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An ecological method for qualitative risk assessment and its use in the management of fisheries in New South Wales, Australia

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Abstract

Risk assessment has become a key part of management plans for wild capture fisheries. However, for data-deficient fisheries and those with limited knowledge of ecological interactions a qualitative risk assessment method is needed. This paper presents such a method. Using a risk analysis framework adapted from the Standards Australia/Standards New Zealand 4360 we used a multi-stage risk assessment process that consisted of risk context (defining the undesirable event to avoid for any component of the ecosystem), risk identification (sources of risk from the activities of a fishery) and risk characterisation (levels of risk for each species or component of the ecosystem). A qualitative risk matrix was developed to determine the risk from fishing for each component of the ecosystem. The matrix combined two independent factors (fishery impact profile and resilience) that described the factors that determined the likelihood (i.e. the risk) of an undesirable event. Specific issues arising from the risk assessment are then identified. These issues are used in the fishery management plan to generate specific responses that will lower risk levels. The strengths of this qualitative method include its adaptability to a range of different ecosystem components within a fishery (e.g. habitats and threatened species as well as target species) and its applicability to a wide range of different fisheries. The steps involved and the decision criteria used to determine risk levels are transparent and logical, thus are open to scrutiny by stakeholders.

This paper seeks to demonstrate that a logical and systematic method for qualitative risk assessment provides effective estimates of risk for input into the management plans of any fishery lacking information about one or more of its ecological components. This qualitative risk assessment method provides an important tool to fishery managers and scientists in developing robust management plans where there are minimal data about and knowledge of the fishery. The method is adaptable, repeatable and robust. Differences between our method and that of [Fletcher, W.J., Chesson, J., Fisher, M., Sainsbury, K.J., Hundloe, T., Smith, A.D.M., Whitworth, B., 2002. National ESD reporting framework for Australian Fisheries: the 'How to' guide for wild capture fisheries. Fisheries Research and Development Corporation Final Report, Project No. 2000/145, Canberra, Australia, ASBN 1877098019; Fletcher, W.J., Chesson, J., Fisher, M., Sainsbury, K.J., Hundloe, T.J., Fisher, M., 2005. A flexible and practical framework for reporting on ecologically sustainable development for wild capture fisheries. Fish. Res. 71, 175–183] are discussed.

Keywords: Qualitative risk assessment; Method assessment; Data-deficient fisheries; Australia; Management plan; Ecosystem components; Ecologically sustainable development; Ecosystem based fisheries management

1. Introduction

The management of wild capture fisheries has come under increasing scrutiny in the last decade (e.g. Caddy and Cochrane, 2001; Baum et al., 2003; Eagle and Thompson, 2003). Much of the impetus for this scrutiny has come from stock collapses of major fisheries such as cod, sardine and capelin (e.g. Hutchings and Myers, 1994; Gjoesaeter, 1995; Myers et al., 1997; Fu et al., 2001; Vasconcellos, 2003), increased awareness of uncertainty and the subsequent incorporation of the precautionary approach into management decisions (e.g. Rosenberg and Brault, 1993), the need for effective stakeholder participation and increased awareness and documentation of the effects of fishing on ecosystems (Dayton et al., 1995; Hall, 1999). This has resulted in the evaluation and reform of existing fishery management plans

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in major fishing areas around the world on the basis of the principles of ecosystem based management (EBM) (Basson and Beddington, 1993; Hilborn et al., 2001; FAO, 2003).

A key aspect of developing fishery management plans is assessing the risks of a fishery to all aspects of an ecosystem against ecological, social and economic criteria. The objective of this paper is to describe a qualitative method for an ecological risk assessment and how the results of the assessments led to the development of fishery management plans. The method is suitable for fisheries that are deficient in information about target species and/or its interaction with the ecosystem, or have few or loosely established management rules. Examples of fisheries that have some of these characteristics include new fisheries and existing fisheries with poorly developed management structures or poorly understood ecological interactions.

2. The process of developing fishery management plans in Australia

Ecologically sustainable development (ESD) and EBM principles have been embodied in international, national and State legislation (see Scandol et al., 2005 for an overview) all of which have influenced the development of fishery management plans in New South Wales (NSW). In Australia, the NSW Government introduced amendments to existing legislation in December 2000 (under the Environmental Planning and Assessment Act, 1979 and Fisheries Management Act, 1994) to ensure fisheries are managed in accordance with ESD. These laws required the development of fishery management plans for each commercial and designated non-commercial fishing activity operating in NSW providing an opportunity to develop ecologically sustainable management regimes that operationalised EBM principles (Sainsbury et al., 2000; FAO, 2003; Scandol et al., 2005). These plans specify major goals and objectives for a fishery, management responses to achieve these goals and objectives, performance indicators and trigger points, research required and how impacts were to be monitored (as set by a state government planning department guidelines).

A five step process was undertaken to develop these fishery management plans (Fig. 1). The first step reviewed the existing fishery in ecological, economic and social terms. Then, a risk assessment was completed using this collated information to identify the sources of risk, determine levels of risk to components of the ecosystem (i.e. major sections of the environment which could be affected directly or indirectly by the fishery including target species, habitats and bycatch) and identify issues that need to be addressed to reduce risk. Steps 2–4 form the content of the fishery management plan. The last step assesses the proposed management plan before it is approved in terms of its feasibility, practicality and whether the proposed management responses are, at least theoretically, effective in reducing risks (the actual effectiveness of management responses cannot be determined until after implementation). This paper will focus on the first step and the risk assessment method. Other steps will be referred to as required.

Progressive consultation occurs throughout steps 1–5 with key stakeholders (e.g. commercial fishers, conservation groups) to exchange information and promote understanding and acceptance of the changes to the fishery management regime. The assessment and draft management plan was reviewed by independent peers and other key stakeholders. The purpose of such consultation was to provide transparency to the process, in addition to promoting understanding and exchanging information (see discussion under Section 10).

