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Ecological risk assessment for effects of fishing on habitats and communities

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Cover illustration: 'Examples of fishing risks to communities and habitats in the SESSF: infaunal community remains active following trawling on muddy sediments; large, slow-growing coral removed by line fishing on canyon hard bottom.

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2009/029	Ecological risk assessment for effects of fishing on habitats and communities

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OBJECTIVES:

1. Complete the development of the ERAEF Level communities (ecosystems) approach
2. Provide a framework for the ERA to ERM for the ERAEF Level 2 Habitat assessment approach

OUTCOMES ACHIEVED TO DATE

Ecosystem-based fisheries management (EBFM) requires going beyond direct species impacts resulting from fishing: impacts on habitats and ecological communities must be understood and managed to enhance overall ecosystem sustainability. Commonwealth fisheries managed by the Australian Fisheries Management Authority (AFMA) are currently assessed for ecological risk using the Ecological Risk Assessment for the Effects of Fishing (ERAEF), a set of hierarchical tools that continue to develop in order to meet the EBFM mandate.

In meeting its two objectives, this project first provides a tool with which Australian fisheries can establish the relative risk of fishing activities on the ecological communities falling within each fishing jurisdiction, consistent with ecosystem-based management needs. These methods can now be applied to a range of fisheries, using project spreadsheets, databases and the 'how-to-guide' provided.

As well as facilitating risk assessments, AFMA is also responsible for using the subsequent results to guide management action. A process for developing species risk management responses, so called Ecological Risk Management (ERM), has been previously established, but results from habitat risk assessments were not yet included in ERM planning; thus the second objective of the project was to provide methods by which habitats assessed at high risk can be managed by AFMA and its fisheries. The transparent pathways for operationalising habitat risk results described in this project offer a range of options for the management of high risk habitats. Overall, this project will assist AFMA to progress management of ecological risk in fisheries, as required under a range of management plans.

The advances made will continue to position Australian fisheries at the forefront of EBFM, and as the ERAEF tools are also being used around the world, particularly in eco-certification, our fisheries will be well placed with regard to a demonstrated ability to meet international best practice guidelines for sustainable fisheries.

It is now widely recognized that fisheries can have impacts on marine species, habitats and ecosystems beyond the direct impacts of fishing on target species. For example, hundreds of species are regularly caught and discarded in many trawl and longline fisheries and in particular, interactions with threatened species are a concern in many fisheries. Impacts on habitats and ecological communities as a result of fishing activities have also been documented. To address these broader impacts of fishing, ecosystem-based fisheries management (EBFM) has emerged as a complementary approach to single-species management. Development of practical methods to implement EBFM has generally lagged the policy mandates, and so development of scientific and management tools to support practical implementation has been critical.

Moves towards EBFM have also evolved in Australian fisheries during the past decade, driven by a number of policy directions and initiatives. These include: (i) a national approach to ecologically sustainable development; (ii) development of fisheries legislation that incorporates explicit reference to wider ecological impacts of fishing (e.g. the Fisheries Management Act 1991); (iii) new environmental legislation that assesses fisheries against environmental standards (e.g. the Environmental Protection and Biodiversity Conservation Act 1999); and (iv) Australia's Oceans Policy, which also adopts an explicit ecosystem-based approach to management.

A key challenge in developing the scientific tools to support EBFM has been limited data and understanding about the broader ecological impacts of fishing in particular fisheries. One response has been the adoption of risk-based assessment methods, notably ecological risk assessment (ERA). A number of ERA approaches exist, and Australia is recognized as the leading country with respect to development of ERA methods and application to fisheries. One example, developed by CSIRO, is the risk-based Ecological Risk Assessment for the Effects of Fishing (ERAEF), which has been used by the Australian Fisheries Management Authority (AFMA). The risk-based ERAEF approach to assessing impacts from fishing underpins strategic assessment for AFMA-managed fisheries. The Ecological Risk Management (ERM) process developed by AFMA integrates the ERAEF results by accounting for existing management actions and other information not included in the ERAEF method. The ERM step is the link between the scientific output and the management uptake of results.

The ERAEF methodology uses a hierarchical set of tools to estimate ecological risk from fishing activities. Level 1 in the hierarchy (qualitative assessment) has been applied to all Commonwealth fisheries across five ecosystem components (target species, bycatch and byproduct species, TEP species, habitats, and ecological communities). The semi-quantitative Level 2 species and habitat assessment tools (PSA) have already been developed and applied to a number of fisheries; however, methods for Level 2 assessment of ecological communities had not yet been completed or tested. There is also a need to develop an ERA to ERM framework for high risk habitats identified from the existing analyses (as for species), and demonstrate it using worked examples.

This project builds on the first Ecological Risk Assessment for the Effects of Fishing (ERAEF) project (FRDC 2003/021). The two objectives were to (i) complete the development of, and test, the ERAEF Level 2 community assessment, and (ii) provide a framework for the ERA to ERM process for the ERAEF Level 2 habitat assessment results.

The Level 2 community assessment is based on the Productivity Susceptibility Analysis (PSA) approach, as for species and habitats. Evaluation of fishing risk to ecological communities is much less advanced compared to species, and even habitats. There is little agreement in the literature on suitable metrics or reference points for evaluating ecosystem health, and even less theory or information for assessing impacts of fishing. This project represents a substantial advance in this area. Here, each community within the fishery jurisdiction was defined on the basis of a foodweb that links species occurring in the community. A generic foodweb was developed that can be modified to fit any community. A set of attributes that represent the productivity and susceptibility of an ecological community were determined, and a scoring system for these attributes devised. The methods were then tested on the Southern and Eastern Scalefish and Shark Fishery (SESSF) otter trawl fishery. A set of 27 benthic communities were identified, and each one scored using the five productivity attributes and seven susceptibility attributes for potential risk as a result of SESSF otter trawl fishing activity. A total of six communities were identified as potential high risk, including two off Western Tasmania, and one off south-east Victoria. Overall, the results for the SESSF case study showed that the communities that might be intuitively considered to be at higher risk due to known fishing patterns, such as the South Eastern 110-250m (general concentration of effort) and the Western Tasmanian Transition 250-565m (targeting of certain species such as spotted trevalla (warehou)), were also ranked as high risk in the community PSA. Targeting of blue grenadier and orange roughy (and high reported catches) in the deeper Tasmanian communities resulted in only medium risk to the communities in this assessment. Communities where fishery effort was relatively low were generally ranked as low to medium risk. These results can now be used to guide risk management responses for the SESSF. Application of the Level 2 community methods to a number of other fisheries, as has occurred for species and habitats, should now be possible, allowing risk to ecological communities to be considered as part of EBFM. We suggest that development or application of Level 3 community assessments should not be pursued at this time; instead ERA to ERM community risk management options should be completed, as for habitats in this project.

The second part of the project details a robust and transparent process to assess, analyse and respond to the risks posed by fisheries to habitats – the so-called ERA to ERM process for habitats. The steps to complete the ERA to ERM process for habitats are detailed, and include evaluation of the residual risk not included in the primary assessment. The management options to respond to the identified high risks to habitats are outlined, and include area closures, gear restrictions or modifications, move-on rules, and bycatch limits for attached fauna. The action list provided for management to advance the ERM process will be particularly useful. As part of the review of the existing Level 2 habitat results for Australian fisheries, a number of improvements to the Level 2 habitat assessment methods are also proposed, including, identification of habitats from photographic imagery, improvements to the set of productivity and susceptibility attributes used to score potential risk to habitats and assessing risk at an appropriate spatial scale. The next steps for achieving the habitat ERA to ERM include establishing an expert Technical Support Group and formalising a reporting structure. Reporting should describe the appropriate management arrangements developed to address the high priority habitats remaining after the risk assessment phase (including evaluation of residual risk) is completed. As for species, the ERM framework will need to link with current fishery management processes and structures so that additional measures to address high risks can be easily implemented.

The outputs from each ERAEF level for species, habitats and communities currently apply to individual fisheries, but in future there is scope for developing cumulative risk assessment and analysis that will integrate across sub-fisheries, fisheries, components, and other threatening processes. Cumulative assessment will be particularly cost-effective at Level 3 in the ERAEF hierarchy, and ecosystem models offer one solution to the challenge.

AFMA will be a direct beneficiary of this research, as it can now complete adoption of ERAEF results and meet national and international obligations associated with fisheries management, leading to clear benefits in allowing fisheries to meet EPBC criteria and pass strategic assessment. Indirect benefits also accrue for fisheries, via clear processes for risk identification and management, which makes business operation more certain. Eco-certification prospects are also enhanced, for example, the Marine Stewardship Council has included ERAEF elements in its assessment process.

The ERAEF approach allows fisheries to demonstrate knowledge of risks to sustainability, while the Ecological Risk Management approach focuses management actions. Together these elements will assist Australian fisheries to be recognized domestically and internationally for meeting the EBFM mandate and providing sustainable seafood.

KEYWORDS
ERAEF, ecosystem impacts, effects of fishing, fisheries management, EBFM.

2 Acknowledgments

Discussion with AFMA staff during this project assisted the development of the Habitat ERA to ERM component. Review of the methods and contribution to discussions by Tony Smith and Shijie Zhou were also valuable.

3 Background

Management of fisheries requires a range of approaches, depending on the availability of data, resources available, types of fishery, and degree of cooperation between stakeholders (Smith *et al.*2007). The past decade has seen a gradual evolution in fisheries management from a primary focus on sustaining target species and resources, to a much wider focus on ecosystems, and the impacts of fisheries on them. This new approach has come to be called ecosystem-based fisheries management (EBFM), or alternatively the ecosystem approach to fisheries (Garcia *et al.*, 2003; Pikitch *et al.*, 2004). Pikitch *et al.,* (2004) outlined the main elements of EBFM, including (i) avoiding the degradation of ecosystems; (ii) minimizing the risk of irreversible change; (iii) obtaining long-term socio-economic benefits from fishing; and (iv) adopting a precautionary approach to uncertainty.

Moves towards EBFM have also evolved in Australian fisheries during the past decade, driven by a number of policy directions and initiatives. These include: (i) a national, government-wide approach to ecologically sustainable development, released in 1991; (ii) development of fisheries legislation that incorporates explicit reference to wider ecological impacts of fishing (e.g. the Fisheries Management Act 1991); (iii) new environmental legislation that assesses fisheries against environmental standards (e.g. the Environmental Protection and Biodiversity Conservation Act 1999); and (iv) Australia's Oceans Policy, which adopts an explicit ecosystem-based approach to management, with explicit requirements for regional ocean planning for all uses and users of the marine environment (Smith et al.2007).

A key challenge in developing the scientific tools to support EBFM has been the paucity of data and understanding about the broader ecological impacts of fishing in particular fisheries (e.g. Leslie *et al.*, 2008). One response to this has been the adoption of risk-based assessment methods, notably ecological risk assessment (ERA). In some cases, application of these tools to fisheries has adopted conventional likelihood-consequence approaches to risk assessment (Fletcher, 2005), while in other cases novel approaches have been developed (Stobutzki *et al.*, 2002).

