for estimating fishing mortality rate, based on limited data, for demersal trawl, Danish seine, gillnet, and longline. The general approach involves estimating spatial overlap between species distribution and fishing effort distribution, catchability resulting from probability of encountering the gear and size-dependent selectivity, and post-capture mortality. We define three reference points (F_{msm}, F_{lim}, and F_{crash}) and use six methods to derive these reference points. As an example, we apply this method to nearly 500 fish species caught in the Southern and Eastern Scalefish and Shark Fishery, a multi-sector and multi-gear fishery in Australia. We assess sustainability risk for all captured fish species in each sub-fishery and the cumulative impact across all the sub-fisheries. The results indicate that chondrichthyans are more vulnerable to fishing impact than teleosts, and that impact differs among sectors of the fishery. This method could be easily applied to other fisheries. However, the results may require fine tuning by other means such as expert judgment.

1. Introduction

Assessment and management of fishery impacts on non-target species is a key aspect of the Ecosystem Approach to Fisheries (FAO, 2003). Major challenges for non-target species management are the lack of clear and practical objectives and the lack of data for non-target species that typically have low economic value. To overcome these difficulties, Zhou and Griffiths (2008) and Zhou et al. (2009) developed a framework for Sustainability Assessment for Fishing Effects (SAFE) that could be applied to data-poor bycatch species. The method involves estimating fishery impacts from limited data and establishing biological reference points based on life history parameters. SAFE fits well into the Ecological Risk Assessment for Effects of Fishing (ERAEF) framework described in Smith et al. (2007a). The ERAEF framework is a hierarchical approach that starts from a qualitative analysis of risk at Level 1, through a semi-quantitative analysis at Level 2, to a quantitative analysis at Level 3. Level 1 is called "Scale Intensity Consequence Analysis (SICA)" and involves the exercise of expert judgment to assess impacts of fishing on species, habitats and ecosystems. Level 2 is called "Productivity Susceptibility Analysis (PSA)" and is based on scoring each species on a number of productivity and susceptibility attributes. Level 3 is a fully quantitative assessment based on a range of methods including formal quantitative stock assessments. However, it is challenging to find quantitative methods that can work within the constraints of limited data and time for analysis of a large number of non-target species. SAFE has been regarded as a Level 3 method as it is in principle similar to formal stock assessment. Zhou and Griffiths (2008) and Zhou et al. (2009) used detection–nondetection data to estimate fish distribution, applied the method to one fishing gear (prawn trawl), and did not quantify uncertainty in reference points. In this paper we improve and

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extend the SAFE methodology, develop new methods to estimate fishing mortalities by four types of fishing gears (trawl, Danish seine, gillnet, and longline) and assess their cumulative impacts. We also extend the SAFE method by quantifying uncertainty in both fishing impacts and reference points. We apply this extended SAFE to the Southern and Eastern Scalefish and Shark Fishery (SESSF) in Australia. This paper provides a detailed description of the method, which could be applied to other fisheries around the world.

2. Materials and methods

The methodology of SAFE consists of two major components: indicators and reference points. This reflects the general approach advocated for ecosystem-based fishery management (Garcia and Staples, 2000; Sainsbury et al., 2000; Garcia and Cochrane, 2005; Smith et al., 2007b). In this case we focus on one single indictor – fishing mortality rate – and develop methods to estimate this indicator for hundreds of species using limited available data. As it is literally infeasible to do full stock assessments for hundreds of non-target species that have little information, we also develop alternative approaches to establish reference points based on simple life history traits.

2.1. The fishery

The SESSF extends from waters off southern Queensland, south and west to Cape Leeuwin in Western Australia. It is a complex multi-sector, multi-gear and multi-species fishery targeting scalefish and shark stocks of various size, distribution and composition (Smith and Smith, 2001). Almost half the waters of the Australian Fishing Zone off southern mainland Australia and Tasmania are in the fishery management area. The SESSF is one of the most important Commonwealth-managed fisheries, with landings of over 35,000 t annually at a value of around $95 million. We assessed five major sub-fisheries in the SESSF using the methods described below: the South East Otter Trawl fishery, the Great Australian Bight Trawl Fishery, the Danish Seine Fishery, the Shark Gillnet Fishery, and the Longline Fishery. All these sub-fisheries target mainly demersal species. For the purpose of illustration, we used fishing effort data from 2003 to 2006 to estimate fishing mortality.

Key data come from commercial logbooks and observer programs. In Australian Commonwealth fisheries, all fishing operators are required to record the location, catch of each species and effort in logbooks each time they deploy and retrieve their gear. The Integrated Scientific Monitoring Program (ISMP) provides port-based and at-sea monitoring, which produces important information on discards, non-commercial species and non-quota commercial species. ISMP observers collect information on all species that come aboard for both discarded and retained species. The level of coverage is designed to achieve specified coefficients of variation for discard rates for principal species.