3. What type of risk assessment—qualitative or quantitative?

Quantitative ecological risk assessment generally uses mathematical models to describe relationships between harvest levels and various parameters of the fish stocks and/or ecosystem. This type of risk assessment is only possible in data-rich fisheries such as the large valuable fisheries in the northern hemisphere (e.g. Hall et al., 1988; Linder et al., 1987; Hilborn et al., 1993; Rosenberg and Restrepo, 1994). Much peer reviewed literature on ecological risk assessment describes quantitative models and methods for assessing these types of fisheries (e.g. Punt and Walker, 1998; McAllister et al., 1999; Collie et al., 2000; Jiao et al., 2005).

Qualitative ecological risk assessment uses a combination of attributes of the ecosystem, target stocks and fishery.

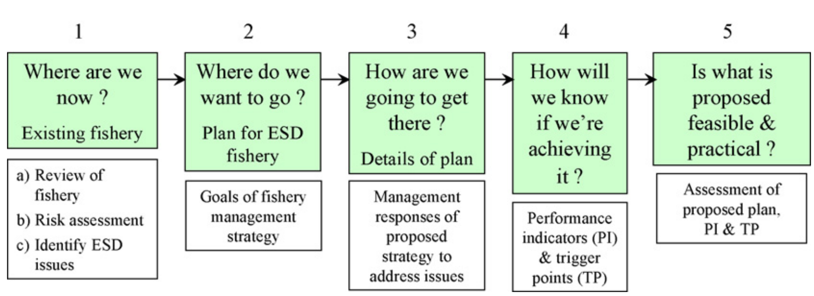

Fig. 1. Steps in the process of developing a fishery management strategy for an existing fishery.

The information is at a general level, such as relative levels of resilience and fishery impact (e.g. high, moderate or low). Qualitative risk assessment is used for data-deficient fisheries, such as in many developing countries, new fisheries, small fisheries for which costs for research may be prohibitive or fisheries with limited or infrequently collected and analysed data.

Qualitative risk analysis may initially appear less rigorous than quantitative risk assessment. The mathematical models used in quantitative risk assessment are meant to represent to some degree how we understand the ecosystem or how fish stocks behave under certain circumstances (e.g. Jorgensen, 1986). The quantification of uncertainty and outputs may make the conclusions from the latter analyses appear more reliable. However, the use of sophisticated quantitative stock modelling techniques alone does not always guarantee a sustainable fishery, as demonstrated by the catastrophic stock collapse of the data-rich northern cod fishery in Canada (Hutchings and Myers, 1994; Myers and Cardigan, 1995). This stock collapse was not prevented despite the vast amounts of resources devoted to quantitative stock assessments in this fishery (Walters and Maguire, 1996; Myers et al., 1997).

The difficulty for both quantitative and qualitative ecological risk assessment methods is that marine ecosystems to which they are applied are very complex (Cochrane, 1999; Underwood and Chapman, 2003). Marine ecosystems encompass multiple ecological, physical and other processes that interact with and are influenced by finfish, shellfish and habitats (Cury, 2004). Processes such as hydrological, geomorphological, oceanographic circulation patterns, climate change, food-webs, interactions among species, interactions of species with habitats, spawning migrations and behaviour, dispersal and recruitment, and natural variability in population abundance may affect the ecology of finfish, shellfish and their environment (Underwood and Chapman, 1995; Underwood, 2000; Brodziak and Link, 2002; Heino and Godo, 2002). Assemblages of species, habitats, ecological and other processes in the marine environment are inter-related and our specific knowledge of these inter-relationships for oceanic and coastal waters in NSW is very limited. Making accurate assessments of fishery-related impacts is, therefore, difficult for both data-rich and data-deficient fisheries (Hall, 1999; Trites, 2002). A qualitative approach to risk analysis may not necessarily be less reliable than a quantitative approach.

A qualitative risk assessment approach was chosen for the fisheries of NSW because the majority are data-deficient and/or the types of data that have been collected has changed over time. This paper demonstrates that a logical, systematic method for qualitative risk assessment can provide effective estimates of risk for input into management plans for any data-deficient fishery or where knowledge of ecological components is deficient. The method can be applied to ecological, social and economic aspects of a fishery but this paper focuses on the ecological aspects.

4. A qualitative risk analysis framework

Our qualitative risk analysis framework was a modification of the ASNZS 4360 (Standards Australia/Standards New Zealand, 2000) risk management framework. It allowed for aspects of an existing fishery to be incorporated into the new management plan. The framework includes all ecological components potentially impacted by a fishery thereby providing a broad ecosystem basis for assessing a fishery in-line with the goals of the fishery. Relative levels of risk (e.g. high, intermediate, low) could be determined using pre-defined criteria to combine qualitative information about the fishery (e.g. catch trends, area of operation, gear types) and about the components of the ecosystem impacted by the fishery (e.g. general biological information such as age at maturity of target species). Risk is the key element in the analysis method.

4.1. Perspectives on risk

In general, there are two ways risk is understood and used in the ecological and fisheries literature (Francis and Shotton, 1997):

1. Risk is an expected loss and thus incorporates both the probability (likelihood) and severity (consequence) of the undesirable event (e.g. Rosenberg and Restrepo, 1994).
2. Risk is the “probability (likelihood) of something undesirable happening” (e.g. Francis, 1992) that will cause a change in the ecosystem as a result of some behaviour or action (in this case, fishing) (Francis and Shotton, 1997; Hayes, 1998).

In the first definition risk is defined as an impact. In the context in which the definition is applied, impacts are generally consistent, well documented and occur with a known probability or are determined in a controlled environment, such as in ecotoxicology studies (e.g. Hayes, 1998; Crane et al., 2004). Each impact is considered independent of any previous occurrences of that impact. In a fisheries context impacts do not occur with known probability nor can they be evaluated independently of each other, as each fishery is unique and has its own set of impacts and consequences. Impacts from one fishery only offer a hint as to what might happen in another, similar fishery, but offer nothing for very different fisheries. Furthermore, impacts within a fishery are not independent of one another.