One way that ERA approaches can be distinguished is in the level of quantitative information required. Particularly for data-deficient fisheries and those with limited knowledge of ecological interactions, a qualitative risk assessment tool is needed (Fletcher 2005, Astles *et al.,* 2006; Walker 2005; Campbell and Gallagher, 2007). Where more data are available, semi-quantitative or quantitative approaches may be useful (Stobutzki *et al.,* 2002; Zhou and Griffiths 2008). Most existing ERA methods operate at a single level of analysis (Scandol *et al.,* 2009). The distinguishing feature of the Ecological Risk Assessment for the Effects of Fishing (ERAEF) relative to other approaches is that it comprises a hierarchical set of methods or tools, representing different levels of "quantification", that are linked within a single framework (Scandol *et al.,* 2009; Hobday *et al.*, 2011). The individual methods used within ERAEF have evolved from several approaches, including Stobutski *et al.,* (2002), Fletcher (2005), Walker (2005), Griffiths *et al.,* (2006) and Zhou and Griffiths (2008). Similar semi-quantitative approaches have also been developed over the last five years (e.g. Astles *et al.,* 2006), some directly based on the ERAEF approach (e.g. Campbell and

Gallagher, 2007; Patrick *et al.,* 2010; Arrizabalaga *et al.,* 2011; Tuck *et al.,* 2011). Australia is recognized as the leading country with respect to development of ERA methods and application to fisheries, such as the CSIRO-led Ecological Risk Assessment for the Effects of Fishing (ERAEF) approach which has received international attention and uptake (e.g. Patrick *et al.,* 2010; Arrizabalaga *et al.,* 2011; Tuck *et al.*, 2001).

This project builds on the first Ecological Risk Assessment for the Effects of Fishing (ERAEF) project (FRDC 2003/021) which provided a hierarchical risk assessment approach to assist fisheries to understand and respond to their ecological risks, in particular to satisfy requirements under the EPBC Act (Hobday *et al.*, 2007; Smith *et al.*, 2007b). The Ecological Risk Management (ERM) process developed by AFMA integrates the ERAEF results by accounting for existing management actions and other information not included in the ERAEF method.

To date, the ERAEF methods have delivered results for all AFMA fisheries to Level 1, and where necessary to Level 2 for species (target, bycatch/byproduct, and TEP) and habitats (nine fishery assessments of habitat risk have been completed to Level 2) (see Hobday *et al.*, 2007). A number of fisheries also have rapid Level 3 assessments based on the SAFE method (Zhou and Griffiths, 2008) completed for the target and bycatch/byproduct species components (Zhou and Griffiths 2007; Zhou *et al.,* 2009; Zhou and Fuller 2011).

The community component though to Level 2 has not been completed for any fishery, as the methods were not tested at the end of the previous project. This finalization of the Community Level 2 methods and testing them on an example fishery is one goal of the current project.

Once results are generated, management response is required to implement the required actions to reduce ecological risk (Smith *et al.*, 2007b). AFMA and CSIRO jointly developed the ERA to ERM process to incorporate ERA results into a management cycle. The ERA to ERM process has shown how results for the species level assessment inform management action (**Figure 1**), but has not been extended to include habitat results. Thus, while the ERAEF methods for habitats have been developed and tested for nine fisheries (Hobday *et al.,* 2007; Williams *et al.,* 2011), implementation of these results has not occurred. This project thus represents a continuing step in the ERAEF process, and a goal of this project is to develop guidelines for how the existing habitat results can be processed for all AFMA fisheries.

A remaining step in the general ERA approach used by AFMA is to determine how to assess cumulative impacts. This is not covered in this project. Methods to assess cumulative impacts on species as a result of fishing are being developed and tested in another current project (FRDC 2011/029, ERA extension to assess cumulative effects of fishing on species).

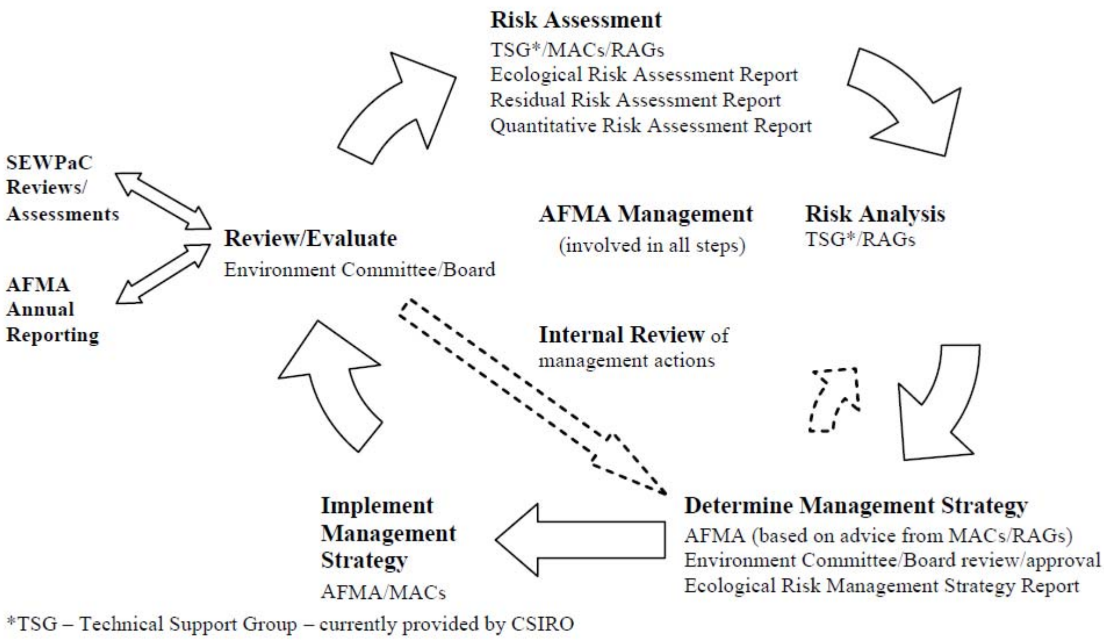

Figure 1. Adaptive management cycle adopted by the Australian Fisheries Management Agency (AFMA), with the ERAEF noted here as the Risk Assessment at the top of the cycle. Within each fishery, the Management Advisory Committee (MAC), Technical Species Group (TSG) and Research Advisory Group (RAG) can contribute during decision making. Source: http://www.afma.gov.au/wp-content/uploads/2010/06/Ecological-Risk-Management-Further-Information.pdf

4 Need

It is now widely recognized that fisheries have impacts on marine species, habitats and ecosystems that go well beyond the direct impacts of fishing on target species (e.g. Hall and Mainprize 2004; Althaus *et al.,* 2009). For example, hundreds of species are regularly caught and discarded in many trawl and longline fisheries, and global annual discards from fishing have been estimated at over 20 million tonnes (FAO 1999). Interactions with threatened species can impact vulnerable populations, and are a concern in many fisheries (e.g. Goldsworthy *et al.,* 2001; Kock 2001). Impacts on habitats and ecological communities as a result of fishing have also been documented (e.g. Thrush *et al.,* 1995; Freese *et al.,* 1999; Thrush and Dayton 2002; Althaus *et al.,* 2009).

To address these broader impacts of fishing, ecosystem-based fisheries management (EBFM), also called the ecosystem approach to fisheries, has emerged over the past decade as an alternative approach to single-species fishery management (Link *et al.,* 2002; FAO 2003; Pikitch *et al.,* 2004). While policy has shifted towards EBFM in a number of countries, development of practical methods to implement EBFM has not been as rapid (Pitcher *et al.,* 2009). For example, the EBFM approach has been broadly adopted at a policy level within Australia through a variety of instruments including fisheries legislation, environmental legislation, and a national policy on integrated oceans management (McLoughlin *et al.,* 2008; Webb and Smith 2008). These policy changes, occurring mainly in the late 1990s, required the rapid development of scientific and management tools to support practical implementation (Smith *et al.,* 2007a; McLoughlin *et al.,* 2008).

The risk-based ERAEF approach to assessing impacts from fishing underpins strategic assessment for AFMA-managed fisheries, and is also crucial in the AFMA ERM process. The ERAEF methodology uses a hierarchical approach to estimate risk from fishing activities. Level 1 (SICA) in the hierarchy has been applied to all Commonwealth fisheries across all five components (target species, bycatch and byproduct species, TEP species, habitats, and ecological communities). The Level 2 PSA species and habitat assessment tools have already been developed and applied for a subset of fisheries in the Stage 1 ERAEF project (Hobday *et al.*, 2007; Smith *et al.*, 2007b).

There is a need to develop an ERA to ERM framework for habitats identified as high risk from the existing analyses (as for species), and demonstrate it using worked examples. The ERAEF results presented here for habitats are integrated with other projects focusing on habitat impacts (FRDC 2003/021). There is also a need to complete the development of the community component methodology through to Level 2 of the ERAEF, and demonstrate it using worked examples. These two elements will assist AFMA to progress management of ecological risk in fisheries, as required under a range of management plans.

5 Objectives

The two project objectives are to advance development of ERAEF methods, widely used in Australia and internationally. The focus was on the non-species components of the assessment, specifically to:

1. Complete the development of the ERAEF Level 2 communities approach
2. Provide a framework for the ERA to ERM stage for the ERAEF Level 2 Habitat assessment approach

6 Methods

A key challenge in developing the scientific tools to support EBFM has been the paucity of data and understanding about the broader ecological impacts of fishing in particular fisheries (e.g. Leslie *et al.,* 2008). One response to this has been the adoption of risk-based assessment methods, notably ecological risk assessment, of which the ERAEF is a leading example (Scanlon *et al.*, 2009). A general methodological overview of the ERAEF is provided in this section, before more specific methods are presented against each of the two project objectives (**Section 7**).

The ERAEF framework involves a hierarchical approach that moves from a comprehensive but largely qualitative analysis of risk at Level 1, through a more focused and semi-quantitative approach at Level 2, to a highly focused and fully quantitative “model-based” approach at Level 3 (**Figure 2**; Hobday *et al.*, 2007; Hobday *et al.,* 2011). This approach is efficient because many potential activities/hazards are screened out at Level 1, so that the more intensive and quantitative analyses at Level 2, and ultimately at Level 3, are limited to a subset of the higher risk activities associated with fishing. It also leads to rapid identification of high-risk activities, which in turn can lead to immediate remedial action (risk management response), particularly in cases where it may be inappropriate to delay action pending further analysis. The ERAEF approach is also precautionary, in the sense that fishing activities are assumed to pose high risks in the absence of information, evidence or logical argument to the contrary (Hobday *et al.,* 2007; Hobday *et al.,* 2011).

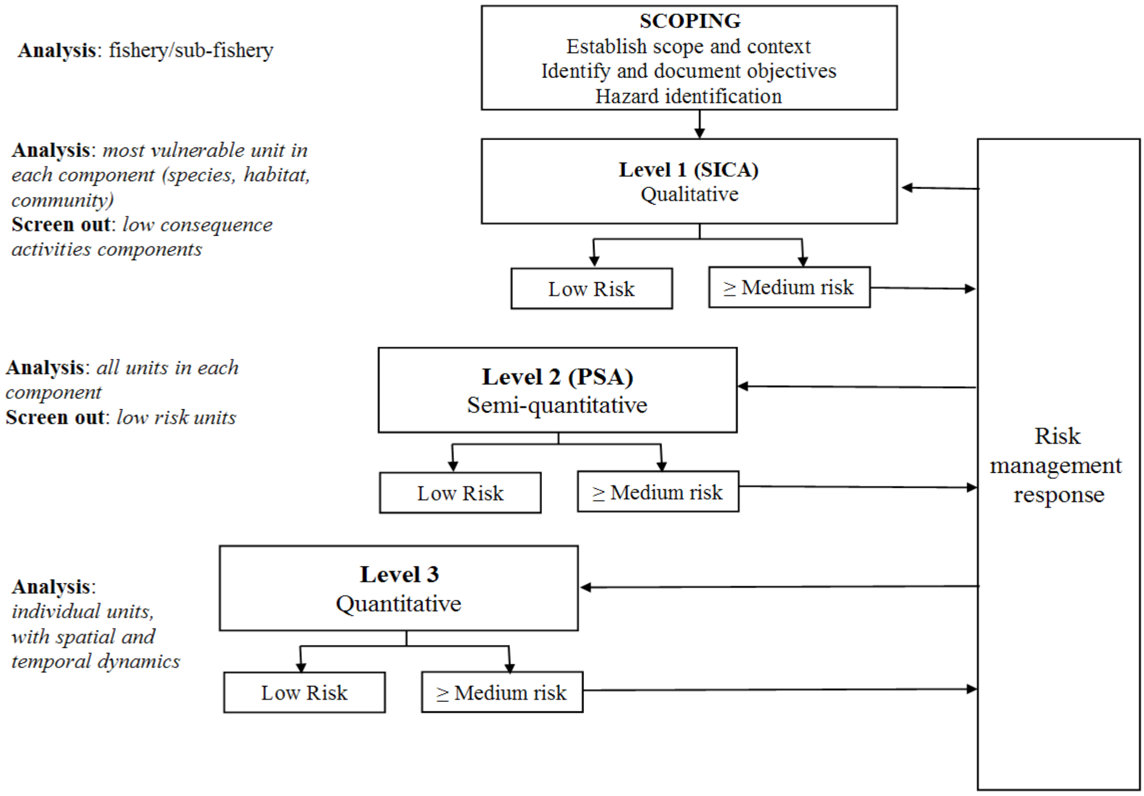

Figure 2. Overview of the ERAEF framework showing focus of analysis for each level in the hierarchy at the left in italics. At each level a risk management response is considered before proceeding to the next level in the hierarchy.