2.2. Estimating fishing impacts

2.2.1. Trawl fishery

Fishing impact is expressed as annual instantaneous fishing mortality rate within the specific fishery management jurisdiction. Instantaneous fishing mortality F can be derived from number of fish killed by fishing in a period of interest (generally one year) and the average population abundance during that period (Quinn and Deriso, 1999). For a trawl fishery, assuming that each unit of fishing effort (expressed in area fished) operates independently and additively, the instantaneous change in catch would then be proportional to trawled area per unit time and density:

$$\frac{dc_i}{dt} = q_i^h q_i^\lambda (1 - S_i) d_{t,i} \frac{da}{dt}, \tag{1}$$

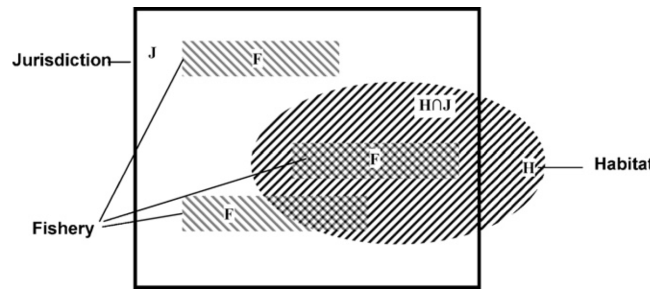

Fig. 1. Diagram of species, fishery, and fishing effort distribution. J = fishery jurisdiction; H = species distribution (habitat may be used); F = fished (trawled) area. The overlap between fished area and species distribution area, #-shaded F ∩ H|J, is the key variable for estimating fishing impact on bycatch species.

where c_i = catch of species i dead after discard; a = area trawled; $d_{t,i}$ = density of species i at time t; q_i^h = habitat-dependent encounterability; q_i^λ = size- and behaviour-dependent selectivity; S_i = the discard survival rate; and $d_{t,i}$ = density of species i at t.

Population size or density $d_{t,i}$ may reduce over time due to fishing mortality and natural mortality. Re-arranging Eq. (1) we have:

$$\int_0^{C_i} \int_{t1}^{t2} dt dc_i = \int_0^{A_{f,i}} \int_{t1}^{t2} q_i^h q_i^\lambda (1 - S_i) d_{0,i} e^{-Z_i t} dt da, \tag{2}$$

where the duration between $t1$ and $t2$ is one year, $A_{f,i}$ is the total area fished during that period, and Z_i = total mortality, i.e., sum of fishing mortality F and natural mortality M. Integrating Eq. (2) results in

$$C_i = q_i^h q_i^\lambda (1 - S_i) \frac{d_{0,i}(1 - e^{-Z_i})}{Z_i} A_{f,i}. \tag{3}$$

The total area fished is $A_{f,i} = \sum_{t1}^{t2} WL_{t,i}$, where W = width of trawl wing spread, and $L_{t,i}$ = trawl length based on start and end locations at time t that occurs within the species distribution range.

Secondly, by assuming individuals of species i evenly distribute within occupied area A_i within the fishery jurisdiction, the mean population size over the one year can be obtained as (Quinn and Deriso, 1999):

$$\begin{aligned} \bar{N}_{y,i} &= \frac{N_{0,i}(1 - e^{-z_i})}{Z_i} \\ &= \frac{A_i d_{0,i}(1 - e^{-z_i})}{Z_i} \end{aligned}, \tag{4}$$

where $N_{0,i}$ is the initial abundance of species i when fishing begins in year y. If space-dependent species density is known (e.g., fish density may vary between fished and unfished areas), there is no need to assume that individuals of species evenly distribute within the occupied area. Density at different locations can be used to obtain more accurate abundance estimates in the equations above. Finally, the annual instantaneous fishing mortality for species i, F_i is derived from (3) and (4):

$$\begin{aligned} F_{y,i} &= \frac{C_{y,i}}{\bar{N}_{y,i}} \\ &= \frac{q_i^h q_i^\lambda (1 - S_i) \sum_t L_{t,i} W}{A_i} \end{aligned}. \tag{5}$$

This equation essentially implies that fishing mortality is the fraction of overlap between fished area and the species distribution area within the jurisdiction (Fig. 1), adjusted by catchability and post-capture mortality. This formulation is similar to that used to estimate fishing mortality for elasmobranchs by Walker (2005a). Eq. (5) assumes that there would be no local depletion effects from