Fletcher et al. (2002, 2005) understood risk from this first perspective for their qualitative risk assessment. Their method was developed for the purpose of reporting on ESD for fisheries rather than environmental impact assessment, as was the case for our method. The purpose of their risk assessment therefore was to prioritise components of an ecosystem to determine how best to achieve the operational objectives of ESD for a fishery. Risk *per se* was not the primary focus of their method. Consequently, there are differences in their method of qualitative risk assessment compared to ours, which will be discussed later.

Table 1
Examples of potential undesirable events and their values for some ecological components

Ecological component	Undesirable event	Value being protected
Target species	Fishery affects their population	Stock sustainability
Threatened and protected species	Fishery inhibits their ability to recover	Recovery of threatened species
Habitats	Fishery irreversibly changes their ability to support particular ecological communities	Ecological function
Ecological processes	Fishery alters or inhibits processes ability to function to maintain particular ecological communities	Ecological function

The second definition of risk was adopted for our method because impacts are not treated as independent of the fishery. Instead a particular level of impact (an "undesirable event") is defined for each component of the marine ecosystem. An undesirable event is defined in terms of the principles of ESD, which are widely adopted in fisheries management (Garcia, 2000; FAO, 2003; Scandol et al., 2005). These principles are an expression of the values that fisheries managers are trying to protect by undertaking the risk analysis procedure (Hayes, 1998). Table 1 gives examples of undesirable events for a few components of an ecosystem and the values the risk analysis is trying to protect. Risk becomes the likelihood of a part of the ecosystem experiencing these undesirable events as a result of an activity. For example, the risks for target species is the likelihood of these stocks becoming overfished as a result of a fishing activity. This definition of risk shows that our concern is not that a fishing activity is taking place, but that it is also causing part of the ecosystem to be overexploited.

5. Stages of qualitative risk analysis

Qualitative risk analysis is an iterative process that has three main stages: risk assessment, risk management and risk communication (Fig. 2). Risk assessment is intended to provide insights about sources and levels of risk and their potential impacts. Risk management takes mitigative action against these risks and undesirable outcomes and monitors whether such action is effective. Risk communication occurs at all stages of a risk analysis between those doing the risk analysis and stakeholders. The latter both receive and provide information to all parts of the risk analysis.

6. Risk assessment

The goals of risk assessment are, first, to rank the species within each component of the ecosystem according to their level of risk relative to a specified undesirable event. Second, to identify the issues that require management action to reduce the risk. Based on these rankings and issues, specific priorities for management action can be determined.

6.1. Risk context

Risk context provides the undesirable event and the spatial and temporal extent of the event. It should be noted that these temporal and spatial boundaries are a minimum limit within which the undesirable event may occur and does not mean that a species or other component will not be at risk outside these boundaries. They merely provide a point of reference for the purposes of the risk assessment. An example of a risk context would be the likelihood of target species being overfished (the undesirable event) within the next 20 years (timeframe based on average turnover of the populations of target species) along the NSW coast out to three nautical miles (spatial extent of trawling activity under NSW jurisdiction).

6.2. Risk identification

Risk identification categorises which components of the system were at risk and why. This was done by generating a comprehensive list of the sources of risk and identify which major components of the ecosystem these sources potentially affect. Sources of risk were identified by dividing the fishing

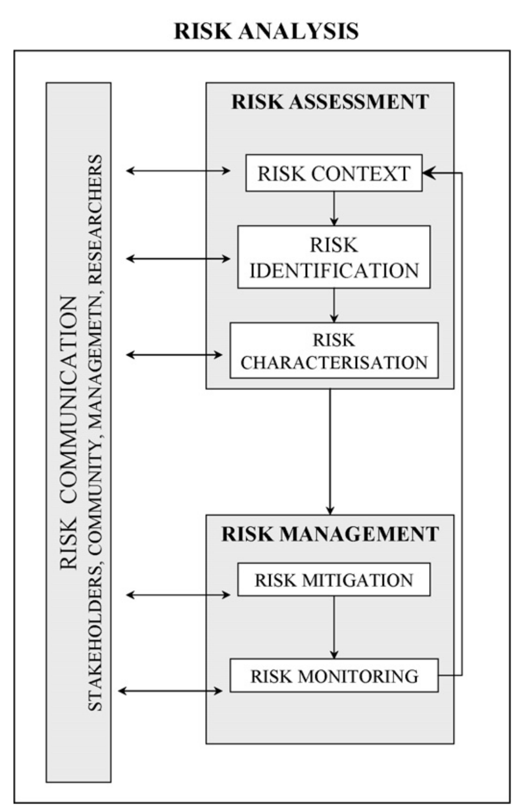

Fig. 2. Framework of the qualitative risk analysis method based on AS/NZS 4360.

operation (e.g. ocean trawling) into its individual activities (adapted from the National Oceans Office method for the south east regional marine plan). For a trawl fishery, these activities include trawling (deployment, towing and retrieval of trawl net), harvesting (capture and retaining fish for sale), discarding, loss of fishing gear, travel to and from grounds, marketing, boat maintenance, and disturbance due to presence in the area (Table 2).

The ecosystem was divided at a broad level into its component parts. Lists of components of the ecosystem and sources of risk can be determined in several ways and include: prescribed by governmental guidelines, determined by a group of experts (e.g. Fletcher et al., 2002, 2005), literature reviews, examination of historical records, and consultation to discover stakeholder opinions and perceptions. The results of this risk identification step are often presented as lists, tables or as component trees (see Fletcher et al., 2002, 2005). Broad components of the ecosystem potentially affected by a trawl fishery include target species, discard species, habitats, ecological processes and threatened and protected species (Table 2) (Fletcher et al., 2002, 2005). Broad components are further sub-divided into individual species, processes or groupings.