The ERAEF approach makes use of a general conceptual model of how fishing impacts on ecological systems, which is used as the basis for the risk assessment evaluations at each level of analysis. Five general ecological components are evaluated, corresponding to five areas of focus in evaluating impacts of fishing for strategic assessment under Australian environmental legislation. The five *components* are:

- Target species
- By-product and by-catch species
- Threatened, endangered and protected species (TEP species)
- Habitats
- Ecological communities

Because a single widely accepted operational definition of an ecosystem is lacking, these five components arguably cover the “elements of an ecosystem”. This compartmental approach allows all five components to be evaluated independently; a single component might be included in a risk assessment if a particular focus is required. Within each of these components, units of analysis are defined: in the three species components (target, bycatch, TEP) the units are species or stocks; for the habitat component the units are habitat types defined by abiotic and biotic elements; and for ecological communities, the units are assemblages or communities.

The analysis at Level 2 is based on scoring each unit of analysis within a component on a number of productivity and susceptibility attributes, and follows from the approach developed by Stobutzki *et al.,* (2002). The level of fishing impact a unit of analysis (e.g. species, habitat type, or community) can sustain, and the capacity to recover from impacts depends on its inherent productivity. For example, the productivity of a species is determined by demographic attributes such as longevity, growth rate, fecundity, recruitment and natural mortality (Stobutzki *et al.,* 2002; Hobday *et al.,* 2011). Habitats and communities can also be described as having an inherent "productivity", representing the ability to recover from impact (Hobday *et al.*, 2007; Williams *et al.,* 2011). The productivity of a unit such as a "habitat type" is determined by habitat attributes such as regeneration rates. For community units, the productivity might be determined by the diversity or size of the members. The productivity attributes for each unit of analysis are scored using a default set of scores, which then determine the overall productivity score (Hobday *et al*., 2007; see **Section 7**).

Susceptibility for species is estimated as the product of four independent aspects: Availability, Encounterability, Selectivity and Post-capture Mortality (PCM). A multiplicative approach is considered more appropriate for susceptibility because low risk for any single aspect acts to reduce the overall risk to a low value (Walker 2005; Hobday *et al*., 2007). For example, if a species is available in a fishing area, encounters the fishing gear, is selected by the gear, but is returned to the water unharmed (post-capture mortality low), then the overall susceptibility should be recognized as low. The level of fishing impact that a unit of analysis can sustain depends on its susceptibility to capture or damage by the fishery activities. For example, the susceptibility of a unit such as a species, habitat or community is determined by attributes such as areal overlap with the fishery, depth in the water column, and feeding method. The susceptibility of a unit such as "habitat type" is determined by abiotic habitat attributes such as substratum type and the fishing method (Williams *et al.,* 2011). The susceptibility of the community units is determined by factors such as spatial overlap of the fishery with the community unit (see **Section 7**).

The productivity and susceptibility attributes are scored as 1 (low), 2 (medium) or 3 (high), based on their relative value. Missing attributes are scored as a 3, which is precautionary. These scores are then plotted for visualization on a PSA plot. An overall risk score is calculated as the Euclidean distance from the origin, which allows an overall relative risk ranking (high, medium, and low). Units identified as potentially high-risk from the PSA analysis are candidates for further quantitative assessment at Level 3 (**Figure 2)**. In some cases, examination at Level 3 may not be necessary if alternative information exists (e.g. a pre-existing quantitative stock assessment that shows that harvest levels are sustainable). The advantage of Level 2 is that it allows the rapid screening of low-risk units, reducing the time and cost of analyses at Level 3. Some units will be identified as high risk from a Level 2 analysis due to missing attributes (which automatically score high risk). For such units, priority is given to collecting missing attribute information rather than moving immediately to Level 3 analysis.

The outcome of the Level 2 community PSA is identification of which communities (or assemblages) are at potential risk from fishing through significant changes to properties such as species composition, structure and function, as detailed in **Section 7** (Objective 1). The outcomes of Level 2 habitat assessment is described by Williams *et al.,* 2011, and in this report we show how to progress these results from ERA to ERM (Objective 2; **Section 7**).

7 Results/Discussion

Objective 1 - Development of Level 2 Community Assessment

In the following sections, we describe how the Objective was achieved. First, an overview of the Level 2 approach for communities is provided, detailing some of the concepts important to the final methods (**Section 7.1**). The selection of the attributes for the community assessment is detailed in **Section 7.2**. The specific set of steps to follow for a community assessment are provided in **Section 7.3**, and this represents the "how-to" part of the Objective. The methods are applied to a case study, the SESSF otter trawl fishery to illustrate the approach (**Section 7.4).** In the final subsection, the results from the case study are used to illustrate strengths and weaknesses of the ERAEF Level 2 assessment of communities (**Section 7.5)**.

7.1 Overview of the Level 2 community approach

The objective of the Level 2 community PSA is to identify which ecological communities are at potential risk from fishing through significant changes to properties such as species composition, structure and function. The focus of the PSA is a fishery or sub-fishery based on the fishing method and/or gear type (Hobday *et al.*, 2007). The unit of analysis for communities is a foodweb-based "assemblage" (e.g. **Figure 3**), but hereafter we refer to these as "communities" following Mangel and Levin (2005) who define communities as "assemblages of species in varying proportions doing different things, and have properties that are the amalgam of the properties of individual populations and interactions among populations".

The community ERA is based on the consideration of several aspects of communities that are commonly considered important in assessing community state (e. g. trophic structure, species composition, species diversity and species abundance distributions, community size composition). Trophic structure is used to help visualise the community, as represented by a foodweb. The approach taken also draws in the same attribute scores that are used in the single species ERA, but recombines and reinterprets them in a community context.

A foodweb is used to represent the unit of analysis for the Level 2 community analysis. This food-web based approach extends work by Bulman *et al.,* (Bulman 2002, Bulman 2006, Bulman *et al.,* 2001, Bulman *et al.,* 2006, Bulman *et al.,* 2011) who developed foodwebs for several regions around Australia, as a first step to generate trophic models. The overall concept in generating a foodweb is to group similar species into functional groups (boxes in Figure 2), and connect these boxes to represent flows between predators and prey. On the basis of this experience and other models, such as the Atlantis model developed for the South East region (Fulton *et al.,* 2004) and the West Florida Shelf model (Okey and Mahmoudi 2002) a generic foodweb was developed that could be modified to fit any fishery/region around Australia (**Figure 3**).

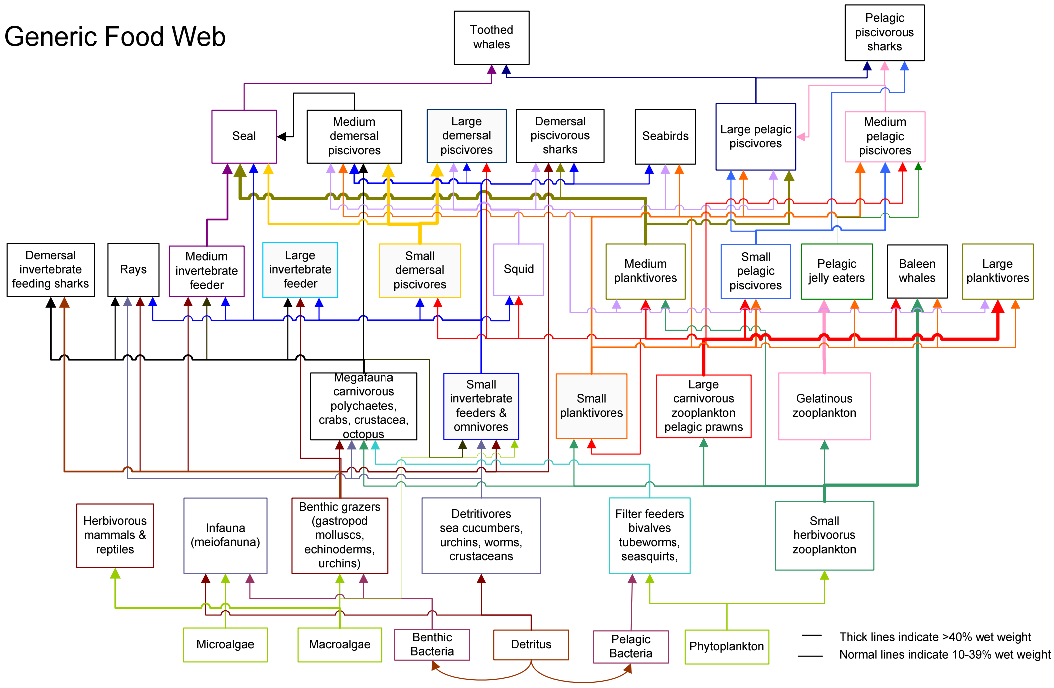

Figure 3. The generic foodweb used as the unit of analysis for the ERAEF Level 2 (PSA) community analysis. Functional groups (boxes) are composed of sets of similar species. The lines connecting boxes indicate predator-prey linkages.

The set of foodwebs representing each individual community covered by the fishery in the Level 2 assessment is generated by modifying the generic foodweb (**Figure 3**), based on a list of species found in the area covered by the particular community. The set of communities found within the jurisdictional boundary of the fishery or sub-fishery to be assessed is based on bioregionalisation studies of the Australian marine and coastal environment (IMCRA 1988, Last *et al.*, 2005, Lyne *et al.*, 2005). This process is required at Level 1 in the ERAEF approach, and is described in Hobday *et al.*, (2007). As explained below for the case study (**Section 7.3.1**), the communities which fall entirely or partially within the jurisdictional boundary of the fishery can be generated using a GIS query to a database. If a functional group is not represented in the community, the box is eliminated when generating the community foodweb[1]. Based on the Level 1 community results for many fisheries (Hobday *et al.*, 2007), up to 20 foodwebs representing the communities within each fishery may be needed. Thus, this modification of a generic foodweb is an efficient approach.

Once the set of foodwebs is generated, productivity and susceptibility scores for each foodweb are calculated based on a set of attributes. This productivity-susceptibility language is consistent across the other four ecological components of the ERAEF (Hobday *et al.*, 2007; Hobday *et al.*, 2011, Williams *et al.*, 2011). Initially, 21 community attributes were described as potentially useful for assessing the risk to communities in the Level 2 community PSA (see Hobday *et al.*, 2007 and **Appendix 2**). This initial attribute set was developed using expert opinion and literature review. The set included many community metrics widespread in community ecology (for comprehensive reviews see Rice (2000); Jennings and Kaiser (2001); Fulton *et al.*, (2004)), which measure system resilience (the ability of the system to maintain its integrity while being perturbed) or stability (the ability to

[1] The generic foodweb was intended to be comprehensive, however, additional boxes, or subdivision of existing boxes, can also occur if necessary when modifying this approach in future.

return to the previous state). The only attempt to classify ecosystems based on a similar set of objectives to the ERAEF is by Bundy *et al.,* (2010), who used a decision-tree approach to classify trends in 19 marine ecosystems based on six indicators relating to four ecological attributes described by Shin *et al.,* (2010): "resource potential, ecosystem structure and function, conservation of functional biodiversity, and ecosystem stability and resistance to perturbation". These attributes were closely aligned with the overall objective of our community ERAEF and those of the sub-components, i.e. to avoid negative impacts of composition, structure, function, distribution of the community.

In selecting a final set of attributes for use in the EREAF for communities, it is important to note that the ERAEF focus is on determining risk from fishing, rather than determining overall ecosystem "health" and ecosystem trends, as in many of the "indicator" studies cited above. Thus, while we use some similar indicators to these ecosystem indicator studies, we also develop other indicators that are more specific to a community and under assessment from potential fishery impact, such as spatial overlap. Some ecosystem attributes that we reviewed also require more quantitative information than is appropriate in the Level 2 semi-qualitative process. For example, Bundy *et al.,* (2010) use an indicator based on the mean length of fish in the community weighted by the known abundance of that species. They also used total biomass of species in the community, and proportions (of predatory fish). Both these indicators require quantitative knowledge of abundance or biomass of species in the community. Thus, some of ecosystem indicators would be suitable for a Level 3 quantitative analysis and even for on-going monitoring where the relevant quantitative data is available, but were not included in the Level 2 ERAEF process. Attributes must also represent the potential current risk of the fishing-community interactions, be relatively independent, and data must be available for all species and communities nationally (Hobday *et al.*, 2007). In selecting the final attribute set, some were difficult to define as either productivity or susceptibility attributes. Here, any attributes that are intrinsic to the community's ability to maintain itself, such as growth, or stability, are deemed "productivity attributes", while those related to exploitation or removal are deemed "susceptibility attributes". The final list and rationale for selection is detailed in the following section.

7.2 Attribute selection

7.2.1 Productivity attributes

From the preliminary set of 11 potential productivity attributes (**Appendix 2**), seven were eliminated and one was added, for a final total of five attributes. Two attributes eliminated were mean length for the community and mean growth for the community. The individual species mean length was used when calculating a productivity score for each species in the Species PSA, and so we instead used the individual PSA productivity scores calculated for each species and calculated the mean productivity over all the species in the community (see Attribute 1 below). This mean community productivity score is not the same as the primary productivity of the system. A primary productivity attribute could be derived from satellite-based chlorophyll estimates for surface communities, but not for sub-surface communities, and so was not included.

Mean growth was unavailable for many species, and so eliminated. Four attributes from qualitative analyses and distinctness tests (**Appendix 2**) were eliminated as they required calculation via two software programs in addition to Excel and the database, and required information more appropriate at a Level 3 (quantitative) analysis. It was unnecessary to include these complex attributes when suitable alternative attributes existed. These complex attributes could be considered in future developments. For instance, the taxonomic distinctness attribute might be a more sensitive measure when determining risk to biodiversity than the species richness attribute. The last attribute that was not considered useful was "high risk species eating high risk prey" which was dependent on detailed trophic data which was not available for many species.

The final set could be relatively easily calculated from the data that was automatically generated by database queries or that existed in the ERAEF species attribute database held at CSIRO (Hobday *et al.*, 2007), and was appropriate for a semi-quantitative assessment (**Table 1**). The final productivity attributes represent aspects of productivity of the community at both a species level (Attributes 1, 2 and 3) and at a functional group level (Attributes 4 and 5). As for the attributes calculated for species (Hobday *et al.*, 2011), some of these attributes are similar: thus, the overall score is an average of the five attribute scores. A set of five attributes for productivity is considered adequate to calculate a robust average score (Hobday *et al.*, 2007; Patrick *et al.*, 2010). These attributes are described below, with rationale for their inclusion.

Table 1. Set of productivity attributes for the Level 2 community analysis.

	Attribute	Rationale
1	Mean productivity score	Calculated as the mean of all the species productivity scores from the Species PSA calculations. Higher productivity scores for the community indicate greater resilience to impact or perturbation i.e. smaller animals with higher turn-over can respond more quickly (e.g. Jamaica trapping, Philippine reefs: Jennings *et al.,* 2001).
2	Fish species richness	Calculated as the total count of fish species in the community. Higher species richness scores indicate greater resilience to impact possibly through redundancy in functional groups, and higher biodiversity (e.g. Fijian reefs: Jennings *et al.,* 2001)
3	Mean trophic level of fishes in the community	Calculated from only the fishes in the community because data for invertebrates and higher trophic levels are often unavailable. Lower mean trophic level typically indicates the community is comprised of species of smaller size and higher growth rates, and hence has higher productivity (e.g. clupeoid fisheries in upwelling systems: Jennings *et al.,* 2001)
4	Functional group richness 1. Proportion of fish groups with <10 species	Calculated from only the fish groups in the community. Higher proportions indicate the community has less redundancy of species overall, more tightly coupled predator-prey interactions and greater likelihood of loss of functionality within trophic structure if species are lost. May also indicate an overfished or impacted state (e.g. Norwegian- Barents Sea: Jennings *et al.,* 2001)
5	Functional group richness 2. Proportion of fish groups with >30 species	Calculated from only the fish groups in the community. Higher proportions indicate greater redundancy of species and reduce likelihood of loss of functionality within trophic structure if some species are lost i.e. similar to attribute 2 and converse argument to attribute 4 (aggregate responses: Jennings *et al.,* 2001).

7.2.1.1 Productivity Attribute 1 - Mean productivity score

The mean productivity of each community is calculated from individual productivity scores (as in a Level 2 species PSA, Hobday *et al.*, 2007) for all species in the community, including additional species that were not in the original species analyses because they were not captured by the fishery. Data for additional species were obtained from FishBase (Froese and Pauly 2005) and added to the ERAEF database. These data were inspected to ensure values were appropriate and were applicable to species from the fishery region. The mean productivity score for all species in the community based on the species productivity scores was calculated. A weighted mean was not derived, as this would require quantitative knowledge of the biomass of each species which was not feasible given the semi-quantitative level of analysis. A high attribute value indicates high productivity therefore lower risk from impact.

7.2.1.2 Productivity Attribute 2 – Species richness

Species richness is calculated as the number of species in the foodweb. It is dependent on sample-size and comprehensive data coverage. The list of species generated to populate each foodweb was compiled from the CAAB distributional database (http://www.cmar.csiro.au/caab): this database does not contain invertebrates, so we restricted the species lists to teleosts and chondrichthyans (see **Section 7.3.2**). The fish lists for each community are still likely to be partially incomplete, as not all species in CAAB have adequate distribution data. Future upgrading of the CAAB distributional database will improve the quality of the data and subsequent assessments. A high attribute value indicates high productivity, therefore lower risk from fishing impact (see scoring in **Section 7.4**).

7.2.1.3 Productivity Attribute 3 – Mean trophic level

The mean trophic level of the community was calculated as the species average. Ideally this measure would be weighted using biomass, as explained for Attribute 1, such data does not exist and so a non-weighted value was used. Lower mean trophic level typically indicates the community is comprised of species of smaller size and higher growth rates, and hence has higher productivity (Jennings *et al.,* 2001). A high attribute value indicates low productivity, therefore higher risk from fishing impact (see scoring in **Section 7.4**).

7.2.1.4 Productivity Attributes 4 – Functional group richness 1

The proportion of fish functional groups with low (<10) species membership was calculated for each foodweb. This attribute is based on the hypothesis that low numbers of species in a functional group suggests a reduction in the degree of species redundancy (Jennings *et al.,* 2001) therefore a greater risk of loss of functional group and, consequently, function of the community. A high attribute value indicates low overall productivity (or resilience) and therefore higher risk from fishing impact (see scoring in **Section 7.4**).

7.2.1.5 Productivity Attributes 5 – Functional group richness 2

The proportion of fish functional groups with high (>30) species membership was calculated for each foodweb. As for attribute 4, this attribute is based on the hypothesis that higher numbers of species in a functional group indicates greater resilience to a loss of species by safeguarding the functioning of the functional group and community. For example, in species –rich systems such as reefs where the phylogenetic groupings contain more species exhibiting more diverse traits (Jennings *et al.,* 2001), the system would be expected to be more resistant to impact from fishing if the functional groups remained intact thus avoiding trophic cascade effects e.g. when cod in the Norwegian -Barents Sea began to cannibalise their juveniles when their usual prey, herring declined and no alternative prey were available (Jennings *et al.,* 2001). A high attribute value indicates high productivity (or resilience) therefore lower risk from fishing impact (see scoring in **Section 7.4**).

7.2.2 Susceptibility attributes

Susceptibility attributes are those relating to removals or exploitation of species in the community that will impact on the structure or function of the community. A total of 7 attributes were selected after considering the original set of 10 reported in Hobday *et al.*, (2007) (see **Appendix 2**). One attribute was dropped because it required information about all gear types or sub-fisheries in the fishery and therefore was a cumulative attribute (percentage fishery catch of total catch over all gear types). Another attribute (spatial overlap of the whole fishery jurisdiction with communities) was dropped because it was similar to one we included (spatial overlap of the effort footprint of the fishery) and was less informative. We also dropped one attribute (the number of trophic levels captured by gear), as preliminary analysis showed the value was similar across all communities because the same fishing gear was being used. Attributes that do not show differences between communities offer no value to the assessment. Finally, an attribute which calculated the "proportion of fished species with high post-capture mortality", was modified to indicate the "proportion of groups containing a majority of high risk species from the species PSA".

Attribute values were automatically generated (see **Section 7.3.4**) and subsequently used in calculations within an Excel PSA-style spreadsheet (available on request). The final set of seven attributes for susceptibility is considered adequate to calculate a robust average score (Hobday *et al.*, 2007; Patrick *et al.*, 2010). These attributes (**Table 2)** are described below, with rationale for their inclusion.

Table 2. Set of susceptibility attributes for the Level 2 community analysis

	Attribute	Rationale
1	Spatial effort overlap with community	Calculated as the percentage actual effort overlap of the fishery with the community. If the effort in the fishery is distributed over a wider area of the community then community is exposed to greater risk.
2	Spatial species overlap across community	Calculated as the percentage of fish species with >0.5 distribution in community. If the overlap between the species and the fishery is high then more are available to the fishery, and therefore the community structure is at higher risk.
3	Total catch percentage	Calculated as the percentage of total catch caught in the community divided by the percentage of area of the community relative to the total area of all communities within fishery jurisdictional boundary. Disproportionately high total catch from a community compared to that from other communities as measured by its relative size within the fishery area means community structure at greater risk from the fishery.
4	Mean trophic level of catch from fishery	Calculated as the mean trophic level of all species that are captured by the fishery. If fishing occurs at lower trophic levels, indicates system either "fished down" or fishery is at risk of destabilising community structure (e.g. Pauly *et al.,* 1998, but see Branch *et al.,* 2010).
5	Functional groups fished by fishery	Calculated as the percentage of functional groups fished by fishery. If a high number of functional groups are fished, then community structure and diversity at risk.
6	Functional groups with >50% of species fished	Calculated as the percentage of functional groups with >50% species of species fished. If high number of functional groups have more than half species membership fished, then community structure and diversity are exposed to risk.
7	Functional groups with >50% species at high risk	Calculated as the percentage of functional groups with >50% species scored at high risk in species PSA. If many functional groups have many species with high risk ratings from PSA analysis then community is at risk.