By explicitly linking the sources of risk (i.e. activities of the fishery) to the broad components of the ecosystem it is possible to also identify where sources could have a direct and/or indirect affect on the various components For example, the physical activity of trawling could have a direct affect on marine habitats by damaging or removing them but an indirect affect (depending on the scale) on ecological processes and target species due to the potential flow on effects from habitat loss or damage (Table 2).

6.3. Risk characterisation

The aim of risk characterisation is to estimate the likelihood that the various sources of risk (identified in the previous step) will cause the undesirable event that has been defined in the risk context. Various activities within a fishery may pose different levels of risk (from negligible to very high) to different parts of the environment.

Risk characterisation is a multi-stage process that assesses the risk for progressively smaller components of the ecosystem. It begins with the broad components of the ecosystem and identifies which components are at negligible risk from the activities of a fishery and those above this threshold (Table 2). Risk levels are assigned based on general knowledge about the effects on these components by the type of fishery being assessed (e.g. trawl fishery operating in the coastal waters of NSW in the case of Table 2) from scientific literature such as the general effects of overfishing (e.g. Jennings and Kaiser, 1998; Murawski, 2000). Components with negligible risk are eliminated from subsequent assessments, and a justification is documented for their elimination.

In the second stage, each of the broad components (e.g. target species, bycatch species and marine habitats) are assessed

Table 2
Broad components of the ecosystem and their relative levels of risk

Ecological component	Main activities of the fishery										
	Trawling (physical damage)		Harvesting (what is kept)		Discarding (what is returned to sea)		Contact but not capture	Loss of fishing gear	Travel to/from grounds	Disturbance due to presence in the area	Boat maintenance and emissions
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Direct	Direct	Direct	Direct
Target species		H	H		H		I	L			
Byproduct species		H	H		H		I	L			
Bycatch species		H			H		I	L			
Threatened and protected species											
Reptiles	I	I						–	L	L	
Mammals and birds							L	–	I	I	
Fish		H			H		I	L	L	L	
Species assemblages and diversity, ecological processes		H	H	H		H	L				L
Marine habitats	H						I	L			L

H = high risk; I = intermediate risk; L = low risk.

Table 3
Factors contributing to the sustainability of target species

Factors needed to maintain ecologically sustainable populations of target species	Activities of the ocean trawl fishery				
	Harvested catch	Discarded catch	Contact but not captured	Gear loss	Boat maintenance and emissions
Food availability and feeding sites	I	I	L	L	
Species interactions	H	H	L	L	
Sustainable levels of exploitable mature biomass and spawning biomass	H	H	I	L	
Spawning sites and spawning aggregations	I	I	L	L	
Dispersal of propagules/larvae					L
Recruitment	H	H	L	L	
Growth	H	H	L	L	
Distribution and movement	I	I	L	L	

Highlighted row indicates factor that contributes most to the sustainability of target species. H = high risk; I = intermediate risk; L = low risk.

in detail. The factors needed to maintain the ecological sustainability of each ecological component are determined based on available ecological knowledge. Taking target species as an example (Table 3), the factors that contribute to the sustainability of this component include sufficient spawning biomass, food availability, dispersal of larvae, recruitment and growth (Table 3). Then the level of risk to these factors from the activities of the fishery is determined based on general ecological knowledge of the fishery from the scientific literature. Activities of the fishery that pose a high risk to some of these factors are harvested catch and discarding (Table 3).

In the third stage of risk characterisation, the factor that directly contributes to maintaining a component's ecological sustainability is chosen (e.g. for target species this would be the exploitable spawning biomass) (Table 3). The level of risk for this factor is determined using a qualitative risk matrix (Harding, 1998) (Fig. 3). Depending upon the component being assessed, this last stage is repeated for the other factors contributing to maintaining a component's ecological sustainability, or they may be assessed under other components.

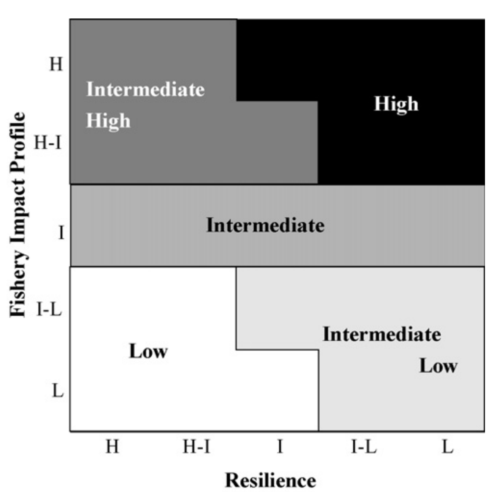

Fig. 3. Risk matrix used to determine levels of risk for components of the ecosystem (e.g. target species, habitats) by combining resilience and fishery impact profile for each entity. H: high, H–I: high to intermediate, I: intermediate, I–L: intermediate to low, L: low.

For example, spawning sites could be assessed under the habitats component and species interaction assessed under ecological processes component.

7. Development of a qualitative risk matrix

Qualitative risk matrices provide a pictorial way of determining levels of risk for each part of an ecosystem (Harding, 1998). A risk matrix is composed of two axes, which describe the overriding factors that would determine the likelihood of each species experiencing a pre-defined undesirable event. The most critical aspect of developing a qualitative risk matrix is choosing appropriate factors for the vertical and horizontal axes. In their study on the sustainability of bycatch species for a tropical prawn trawl fishery of northern Australia, Stobutzki et al. (2001) based their axes on two factors—recovery and susceptability. The horizontal axis was the recovery axis and it considered criteria that influenced the capacity of a species to recover after a population had been depleted. The vertical axis was the susceptibility axis and it considered criteria that influenced the susceptibility of a species to capture and mortality. Using the principles of Stobutzki et al. (2001) we adapted these factors for our qualitative method to reflect both the biological characteristics of ecological components and the fishing activities that may influence the ability of a component to resist an undesirable event.