7.2.2.1 Susceptibility Attribute 1 – Spatial overlap with fishery

The spatial overlap of each community with the fishery was determined from the number of shots in each one km^2 grid recorded in the available commercial logbooks. Communities with high overlaps were considered more at risk, and hence scored as high susceptibility. This does not account for patchiness of species distributions, habitat preferences, or refugia from fishing gear but this sort of enhanced information could be incorporated into future analyses. A high attribute value indicates high susceptibility.

7.2.2.2 Susceptibility Attribute 2 – Spatial overlap with species

The risk to individual species based on their distribution in the community and potential exposure to the fishery. If a high proportion of the species in the community had high overlaps with the fishery then the community was considered at greater risk from fishing, and susceptibility was scored high. A high attribute value indicates high susceptibility.

7.2.2.3 Susceptibility Attribute 3 – Relative impact (targetedness) of fishing

This attribute indicates the relative "targettedness" of the community from the fishery by calculating the level of the catch from the community relative to its spatial area (as a proportion of the whole fishery). For example, if a large proportion of the total fishery catch is caught from a community that comprises only a small proportion of the fishery area, then this community may be potentially at greater risk. This measures a different type of impact to that indicated by the spatial overlap which assumes only equally-distributed effort (Susceptibility attributes 1 and 2). A high attribute value indicates high susceptibility.

7.2.2.4 Susceptibility Attribute 4 – Mean trophic level of the catch

Mean trophic level of the catch has been used to indicate the health of an ecosystem i.e. a decline in mean trophic level of catch over time suggests a more impacted system (e.g. Pauly *et al.,* 1998; but see Branch *et al.,* 2010 for cautionary note regarding the interpretation of mean trophic level). However, these indices were calculated over the full range of fishing methods, i.e. they included pelagic fishing methods catching the highest predators and thus trophic levels. However, the principle is the same if applied only to the demersally-trawled species here and, while the differentiation in attribute scores may be lower; this attribute has the capability to indicate changes in mean trophic levels of catches. The mean trophic level of the catch was calculated as a weighted average of all species caught from the proportional catch and the reported trophic level from FishBase. A high attribute value indicates lower susceptibility.

7.2.2.5 Susceptibility Attributes 5, 6 and 7 – Functional group attributes

Several attributes were based on the proportions within a functional group of the community: the proportion of functional groups with members captured by the fishery (Attribute 5); proportion of functional groups with >50% of species captured (Attribute 6) and the proportion of functional groups with >50% species at high risk based on the species PSA (Attribute 7). For each community, the proportion of functional groups fished by the fishery (Attribute 5) and the proportion of functional groups with more than half their species fished (Attribute 6) indicate the scale of impact of the fishing on the functional groups specifically. Additional impacts on functional groups may occur that are not represented by these two attributes. A major disruption in only one or two functional groups could impact on the overall functioning of the community, while broadly-spread impact could be sustainable depending on the level of impact and allow the community to function normally (e.g. Zhou *et al.,* 2010). If, on closer inspection of the effort spread, the latter case applies, then the high risk could in fact be reversed. If many functional groups in the community are comprised of many high risk species, then the risk of impact on the functioning of the community would be high. Thus, the final susceptibility attribute (Attribute 7) was intended to capture this element. In a similar fashion to the productivity attribute based on species PSA scores, susceptibility scores were calculated for all species in the community, including those not included in the original species PSA analyses. These scores were used to identify high risk species (defined as those species that scored greater than 3.18 in the species PSA) and then the proportion of functional groups with high proportions (>50%) high risk species was scored. For these three attributes, the higher the attribute value the greater the risk to the functional group from impact and consequently to the community. Thus, a high attribute value indicates high susceptibility.

7.2.3 Overall risk score calculation

The calculated risk score, based on the productivity and susceptibility attribute scores, is used a measure of the potential vulnerability of each community to be impacted by the fishery being assessed. This is consistent with the other ecological components in the ERAEF (Hobday *et al.,* 2007; Hobday *et al.,* 2011, Williams *et al.,* 2011).

Correlation between some attributes is likely (Hobday *et al.,* 2007), and so a correlation matrix is generated for each set of productivity and susceptibility attributes (see case study example that follows, **Table 7** and **Table 11**). In the case of high correlations, an average productivity score can be biased, and so one of the two highly correlated attributes may be discarded. This will be a judgement of the assessment team, as all attributes are designed to estimate "productivity" or "susceptibility". In general, correlation (r) above 0.9 would be reason to discard one of the attributes before calculating the overall score.

The productivity attributes are scored and averaged to generate the overall productivity score for each community. In the Level 2 species PSA, susceptibility attributes are assigned to one of four aspects; availability, encounterability, selectivity and post-capture mortality, and multiplied to generate the overall susceptibility risk score (Hobday *et al.,* 2007). However, the susceptibility attributes derived for the community component (**Table 2**) do not fit into these aspects. Consequently, the community susceptibility attributes were treated similarly to the productivity attributes in the overall risk score calculation - i.e. the scores for the susceptibility attributes were averaged. The Euclidean distance on a plot of productivity and susceptibility is used as an overall measure of potential risk (**Figure 4**).

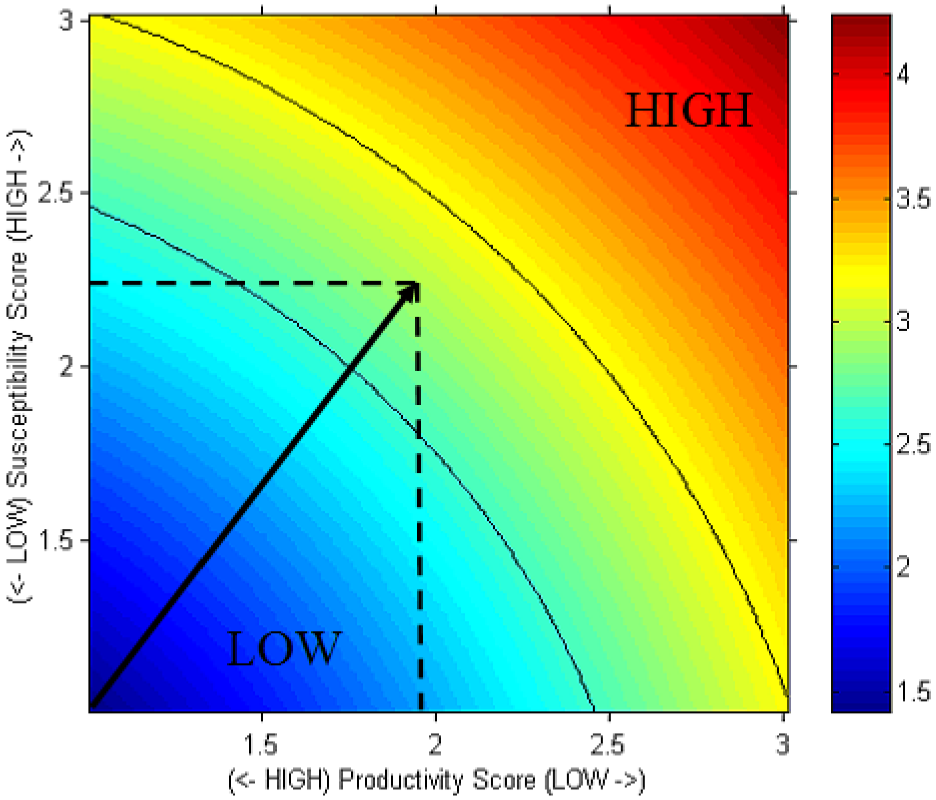

Figure 4. Productivity Susceptibility Analysis (PSA) Plot. The productivity and susceptibility score are plotted for each community (dashed lines), and the resulting Euclidean distance (solid line) is calculated to determine relative risk score. This example is a medium overall risk score.

7.3 Generating a Level 2 community PSA – the "how to" guide

The previous sections described development of methods to undertake a Level 2 community assessment in the ERAEF. The five specific steps to complete a Level 2 community assessment, based on the methods described above are:

1. Generate the list of communities to be assessed for the fishery
2. Generate a list of species to populate each community
3. Populate the generic community (modify the generic foodweb)
4. Calculate the attribute values for productivity and susceptibility
5. Score the productivity and susceptibility attributes

7.3.1 Step 1. Generate the list of communities to be assessed for the fishery

The first step in the Level 2 community assessment process is to select the communities to be assessed within the jurisdictional boundary of the fishery. Communities were derived from results of bioregionalisation studies of the Australian marine and coastal environment (IMCRA 1988, Last *et al.*, 2005, Lyne *et al.*, 2005) and were fully described in Hobday *et al.*, (2007). Two of the bioregionalisation studies are now updated (Commonwealth of Australia 2006, Heap *et al.*, 2005); however, no change has been made to our spatial definition of communities. The communities (boundaries) were defined spatially as GIS shape files. Using a GIS database query the set of communities which fall entirely or partially within the jurisdictional boundary of the fishery being assessed can be generated.

7.3.2 Step 2. Generate a list of species to populate each community

Each community in the fishery is then populated with species based on an electronic query of the CAAB bioregional database and from AFMA fishery catch records. Not all species within the CAAB database have distributional data, therefore species lists may be incomplete. However, we are confident that this approach will include the most commonly-occurring species for most fisheries. The preliminary community analysis in Stage 1 of the ERAEF (Hobday *et al.,* 2007) also used survey and observer catch composition information to confirm species distributional data. Since then, the CAAB distributional data has been upgraded and now includes many more species, however, species that are added with no distributional data can still result in missing attributes (which are scored as missing data).

The automatic data and attribute collation process (**Appendix 3**) does not calculate the distributional attributes if the species does not occur within the community boundaries. This is a possible area of concern, since species may be recorded from the community even though their CAAB distribution does not recognise them from the area. Validation is often required when missing attributes values are returned.

It is worth noting that pelagic community species lists are the most difficult to compile as there is only limited distributional data available in CAAB. Species lists for pelagic communities during the earlier stages of the ERAEF project (Hobday *et al.,* 2007) were obtained from the relevant fisheries such as the SBT or skipjack tuna fisheries. Some species were added from information on FishBase. Most information was obtained from studies on midwater fishes and tunas (Young and Blaber 1986, Young and Davis 1990, 1992, Young *et al.,* 2001, Williams and Koslow 1997). These lists are likely to be incomplete and will need some expert verification if pelagic fisheries are assessed at Level 2.

7.3.3 Step 3. Populate the generic foodweb

The generic foodweb (**Figure 3**) is populated using the species list generated for each community in the previous step. These species are allocated into a functional group (a box in the foodweb model) based on knowledge of their diets and/or based on eco-morphometric analyses by P. Last and D. Gledhill (unpublished data, CSIRO). This allocation is based on the experience of these experts from review of published literature and inspection of museum records and specimens. If no specific data are available, the species is assigned to a functional group to which congeners or close allies are assigned. This results in a specific set of communities, represented as foodwebs, for the fishery under assessment.

As part of this project, over 1500 species have been assigned to functional groups. These functional group memberships are stored in the community datasets in the ERAEF database, and will assist Level 2 community assessment for other fisheries.

7.3.4 Step 4. Calculate the attribute values for productivity and susceptibility

Values for each attribute are calculated using an Excel PSA workbook which is populated from the PSA attribute data residing in the ERAEF Microsoft Access database. The data processing methods and export tables required to calculate the attribute data have been developed to allow application across all ERAEF fisheries and are described in more detail in **Appendix 3**.

The data required to generate the individual foodwebs needed to assess each fishery is large, particularly when the community (foodweb) includes species that were not included in the Level 2 species components (target, bycatch/byproduct or TEP) for the fishery being considered. These additional species need to have data collated to first calculate species PSAs, that are then aggregated to generate some of the attributes required in the community assessment.

7.3.5 Step 5. Score the productivity and susceptibility attributes

In the Excel PSA workbook, numerical scores are allocated to the susceptibility and productivity attributes. The five productivity attributes and the seven susceptibility attributes are scored either 1, 2 or 3 (reflecting relatively low, medium or high risk) based on the intrinsic properties of the habitat (productivity attributes) or the degree and type of interaction with fishing (susceptibility attributes). Allocation of scores is based on predetermined thresholds or explicit hypotheses for each attribute (**Tables 1 and 2**).

The Excel PSA workbooks contain linked worksheets to calculate overall scores of susceptibility, productivity, risk value, risk ranks, and generate simple summary statistics. The attribute scores for both productivity attributes and for susceptibility attributes are averaged to provide a single estimate for each component on the interval 1 to 3. No weighting is applied to individual attributes, although other modifications to the ERAEF approach have done so (e.g. Patrick *et al.*, 2010). The ERAEF approach is precautionary with respect to uncertainty: where an attribute has no information the score defaults to 3 (high risk).

The overall potential risk score for each community is calculated as the Euclidean distance from the origin (0, 0) on a plot of susceptibility against productivity (**Figure 4)**. To determine the overall PSA risk classification, the PSA plot is divided into equal thirds, based on the distribution of Euclidean scores that result from the combination of the productivity and the susceptibility scores. Scores that fall in the upper third of all possible scores (risk value > 3.18) are classified as high risk, those in the middle third of possible scores (2.64 < risk value <3.18) as medium risk while those in the lower third of possible scores (risk value < 2.64) are low risk (Hobday *et al.*, 2007). Therefore, communities with high susceptibility and low productivity scores are classified as high potential risk (**Figure 4)**.

7.4 Case Study demonstrating the Level 2 methods

The Southern and Eastern Scalefish and Shark Fishery (SESSF) otter trawl fishery was selected as the case study to demonstrate the methods, based on the available supplementary information in the form of survey data, ecological modelling, fishery and biological statistics. Fishery catch data from 2009 was used in this case study.

The SESSF is Australia’s oldest fishery and has operated for over 100 years (Smith and Smith 2001). It is now primarily a quota-managed fishery, and operates from inner shelf to mid slope depths (~25–1300 m) over a broad geographical range spanning large areas of Australia’s eastern, south-eastern and southern coastline. The fishery exploits numerous species with varied life histories in many demersal habitats (Smith and Smith 2001). Five primary sub-fisheries exist and are distinguished by gear types and by the spatial and depth distribution of effort: south-east region otter trawl (SE OT); south region (Great Australian Bight) otter trawl (GAB OT); bottom set auto-longline (ALL); bottom set gill net (GN); and Danish Seine (DS). The south-east region otter trawl sub-fishery is the largest in the SESSF; it has many vessels taking the greatest tonnage, it lands the most species (>80), and it operates over the broadest range of habitats and depth zones (~50–1300 m).

The SESSF otter trawl fishery was assessed in a Level 1 community (SICA) analysis (Wayte *et al.*, 2007) where the community most at risk (defined as the one in which most fishing occurs) within the fishery jurisdictional boundary was determined. If at Level 1, the community is deemed high risk, then all communities in the fishery should be assessed at Level 2 (Hobday *et al.,* 2007). The SESSF otter trawl sub-fishery Level 1 SICA assessment identified that some communities had risk scores of 3 or greater which required a Level 2 assessment of this component (Wayte *et al.*, 2007). The South East Transition 110-250m (outer shelf) and the South East Transition 250-500m (upper slope) communities were scored as the most vulnerable in the Level 1 analysis, as a result of the direct impact of fishing (Wayte *et al.,* 2007). Following the ERAEF methodology, this outcome required a Level 2 assessment of all assemblages in the fishery. However, at the time of completion of the Stage 1 ERAEF project (Hobday *et al.,* 2007), the Level 2 community methodology was still in development.

7.4.1 Step 1. Generate the set of SESSF otter trawl communities

For the Level 2 SESSF otter trawl fishery, only the demersal communities were selected for assessment in this report because the otter trawl method does not interact with the overlying pelagic communities while directly fishing[2]. An example distribution of these communities is illustrated in **Figure 5.** Within the SESSF jurisdictional boundaries, 28 benthic communities occur from the shelf to deepwater from NSW to Kangaroo Island including Tasmanian communities and two seamount communities (**Table 3)**.

7.4.2 Step 2. Generate the species lists for the SESSF otter trawl communities

For each community identified in step 1, species lists were generated from the CAAB lists and the ERAEF database, and attributes were downloaded from the ERAEF database. At this stage, the South Eastern Transition 1100-3000m Seamount Community was excluded from the analysis since the generation of species produced only two species as occurring in the community. This paucity of data confounded any further sensible calculation of attributes. Furthermore, there was no fishery effort in the community for the year examined. Future assessments that include this community will need to populate the species lists manually, if fishing occurred in this community. Scrutiny and further population of the species lists by local experts and from other data sources such as local surveys and literature searches is recommended.

7.4.3 Step 3. Populate the foodwebs for the SESSF otter trawl communities

The species were allocated to a functional group in each foodweb, and the functional groups with no species were eliminated.

7.4.4 Step 4. Calculate the attribute values for the SESSF otter trawl communities

Statistics and values required for calculating community productivity and susceptibility attributes for the remaining 27 communities were generated using the data processing methods outlined in **Section 7.3**. To determine some of the attributes, as described in **Section 7.3.4**, each species, PSA scores were generated using the species PSA methodology and spreadsheets (Hobday *et al.,* 2007). Attribute values for each community are shown in **Table 3**.

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[2] Naturally the vessels and gear interact with pelagic and epi-pelagic communities during the fishing operations, but this activity does not constitute “direct impact from fishing” (Hobday *et al.,* 2007).

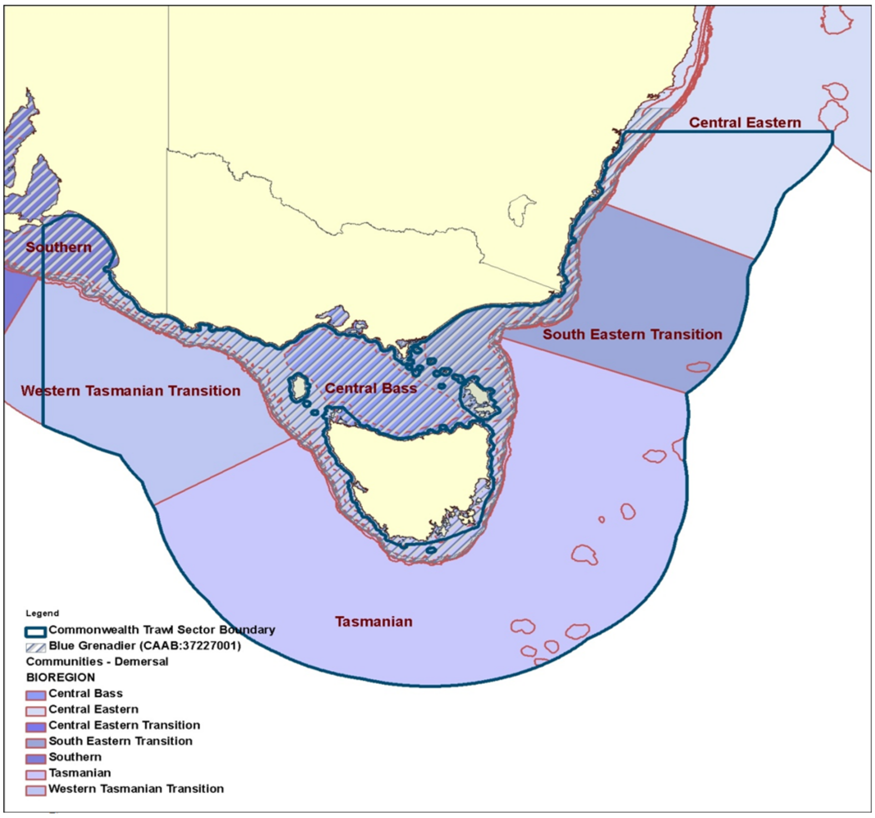

Figure 5. Demersal communities within the SESSF jurisdictional boundary (heavy blue line). Depth-defined bathomes within each bioregion are shown in red and constitute community boundaries within the bioregions. Seamount communities are also shown in the Central Eastern, South Eastern Transition and Tasmanian bioregions. The species distribution of blue grenadier (blue hatched area) as documented in the Bioreg species distribution database is shown on the map as illustration.

Table 3. Productivity and susceptibility attribute values for communities in SESSF. The community names are followed by the depth range in m.

	Productivity					Susceptibility								
	Life-history		Diversity			Trophic structure					Fishery specific			
Community	Mean PSA Productivity	Mean trophic level of community	Fish species richness	Proportion of fish groups with <10 species	Proportion of fish groups with >30 species	Proportion of fish functional groups fished	Proportion of fished functional groups with >50% species fished	Proportion of functional groups with >0.5 species with high risk rating	Proportion of community overlapped by actual effort	Proportion of fish species with >.5 distribution in community	Mean trophic level of catch	Proportion of fishery catch of total catch cf proportion by area of fishery	Total P attributes	Total S attributes
Central Bass 0-110	2.01	2.96	328	0.62	0.05	0.86	0.143	0.50	0.01	0.48	3.11	0.1416	5	7
Central Eastern 0-110	1.94	2.95	553	0.38	0.19	0.81	0.095	0.80	0.04	0.53	3.03	0.6639	5	7
Central Eastern 110-250	2.01	2.96	522	0.43	0.19	0.81	0.095	0.90	0.16	0.58	3.17	4.0885	5	7
Central Eastern 250-565	2.16	2.89	307	0.62	0.14	0.62	0.095	0.88	0.13	0.48	3.16	11.2518	5	7
Central Eastern 565-820	2.22	2.93	240	0.67	0.05	0.57	0	0.88	0.04	0.39	3.26	0.4968	5	7
Central Eastern 820-1100	2.25	2.91	190	0.71	0.00	0.43	0.143	0.71	0.02	0.46	3.29	0.1229	5	7
Central Eastern 1100-3000	2.30	2.95	141	0.76	0.00	0.29	0.048	0.40	0.00	0.02	3.19	0.00012	5	7
South Eastern Transition 0-110	2.03	2.90	595	0.38	0.10	0.86	0.095	0.75	0.10	0.29	3.12	2.4492	5	7
South Eastern Transition 110-250	2.01	3.01	353	0.62	0.14	0.81	0.143	0.89	0.90	0.55	3.17	35.7798	5	7
South Eastern Transition 250-565	2.10	2.95	295	0.57	0.14	0.76	0.143	0.94	0.78	0.48	3.33	44.9189	5	7
South Eastern Transition 565-820	2.18	2.98	262	0.57	0.14	0.67	0.048	0.88	0.32	0.44	3.38	2.4929	5	7
South Eastern Transition 820-1100	2.22	3.00	181	0.76	0.00	0.48	0.143	0.82	0.14	0.71	3.31	0.5199	5	7
South Eastern Transition 1100-3000	2.24	2.99	156	0.81	0.00	0.38	0.191	0.71	0.01	0.04	3.17	0.0077	5	7
Southern 0-110	2.03	2.97	355	0.52	0.05	0.86	0.095	0.50	0.00	0.41	2.96	0.0009	5	7
Tasmanian 0-110	1.98	2.99	271	0.71	0.05	0.86	0.143	0.50	0.05	0.52	3.23	0.6461	5	7
Tasmanian 110-250	1.98	2.92	274	0.81	0.00	0.52	0.095	0.76	0.04	0.04	3.68	26.3922	5	7
Tasmanian 250-565	2.01	3.04	259	0.67	0.10	0.81	0.095	0.89	0.32	0.52	3.40	33.8413	5	7
Tasmanian 565-820	2.16	3.04	214	0.57	0.10	0.76	0.143	0.95	0.52	0.45	3.55	61.4879	5	7
Tasmanian 820-1100	2.21	2.94	209	0.71	0.10	0.57	0.143	0.88	0.42	0.47	3.54	20.5677	5	7
Tasmanian 1100-3000	2.26	2.88	174	0.76	0.05	0.48	0.095	0.88	0.29	0.56	3.64	1.6795	5	7
Tasmanian 1100-3000 Seamount	2.19	2.82	141	0.76	0.05	0.48	0.143	0.71	0.002	0.03	3.35	0.1008	5	7
Western Tasmanian Transition 0-110	2.02	2.96	348	0.62	0.05	0.86	0.143	0.44	0.01	0.46	3.15	0.0556	5	7