The two factors chosen therefore to determine risk were resilience (horizontal axis) and the fishery impact profile (vertical axis). These factors were designed to be independent of one another which is important not only to determine initial levels of risk but also to detect changes in risk levels if management action results in changes to the vertical axis.

7.1. Resilience

Resilience describes the capacity of a species to recover from a disturbance. The more quantitative definition of resilience in the ecological literature – a measure of the response a population or an assemblage of species has to a disturbance of a known magnitude (Underwood, 1989) – could not be used in our qualitative risk assessment. In data-deficient environments it is unlikely that the magnitude of the disturbance on a component of the ecosystem can be determined. Substantial knowledge gaps in NSW fisheries and other fisheries worldwide, such as discard rates, relative abundance of fish stocks and fishing effort, prevent the magnitude of fishing activities from being accurately quantified. Instead resilience was based on biological characteristics known to affect fish species recovery from a disturbance. The biological characteristics for target species, for example, included fecundity, life history strategy, habitat specificity, stock/population size, growth rate, longevity, age at maturity, geographic distribution and diet specificity. These characteristics themselves are not resilient but together contribute to a population's ability or lack of ability to recover from a disturbance. Care needs to be taken in compiling a list of biological characteristics, as some will be highly correlated, such as growth rate and age at maturity (see Hobday et al., 2004 for methods to address correlations between factors). However, not all species or other components will have information available for each characteristic and so combinations of characteristics need to be chosen judiciously.

7.2. Fishery impact profile

The fishery impact profile describes the pressure exerted on a component by a fishing activity. Various factors that make up the operation of a fishery are chosen, which collectively indicate the level of fishery impact being exerted. The combination of factors will vary depending on the component being assessed. For example, for target species fishery factors might include catch levels and trends over a specified period, discard rates, exploitation status, gear selectivity, proportion of catch taken by the particular fishery being assessed and adequacy of stock assessments. In contrast, non-commercial bycatch species might only need to include a few fishery factors such as survival after capture and overlap of distribution of a species with depth of fishing. Information for these factors is collated from scientific literature, fishery status reports and other relevant literature.

7.3. Determining the qualitative level of risk

A set of criteria was used to determine whether the characteristics or factors for each of the resilience and fishery impact profile axes made them risk prone or risk averse. A risk prone factor is likely to make a species or other entity less resilient or have a higher fishery impact profile, whilst a risk averse factor would make them more resilient or have a lower fishery impact profile. For each species the number of risk prone factors is summed and then allocated a level of resilience or fishery impact profile of high, intermediate-high, intermediate, intermediate-low or low according to the number of prone factors. Table 4 provides an example of this for two contrasting finfish species—*Sillago flindersi* and *Aptychotrema rostrata*.

The resilience or fishery impact profile level for a species or other entity are determined by the number of risk prone characteristics or factors. Finally, the level of risk is determined by following the "coordinates" of the two axes, i.e. vertical axis fishery impact profile and horizontal axis resilience of the risk matrix (Fig. 3) they have (Table 5).

7.4. Explanation of risk levels

The 2 axes formed a 5 by 5 matrix (25 squares), which was divided into 5 equal levels of risk (Fig. 3). Two things determined the arrangement of the five risk levels on the matrix. First, the complexity of marine ecosystems means that the relationship between resilience and the fishery impact profile is likely to be non-linear. In the absence of specific information on how the fishery impact profile interacts with resilience, the simplest approach of allocating an equal number of squares to each level of risk (five each) was adopted. Second, only the fishery impact profile (vertical axis) can be changed by the implementation of effective management action. The resilience axis (horizontal axis) cannot be changed by management intervention because it is determined by the biology and ecology of the species. Therefore, the risk levels were arranged in the matrix so that, if there were sufficient change in the fishery impact profile, risk could increase or decrease.

High levels of risk correspond to components with lowest resilience and largest level of fishery impact. Management measures should give first priority to those entities or components with the highest levels of risk. They require direct and immediate action to decrease the level of the fishery impact exerted on them to reduce their risk of becoming ecologically unsustainable. Components with low risk levels need only to be monitored to check that their risk levels do not increase due changes in the management regime. Intermediate high levels of risk corresponded to components that have larger levels of the fishery impact profile but higher resilience. The focus of management action for components at this level should be to decrease their fishery impact but because their resilience is higher than those components at highest risk they would be second in priority. Intermediate low levels of risk correspond to components that have smaller levels of fishery impact but lower resilience. The lower resilience of these components means that potentially any increase in the fishery impact profile could put these components at a higher level of risk. Therefore, management measures should be focused on ensuring the fishery impact profile does not increase on these components. Intermediate levels of risk correspond to components with an intermediate level of fishery impact and resilience levels from high to low. Management measures for these components should focus on reducing their fishery impact profile starting with those species with lowest levels of resilience.

Table 4
Example of how the levels of: (i) resilience and (ii) fishery impact profile were determined for two target species in a trawl fishery using risk prone and risk averse factors

Category	Biological characteristics	Target species	
		Sillago flindersi	*Aptychotrema rostrata*
(i) Determination of resilience			
Life history	Fecundity	A	A
	Life history strategy	A	PP
Distribution and abundance	Geographic distribution	A	P
	Habitat specificity	A	A
	Stock/population size	U	U
Other	Growth rate[a]	A	P
	Longevity	A	P
	Age at maturity[a]	A	NA
	Diet specificity	A	A
Number of risk prone characters		0	5

Category	Fishery impact factor	Target species	
		Sillago flindersi	*Aptychotrema rostrata*
(ii) Determination of fishery impact profile			
What is caught	Species identification problem	A	P
	Marketability	P	A
Where fished	Refuge availability	A	P
How is it fished	Fishery targets aggregations	P	A
	Gear selectivity	P	P
	BRD used to remove juveniles of the species	A	NA
How much caught	Catch level and trends	A	PP
	CPUE trends	A	U
	Discard rate/% discarded[b]		
	Stock assessment adequacy	P	P
	NSW exploitation status[b]	U	U
How many fishers	Proportion fishery taking total catch	P	P
Number of risk prone factors		5	7

A: averse, P: prone, PP: double prone, U: unknown. NA: not applicable.
[a] Correlated characteristics.
[b] Insufficient information to use.

It is important to note that the arrangement of the levels of risk within the matrix is arbitrary for qualitative risk assessment. Given prior knowledge, the arrangement could be modified to suit different situations or fisheries. Regardless of the arrangement chosen, the risk levels must decrease as the fishery impact profile becomes less, because this is the only axis that can be changed to reduce risk.

8. Identification of issues arising from the risk assessment

The outcome of risk characterisation is the identification of specific issues arising from the risk assessment. These issues point to the reasons why species of the ecosystem are at risk and are derived from the collated and categorised information of the biological and fishery factors used to determine the levels of risk. For example, the combination of a species reproductive strategy, habitat specificity, fishing method and area of operation of a fishery may put a bycatch species at high risk (e.g. some species of elasmobranch in trawl fisheries, see NSW Fisheries, 2004). The issue arising for management therefore is to decrease the level of interaction between this species and the operation of the fishery by, for example, providing appropriate refuge areas.

Issues arising from a risk assessment of target species may include inappropriate gear selectivity, lack of adequate stock assessments and lack of information on discard rates of undersized species. All of the relevant issues can be clearly identified because the decision-making process used to determine risk levels has been made explicit and the relevant information (and lack thereof) has been documented. Furthermore, because the issues are directly related to the levels of risk of a species or other entity any management action proposed to address the issues can be evaluated in terms of how it contributes to reducing risk. The relationship between risk, issues arising and management action is essential for developing an effective fishery management plan.

Table 5
Example of two target species showing their resilience and fishery impact profile levels and how these determine their level of risk from the risk matrix to becoming unsustainable

Number of risk prone characters	Resilience level	Target species resilience
(i) Resilience level		
0	High	*Sillago flindersi*
1	High–Intermediate	
2	Intermediate	
3	Intermediate–low	
4 or more	Low	*Aptychotrema rostrata*

Number of risk prone factors	Fishery impact profile level	Target species fishery impact profile
(ii) Fishery impact profile level		
<4	Low	
4 and 0 PP	Intermediate–low	
5 or 4 + 2 PP	Intermediate	*Sillago flindersi*
6	High–intermediate	
>6	High	*Aptychotrema rostrata*

Target species	Resilience level	Fishery impact profile level	Risk level
(iii) Risk levels determined from the risk matrix (Fig. 3) using the resilience and fishery impact profile level information from (i) and (ii)			
Sillago flindersi	High	Intermediate	Intermediate
Aptychotrema rostrata	Low	High	High

9. Risk management—development of fishery management plans

Risk management is the second major stage in the risk analysis process. The goal of risk management is to address the high risk issues raised in the risk assessment and to ensure there is not an increase in risk to other components of the fishery. Risk management contains two parts: (a) risk mitigation and (b) risk monitoring (see Fig. 2).

9.1. Risk mitigation

The aim of risk mitigation is to minimise the risk of an undesirable event, defined in the risk context. This is done by evaluation and implementation of regulatory and/or voluntary (e.g. code of conduct) management responses. A fishery management plan sets goals and objectives for the fishery and provides a detailed overview of the proposed management initiatives that are designed to address issues raised by the risk assessment stage and mitigate the higher risks to all components of the ecosystem. This covers steps 2–4 of the process in developing a fishery management strategy (Fig. 1).

It should be noted that fishery management plans encompass more than reducing risks identified by the risk assessment process. They also set out the regulations that are to govern a whole fishery including specifying gear types, boat and engine sizes, area of operations, penalties for breaches and licensing procedures and costs.

9.2. Risk monitoring

Risk monitoring is the second part of risk management. The aim of risk monitoring is to collect information to determine whether the initiatives implemented in the strategy effectively minimised the risk of the undesirable event. Risk monitoring is useful for: (a) validating management actions when they have been effective and (b) highlighting areas that need further management response when previous initiatives have been shown to be ineffective. Risk monitoring should be regarded as a practical appraisal of management initiatives and an opportunity to modify management plans in a timely manner.

10. Risk communication

The purpose of risk communication between scientists, managers, stakeholders and the public is to provide information and feedback for decision-making and better understanding (Peterman, 2004; Garcia, 2005). It is a two-way process between government regulators responsible for the fishery and key stakeholders. Careful attention needs to be paid as to how information and feedback is given, interpreted and incorporated into a fishery management plan (Harding, 1998; Standards Australia/Standards New Zealand, 2000). Table 6 describes areas of communication that need to be planned.

Despite its importance, risk communication has not been given adequate attention in fisheries environmental impact assessment (Peterman, 2004). Often little attention is given to how information is communicated especially by scientists and managers when directed towards stakeholders. Improved communication would result from consideration of how the target audience perceives the natural world, risk and their level of tolerance to risk (Adams, 1995). Furthermore, technical terms need to be defined and government departments need to avoid the use of “weasel words” (Watson, 2004) so as to promote better understanding and restore trust between them and the people upon whom their decisions impact. Fish-

Table 6
Areas of communication that need to be planned for effective risk communication

Area of communication	What it determines
Who is doing the communicating	Credibility of communication
To whom it is directed	Purpose of communication
What is to be communicated	Relevance of the content to whom it is directed
How it is to be communicated	Extent the content will be received and integrated
Reception of communication	How information and feedback is incorporated into decision making processes or increases understanding of stakeholders

eries scientists and managers would do well to learn from other fields (e.g. Gigerenzner and Hoffrage, 1995; Anderson, 1998) to improve their communication strategies.