Community	Productivity					Susceptibility								
	Life-history		Diversity			Trophic structure					Fishery specific			
	Mean PSA Productivity	Mean trophic level of community	Fish species richness	Proportion of fish groups with <10 species	Proportion of fish groups with >30 species	Proportion of fish functional groups fished	Proportion of fished functional groups with >50% species fished	Proportion of functional groups with >0.5 species with high risk rating	Proportion of community overlapped by actual effort	Proportion of fish species with >.5 distribution in community	Mean trophic level of catch	Proportion of fishery catch of total catch cf proportion by area of fishery	Total P attributes	Total S attributes
Western Tasmanian Transition 110-250	1.96	3.11	212	0.76	0.05	0.81	0.143	0.83	0.31	0.74	3.12	8.5538	5	7
Western Tasmanian Transition 250-565	2.01	3.05	226	0.76	0.05	0.76	0.143	1.00	0.80	0.44	3.35	66.8345	5	7
Western Tasmanian Transition 565-820	2.14	2.88	177	0.81	0.00	0.67	0.143	0.94	0.64	0.47	3.33	16.8237	5	7
Western Tasmanian Transition 820-1100	2.22	2.90	152	0.81	0.00	0.52	0.143	0.71	0.26	0.67	3.46	1.3404	5	7
Western Tasmanian Transition 1100-3000	2.27	2.84	119	0.81	0.00	0.38	0	0.57	0.002	0.04	3.37	0.0072	5	7
Count	27	27	27	27	27	27	27	27	27	27	27	27		

7.4.5 Step 5. Score the attributes for the SESSF otter trawl communities

Attributes were scored as high (3), medium (2), or low (1) according to cut-offs determined by post-hoc examination of the distribution of attribute values (**Tables 4 and 5**). While the determination of the cut-offs was subjective, generally we used the premise that the range of the results should be split into equal thirds, unless a more relevant and logical justification could be made (as for species, Hobday *et al.*, 2007 and habitats, Williams *et al.*, 2011). For example, the range of the mean PSA productivity attribute value was divided into approximately equal thirds, representing high (3), medium (2) and low (1) values. Scoring of the mean trophic level of the community attribute was not based on equal thirds. This was because the potential range of the trophic level within the whole SESSF ecosystem would be wider if the higher trophic level predators (such as tuna from the pelagic communities) were included. Consequently, more communities were scored at a medium risk rather than at a low risk as would have occurred if the smaller range of trophic levels based on the demersal community had been used.

Table 4. Statistics and scoring cut-offs for risk categories for community productivity attributes.

Statistic	Attribute 1: Mean productivity score	Attribute 2: Fish species richness	Attribute 3: Mean trophic level of community	Attribute 4: Proportion of fish groups with <10 species	Attribute 5: Proportion of fish groups with >30 species
Maximum value	2.30	595	3.11	0.81	0.19
Minimum value	1.94	119	2.82	0.38	0.01
Low risk (1)	<2.06	>435	<2.9	<0.52	>0.12
Med risk (2)	2.06-2.18	278-435	2.9-3.4	0.52-0.68	0.8-0.12
High risk (3)	>2.18	<278	>3.4	>0.68	<0.08
Total scores for attribute	27	27	27	27	27

Table 5. Statistics and scoring cut-offs for risk categories for community susceptibility attributes.

Statistic	Attribute 1: Proportion of community overlapped by actual fishing effort	Attribute 2: Proportion of fish species with >50% distribution in community	Attribute 3: Mean trophic level of catch	Attribute 4: Proportion of fishery catch of total catch compared with proportion by area of fishery	Attribute 5: Proportion of fish functional groups fished	Attribute 6: Proportion of fished functional groups with >50% species fished	Attribute 7: Proportion of functional groups with >50% species with high risk rating
Maximum value	0.90	0.74	3.68	66.83	0.86	0.19	1.00
Minimum value	0.00	0.02	2.96	0.00012	0.29	0.00	0.40
Low risk (1)	<0.33	<0.33	>3.4	<1	<0.33	<0.1	<0.33
Med risk (2)	0.33-0.67	0.33-0.67	3.2-3.4	1-10	0.33-0.67	0.1-0.2	0.33-0.67
High risk (3)	>0.67	>0.67	<3.2	>10	>0.67	>0.2	>0.67
Total scores for attribute	27	27	27	27	27	27	27

The productivity scores (**Table 6**) were calculated by averaging the five productivity attribute scores. The range of scores was 1.6-2.8 with an average of 2.23 and no missing attributes. The ranking resulted in slightly skewed distributions of scores within the low, medium and high categories (**Table 7**), which may be a result of fairly subjective cut-offs and/or indicative of incomplete information on which to base the cut-offs. Five of the ten combinations of attribute pairs were significantly correlated (**Table 8**). The correlations between productivity attributes that depended heavily on numbers of species (i.e. the proportions of groups) were significant. Significant correlations between the 27 communities (df =26), at p=0.05 were ± 0.374, while for p=0.10 were ± 0.317) (**Table 8**). Some correlated attributes are expected, as the attributes are all designed to measure a similar property, but care should be taken to exclude highly correlated (r > 0.7) attributes as these just bias the overall score to the correlated indicators (Hobday *et al.*, 2007).

Table 6. Productivity attribute risk scores for communities in the SESSF.

Community	Attribute 1: Mean PSA productivity score	Attribute 2: Fish species richness	Attribute 3: Mean trophic level of community	Attribute 4: Proportion of fish groups with <10 species	Attribute 5: Proportion of fish groups with >30 species	Productivity score
Central Bass 0-110	3	2	2	2	3	2.40
Central Eastern 0-110	3	1	2	1	1	1.60
Central Eastern 110-250	3	1	2	1	1	1.60
Central Eastern 250-565	2	2	1	2	1	1.60
Central Eastern 565-820	1	3	2	2	3	2.20
Central Eastern 820-1100	1	3	2	3	3	2.40
Central Eastern 1100-3000	1	3	2	3	3	2.40
South Eastern Transition 0-110	3	1	1	1	2	1.60
South Eastern Transition 110-250	3	2	2	2	1	2.00
South Eastern Transition 250-565	2	2	2	2	1	1.80
South Eastern Transition 565-820	1	3	2	2	1	1.80
South Eastern Transition 820-1100	1	3	2	3	3	2.40
South Eastern Transition 1100-3000	1	3	2	3	3	2.40
Southern 0-110	3	2	2	2	3	2.40
Tasmanian 0-110	3	3	2	3	3	2.80
Tasmanian 110-250	3	3	2	3	3	2.80
Tasmanian 250-565	3	3	2	2	2	2.40
Tasmanian 565-820	2	3	2	2	2	2.20
Tasmanian 820-1100	1	3	2	3	2	2.20
Tasmanian 1100-3000	1	3	1	3	3	2.20
Tasmanian 1100-3000 Seamount	1	3	1	3	3	2.20
Western Tasmanian Transition 0-110	3	2	2	2	3	2.40
Western Tasmanian Transition 110-250	3	3	2	3	3	2.80
Western Tasmanian Transition 250-565	3	3	2	3	3	2.80
Western Tasmanian Transition 565-820	2	3	1	3	3	2.40
Western Tasmanian Transition 820-1100	1	3	1	3	3	2.20
Western Tasmanian Transition 1100-3000	1	3	1	3	3	2.20
Unknown attributes	**0**	**0**	**0**	**0**	**0**	
Mean score						**2.23**

Table 7. Numbers of communities scored in each productivity category for each attribute.

Productivity category	Attribute 1: Mean productivity score	Attribute 2: Fish species richness	Attribute 3: Mean trophic level of community	Attribute 4: Proportion of fish groups with <10 species	Attribute 5: Proportion of fish groups with >30 species	Total
3 (Low Productivity, High risk)	12	18	0	14	17	61
2 (Medium productivity, med risk)	4	6	20	10	4	44
1 (High productivity, low risk)	11	3	7	3	6	30
Total scores for attribute	**27**	**27**	**27**	**27**	**27**	**135**

Table 8. Correlation of productivity attributes. Red shaded boxes denote significant positive correlation, blue shaded boxes denote significant negatively correlated.

Productivity attributes	Attribute 1: Mean productivity score	Attribute 2: Fish species richness	Attribute 3: Mean trophic level of community	Attribute 4: Proportion of fish groups with <10 species	Attribute 5: Proportion of fish groups with >30 species
A1: Mean productivity score	X				
A2: Fish species richness	-0.56	X			
A3: Mean trophic level of community	0.30	0.00	X		
A4: Proportion of fish groups with <10 species	-0.50	0.86	-0.14	X	
A5: Proportion of fish groups with >30 species	-0.21	0.58	-0.12	0.69	X

Susceptibility scores were averaged across the seven attributes (**Table 9**). The range of scores was 1.43 to 2.71 with an average of 1.94 and with no missing attribute data. About half the susceptibility scores for all attributes were somewhat skewed, with some risk categories used more often than others (**Table 10)**.

Table 9. Susceptibility scores for communities in the SESSF.

Community	Attribute 1: Proportion of community overlapped by actual effort	Attribute 2: Proportion of fish species with >50% distribution in community	Attribute 3: Mean trophic level of catch	Attribute 4: Proportion of fishery catch of total catch cf proportion by area of fishery	Attribute 5: Proportion fish functional groups fished	Attribute 6: Proportion fished functional groups with >50% species fished	Attribute 6: Proportion functional groups with >50% species with high risk rating	Susceptibility score
Central Bass 0-110	1	2	3	1	3	2	2	2.00
Central Eastern 0-110	1	2	3	1	3	1	3	2.00
Central Eastern 110-250	1	2	3	2	3	1	3	2.14
Central Eastern 250-565	1	2	3	3	2	1	3	2.14
Central Eastern 565-820	1	2	2	1	2	1	3	1.71
Central Eastern 820-1100	1	2	2	1	2	2	3	1.86
Central Eastern 1100-3000	1	1	3	1	1	1	2	1.43
South Eastern Transition 0-110	1	1	3	2	3	1	3	2.00
South Eastern Transition 110-250	3	2	3	3	3	2	3	2.71
South Eastern Transition 250-565	3	2	2	3	3	2	3	2.57
South Eastern Transition 565-820	1	2	2	2	2	1	3	1.86
South Eastern Transition 820-1100	1	3	2	1	2	2	3	2.00
South Eastern Transition 1100-3000	1	1	3	1	2	2	3	1.86
Southern 0-110	1	2	3	1	3	1	2	1.86
Tasmanian 0-110	1	2	2	1	3	2	2	1.86
Tasmanian 110-250	1	1	1	3	2	1	3	1.71
Tasmanian 250-565	1	2	1	3	3	1	3	2.00
Tasmanian 565-820	2	2	1	3	3	2	3	2.29
Tasmanian 820-1100	2	2	1	3	2	2	3	2.14
Tasmanian 1100-3000	1	2	1	2	2	1	3	1.71
Tasmanian 1100-3000 Seamount	1	1	2	1	2	2	3	1.71
Western Tasmanian Transition 0-110	1	2	3	1	3	2	2	2.00
Western Tasmanian Transition 110-250	1	3	3	2	3	2	3	2.43
Western Tasmanian Transition 250-565	3	2	2	3	3	2	3	2.57
Western Tasmanian Transition 565-820	2	2	2	3	2	2	3	2.29
Western Tasmanian Transition 820-1100	1	3	1	2	2	2	3	2.00
Western Tasmanian Transition 1100-3000	1	1	2	1	2	1	2	1.43
Unknown attributes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Mean score								**1.94**

Table 10. Numbers of communities scored in each risk category based on susceptibility attributes.