11. Accounting for uncertainty in qualitative risk analysis

Assigned levels of risk may be incorrect because of the uncertainty about exactly how a fishery might impact components of the ecosystem. This uncertainty is due to the lack of understanding of the nature of a fishery and the ecosystem in which it operates (also known as structural uncertainty, *sensu* Charles, 1998). Data-deficient fisheries usually have a high degree of this type of uncertainty, which can lead to errors in assigning risk levels (Peterman, 1990; Scandol, 2003). The decision to assign a level of risk carries with it the possibility that the assigned risk could be either higher or lower than the actual risk. These types of errors have different consequences. Assigning a higher level of risk than the actual (equivalent to a type I error) may cause management to commit resources for mitigative measures that are unnecessary. However, the error of assigning a lower level of risk than the actual (equivalent to a type II error) could result in inadequate management action, leading to major damage to that component of the fishery, threatening sustainability and requiring long-term remediation. The consequences of the latter type of error are more costly than the former (Fairweather, 1991; Peterman and M'Gonigle, 1992; Mapstone, 1995; Underwood and Chapman, 2003).

To reduce the likelihood of assigning lower levels of risk than is actually the case, the decision rules used to determine the resilience and fishery impact profile for each species were made more sensitive to risk-prone characteristics than risk-averse ones (Table 7). Increasing the sensitivity to risk-prone characteristics would give the species a lower level of resilience and/or a higher fishery impact profile, resulting in a higher level of risk. In addition, where stock assessment information and exploitation status was inadequate or unknown a risk prone score was given. Sensitivity to risk prone characters leads to precautionary management responses that allow for the possible of recovery of a species should the actual risk levels be larger.

12. How the qualitative risk assessment method contributes to the development of fishery management plans

There are four ways the qualitative risk assessment contributes to the development of fishery management plans. First, the issues a management plan needs to address are clearly identified for each component or species of the ecosystem. This occurs by the link between level of risk for a component and the issues arising from the risk assessment. For example, if a species of fish is at high risk because of

Table 7
Example of decision rules used to distinguish between risk prone and risk averse: (i) biological characteristics and (ii) fishery factors to determine levels of resilience and fishery impact profile respectively for target species

Category	Character	Risk averse	Risk prone	
		A	P	PP
(i) Biological characteristics—for resilience level				
Life history	Fecundity	100–500000 to 1–3 million eggs	Large eggs (≥2 mm) and/or <50,000	<10 pups (live bearers)
	Life history strategy	Pelagic eggs; internal fertilisation or mouth brooders	Egg cases and/or parental care; demersal eggs	Live bearing
Distribution and abundance	Geographic distribution	Widespread in NSW and adjacent jurisdictions common	Restricted range	
	Habitat specificity	Broad habitat requirements; narrow habitat requirements but large area of available habitat	Narrow habitat requirements but small area of available habitat	

Factor	Measure of factor	Averse	Prone
(ii) Fishery factors—for fishery impact profile level			
How is it fished	Fishery targets aggregations	No	Yes
	Gear selectivity	Select predominately adult fish	Selects a large proportion of juvenile fish
	BRD used to remove juveniles of species	Effective in excluding undersized fish	Ineffective in excluding undersized fish
How much is caught	Catch level and trends	Stable for 5 year or greater	Decline for 5 years or more or highly variable

Categories are a subset of the actual list used. A: averse, P: prone, PP: double prone, NA: not applicable, BRD: bycatch reduction device.

recruitment overfishing qualitative risk assessment may find that it is due to inappropriate gear selectivity of the nets used by fishers. Therefore, the issue management needs to address in this case is gear selectivity.

Second, the link between risk levels and issues makes monitoring the effectiveness of a fishery management plan more straightforward. As noted earlier, the fishery impact profile is the only axis of the risk matrix that can change as a result of management action. Therefore, changes to any of the factors that make up this axis (e.g. improved gear selectivity, decreased discard rates) will be reflected in the matrix by increasing, decreasing or leaving unchanged the levels of risk. As a result, managers are better informed about how their changes to the management regime of a fishery affect levels of risk. Thus the method provides a consistent way of reassessing the levels of risk once changes in management have occurred and time has been allowed for them to take effect.

Third, it identifies which activities of a fishery are putting the components of the ecosystem at risk. This gives direction to the management plan as to which activities require change. For example, in a trawl fishery the activities of harvesting, discarding and trawling pose the highest risk to the majority of the components of the ecosystem, but boat maintenance and bait harvest pose the least. In a trap and line fishery, activities such as incidental catches and fishing for bait may pose the greater risk for some species.

Fourth, the qualitative risk assessment reveals significant knowledge gaps in our understanding of the fishery and its interaction with the ecosystem. By documenting the information we have for each component and/or species in a systematic manner and dividing it into appropriate categories (e.g. fishery and biological factors), the risk assessment can identify which research areas are the most important to help reduce uncertainty in the risk analysis. The consequences of not filling these knowledge gaps for achieving the objectives can then be made clear. This gives research and management clearer guidance about the allocation of resources to research.

13. Comparison with Fletcher et al. (2002, 2005) qualitative method

Fletcher et al. (2002, 2005) (hereafter referred to as Fletcher) have also developed a qualitative risk assessment method for the purpose of reporting on ESD objectives for wild capture fisheries. Their method has been used across a number of diverse fisheries in Australia to meet federal legislative requirements for export licenses of their major fisheries (Fletcher, 2005). Our method was designed to meet these same federal legislative requirements but it was also developed to meet NSW legislation concerning the environmental impact of fishing activities in NSW. Fletcher et al. (2002, 2005) and our methods have some aspects in common but also some important differences.

A major difference between Fletcher's qualitative risk assessment method and that presented here is in the definition of risk used and the way risk levels are determined. In Fletcher risk is the chance of something bad happening that will have an impact (Table 8). The impact is the consequence that is to be avoided. There can be a number of levels of consequence for a component. The level of consequence for each impact must be determined, then the likelihood of that consequence occurring is assessed. The level of risk is calculated by multiplying these two aspects together (i.e. consequence × likelihood) (Table 8). Thus, in Fletcher's calculation of risk, consequence occurs both as the impact to be mitigated and as part of the means to determine the level of risk. As a result the independence of risk from the impact may be compromised.

Table 8
Comparison between two qualitative methods of risk assessment of Fletcher et al. (2002, 2005) and the model presented in this paper

Area of comparison	Investigators	
	Fletcher et al. (2002, 2005)	Our model
Definition of risk	The chance of something bad happening that will have some impact on ESD objectives	The likelihood of a pre-defined undesirable event occurring as a result of a fishing activity
Risk "calculation"	Risk = consequence × likelihood	Risk = risk matrix using resilience vs. fishery impact profile as horizontal & vertical axes respectively
Event	Impact = consequence (used interchangeably in Fletcher et al., 2002).	Pre-defined based on goals of plan
Consequence	The severity of the impact	Stated severity of event that has already been incorporated into definition of risk and therefore not used in calculation of risk
How level of consequence determined	Collective judgement of experts in a workshop setting, based on the biological characteristics of a component; Uncertainty implicit	Pre-determined based on goals of plan
Likelihood	The likelihood of the consequence occurring	Probability of the undesirable event occurring
How level of likelihood determined	Collective judgement of experts in a workshop setting, based on available information on the factors of the operation of the fishery; Uncertainty implicit	Summation of risk prone biological characters & risk prone fishery factors using pre-defined decision rules to produce levels of resilience and fishery impact profile; uncertainty incorporated into decision rule explicitly

In our method the consequence is included in the definition of risk of a component being assessed (e.g. target species) (Table 8). Further, risk is only focused on one consequence at a time (e.g. collapse of a target species stock as a result of recruitment overfishing) and the probability of that one consequence occurring. The decision of whether the consequence is severe, major, moderate or negligible is determined by the objectives of ESD. For example, the consequence of a stock collapse would be severe based on the objective of maintaining sustainable levels of fishing mortality. Once the consequence has been stated, all that remains is to determine the likelihood of it occurring (Table 8).

Second, Fletcher uses tables to describe different levels of consequence and likelihood, which are adapted for specific components of a fishery. Investigators rely on the consensus of expert opinion to use these tables. This may result in a lack of consistency in applying the information to assess risk for different species. Our method sets out what information is needed and the decision criteria to determine resilience and fishery impact profile (Table 8).

The third important difference is that in Fletcher, factors relating to the operation of a fishery and the biological characteristics of a component to justify the risk level are intermingled. Those aspects that management can influence in a fishery are not made explicitly distinct from those aspects that it cannot influence (i.e. biological characters). Such a lack of distinction makes it more difficult to identify what is required to lower risk. In our method the factors in the fishery impact profile direct management to what needs to be done to lower risk.

14. Conclusion

The qualitative risk assessment method presented in this paper has four main strengths. First, it can be used in a wide range of fisheries, particularly those with little or sporadic data available. The method can also be used for fisheries with good historical data for target species, but no or little information for discards, habitats and ecological processes. Furthermore, adaptation of the risk matrix for different fisheries can be completed relatively easily provided the principles undergirding it are maintained. These principles are that risk is defined as the likelihood of an undesirable event occurring, the two variables used for the risk matrix are independent of each other (in our case fishery impact profile and resilience) and maintaining a clear link between levels of risk and what management can actually change to reduce these risks.

Second, the decision-making process is clearly documented throughout the qualitative risk assessment. The documentation includes: (i) definition of the risk being assessed for each component, (ii) sources of risk from the operation of the fishery, (iii) components from the ecosystem being assessed, (iv) information used to determine levels of resilience and fishery impact profile and hence risk, (v) the decision rules to determine risk prone and risk averse characteristics of each axes of the risk matrix, and (vi) where precaution has been applied to account for uncertainty. Such documentation gives transparency at all stages so that the information used and the basis for decisions can be scrutinised by stakeholders and peer reviewers. Such transparency is a key characteristic of the ESD of fisheries worldwide (Cochrane, 2000; Mikalsen and Jentoft, 2001). Along with other means of transparency within the management process (e.g. stakeholder consultation) the risk assessment process used here facilitates the exchange of information and understanding between parties, which in turn can lead to more cooperative action to address difficult issues within a fishery (Jentoft and McCay, 1995).

Third, systematic use and documentation of a large volume of information and decision rules in interpreting the information minimises the need to rely on collective expert judgement as other qualitative risk assessments do in various forms (Ward et al., 2002; FAO, 2003; Fletcher et al., 2002, 2005). Expert panels can suffer from a lack of transparency, objectivity and repeatability. Unless specific steps are taken to support expert panel approaches, as environmental assessments in other fields have done, the judgements of these panels are always open to dispute from other experts and stakeholders (Yamada et al., 2003; Young et al., 2004). Our qualitative risk assessment method does not rely heavily on the decisions of collective expert judgements.

Fourth, it is a method that is known to work in practice. It was developed in the process of doing an actual risk assessment on multi-species commercial fisheries in NSW (NSW Fisheries, 2004). The outcome of the whole risk analysis process was published in publicly exhibited environment impact statements and has been peer reviewed by scientists and commented on through Ministerial advisory bodies. The logic and structure of our qualitative risk assessment method remained intact at the end of this review process.

The strengths discussed above make our qualitative risk assessment method adaptable, repeatable, robust and interpretable for fisheries that are similarly data and knowledge deficient in one or more areas. For Australian fisheries such methods are greatly needed in developing mandatory management plans for ecologically sustainable harvesting. Practical examples of the method will be published in a subsequent paper.

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