Rank	Attribute 1: Proportion of community overlapped by actual fishing effort	Attribute 2: Proportion of fish species with >50% distribution in community	Attribute 3: Mean trophic level of catch	Attribute 4: Proportion of fishery catch of total catch compared with proportion by area of fishery	Attribute 5: Proportion of fish functional groups fished	Attribute 6: Proportion of fished functional groups with >50% species fished	Attribute 7: Proportion of functional groups with >50% species with high risk rating	Total
3 (High)	3	3	11	9	13	0	21	60
2 (Medium)	3	18	10	6	13	15	6	71
1 (Low)	21	6	6	12	1	12	0	58
Total scores	27	27	27	27	27	27	27	189

Some attributes were significantly correlated, although only 4 of a possible 21 pair-wise combinations were significant, indicating the susceptibility attributes were measuring slightly different characteristics of fishing risk. Some correlated attributes are expected, as the attributes are all designed to measure a similar property, but care should be taken to exclude highly correlated ($r > 0.7$) attributes as these just bias the overall score to the correlated indicators (Hobday *et al.,* 2007). Attribute 1 (the proportion of area in which the effort occurred) was positively correlated with both the proportion of catch caught (Attribute 4) and the proportion of functional groups in which more than half the species were fished (Attribute 6). Significant correlations for 27 communities (df = 26) are at $p = 0.05$ corresponding to a correlation coefficient of ± 0.374, while for p = 0.10 the correlation needs only be ± 0.317. The more an area was targeted (i.e. the greater the community's disproportionate catch to area value, indicated with Attribute 4), the more likely the species caught were scored as a PSA species high risk (attribute 6, proportion of functional groups with >50% high risk species) and the lower the mean trophic level of catch (Attribute 3) (**Table 11**).

Table 11. Correlation matrix of susceptibility attributes. Red shaded boxes denote significant positive correlation and blue significant negative correlations.

Susceptibility attributes	Attribute 1: Proportion of community overlapped by actual fishing effort	Attribute 2: Proportion of fish species with >50% distribution in community	Attribute 3: Mean trophic level of catch	Attribute 4: Proportion of fishery catch of total catch compared with proportion by area of fishery	Attribute 5: Proportion of fish functional groups fished	Attribute 6: Proportion of fished functional groups with >50% species fished	Attribute 7: Proportion of functional groups with >50% species with high risk rating
A1: Proportion of community overlapped by actual effort	X						
A2: Proportion of fish species with >50% distribution in community	0.10	X					
A3: Mean trophic level of catch	-0.12	-0.12	X				
A4: Proportion of fishery catch of total catch cf proportion by area of fishery	0.64	0.12	-0.41	X			
A5: Proportion of fish functional groups fished	0.29	0.27	0.24	0.17	X		
A6: Proportion of fished functional groups with >50% species fished	0.45	0.35	-0.08	0.06	0.18	x	
A7: Proportion of functional groups with >50% high risk species	0.27	0.21	-0.33	0.54	-0.05	0.06	x

Overall, six communities were scored as high potential risk in the SESSF case study (**Figure 6**, **Table 12**). The Western Tasmanian Transition 250-565m scored the highest overall risk (3.80) followed by the Western Tasmanian Transition 110-250m (3.71). While both these communities had two of the highest productivity scores (2.8), their susceptibility scores (2.57 and 2.42, respectively) were not as high as for South Eastern Transition 110-250m (2.71). This community had the third highest overall risk score. The two other communities with the highest productivity risk scores (Tasmanian 0-110m and Tasmanian 110-250m) did not have particularly high susceptibility scores, suggesting that the fishing pressure in those communities was lower than for the three highest risk communities.

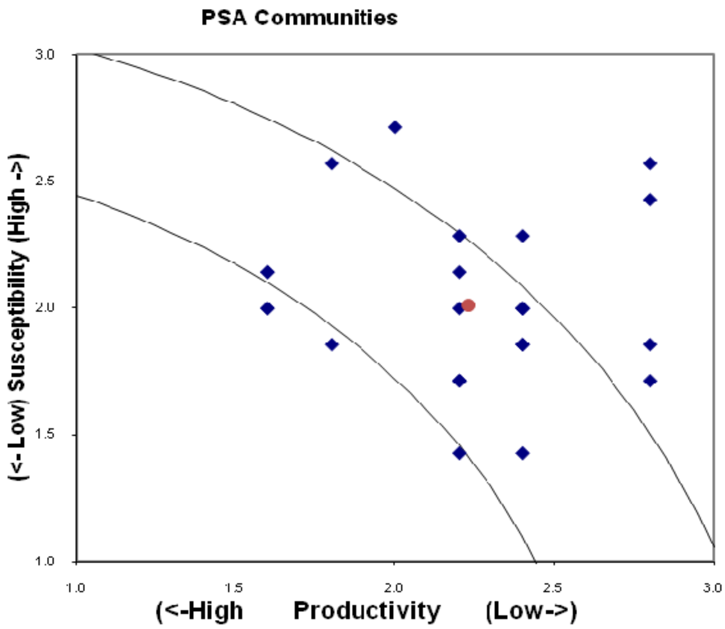

Figure 6. Productivity susceptibility plot for the communities assessed in the SESSF case study.

The top two ranked medium risk communities were the Tasmanian 565-820 m and the Southeast Transition 250-565 m. Their susceptibility scores were as high as those for communities in the high risk group but their productivity scores (2.2 and 1.8 respectively) were similar to the South Eastern Transition 110-250 m (2.0).

The highest of the medium risk scores (e.g. risk score of 3.17 for the Tasmanian 565-820 m community) likely reflects the impact blue grenadier fishery. The impact of this particular fishery, i.e. the targeting of this species, also contributed to high susceptibility scores for Tasmanian communities between 110 and 820 m while the impact (targeting) of the orange roughy fishery was reflected in the Tasmanian 820-1100 m susceptibility score. In all cases, the disproportionately high catches from the communities were ranked as high for that attribute. The mean trophic levels of the catches for the Tasmanian communities were amongst the highest, suggesting targeting a high–order predator which consequently lowers potential community risk compared to fishing further down the food-chain. Central Eastern communities ranked as only medium risk, with the exception of the Central Eastern 0-110m community, which was ranked low. The effort overlaps in all cases were small and consequently the impacts of the fishery were also ranked as low. In general, the productivity scores were relatively low, because species richness values were generally high.

The majority of communities scored as high risk high on the attribute indicating the proportion of functional groups with high proportions of high risk species (Susceptibility Attribute 7). This means this attribute was not particularly discriminating for this case study, but the high scores still imply that a significant impact from fishing occurs broadly within the communities in this fishery.

Table 12. Ranked SESSF community PSA potential risk scores and categories.

Community	Productivity score	Susceptibility score	Overall Risk Value	Risk Category
Western Tasmanian Transition 250-565	2.80	2.57	3.80	High
Western Tasmanian Transition 110-250	2.80	2.43	3.71	High
South Eastern Transition 110-250	2.00	2.71	3.37	High
Tasmanian 0-110	2.80	1.86	3.36	High
Western Tasmanian Transition 565-820	2.40	2.29	3.31	High
Tasmanian 110-250	2.80	1.71	3.28	High
Tasmanian 565-820	2.20	2.29	3.17	Med
South Eastern Transition 250-565	1.80	2.57	3.14	Med
Central Bass 0-110	2.40	2.00	3.12	Med
South Eastern Transition 820-1100	2.40	2.00	3.12	Med
Tasmanian 250-565	2.40	2.00	3.12	Med
Western Tasmanian Transition 0-110	2.40	2.00	3.12	Med
Tasmanian 820-1100	2.20	2.14	3.07	Med
Central Eastern 820-1100	2.40	1.86	3.03	Med
South Eastern Transition 1100-3000	2.40	1.86	3.03	Med
Southern 0-110	2.40	1.86	3.03	Med
Western Tasmanian Transition 820-1100	2.20	2.00	2.97	Med
Central Eastern 1100-3000	2.40	1.43	2.79	Med
Central Eastern 565-820	2.20	1.71	2.79	Med
Tasmanian 1100-3000 Seamount	2.20	1.71	2.79	Med
Tasmanian 1100-3000	2.20	1.71	2.79	Med
Central Eastern 110-250	1.60	2.14	2.67	Med
Central Eastern 250-565	1.60	2.14	2.67	Med
Western Tasmanian Transition 1100-3000	2.20	1.43	2.62	Low
South Eastern Transition 565-820	1.80	1.86	2.59	Low
Central Eastern 0-110	1.60	2.00	2.56	Low
South Eastern Transition 0-110	1.60	2.00	2.56	Low

Lower productivity scores for some communities were often a result of a high number of fish species identified for the community; many of which were non-target species. This meant that attributes based on the proportions of species fished (productivity attributes 4 and 5) were scored lower. Of the six high risk communities, the South Eastern Transition 110-250m comprised 56% more species than the highest ranked community, and had from 28% - 206% more species than the other high risk communities. Of the four communities that scored low risk, Central Eastern 0-110m and South Eastern Transition 0-110m had the highest number of species (553 and 595 respectively) and were two of the four lowest productivity scores (1.6), indicating the effect on attribute calculations flowing on from the species composition value. The Central Eastern 110-250m community also had a low productivity score, reflecting the third highest number of fish species.

The mean trophic level of the catch (susceptibility attribute 4) was not particularly discriminating in this analysis as the majority of scores were medium risk (score 2.0). Comparing these results to other communities from different regions may produce a broader range of mean trophic level scores, but if not then it would be worth re-considering the value of this attribute as it stands, if it contributes little to the overall result. There is debate in the literature about the use of this metric for tracking changes in trophic level (e.g. Branch *et al.*, 2010), however, here we use it as measure of susceptibility given the present state of the fishery.

The susceptibility scores more directly reflected the actual risk to communities from the impact of direct fishing. The South Eastern Transition 110-250m scored the highest susceptibility score (2.71), with the Western Tasmanian Transition 250-565m and the South Eastern Transition 250-565m next highest (both 2.57). All of these communities scored highly (score 3) for overlap by the actual effort of the fishery and, in fact, were the only high scores. Of the latter two, the Western Tasmanian Transition 250-565m scored an overall high risk while the South Eastern Transition 250-565m scored only a medium risk. The difference between the two South Eastern Transition communities was due only to two attributes (mean productivity score (productivity attribute) and mean trophic level of catch (susceptibility attribute)) being scored a category lower for the 250-565m community than for the 110-250m community. The difference between the Western Tasmanian Transition 250-565m and the South Eastern Transition 250-565m was due to differences in most of the productivity attributes.

The community scores for attributes measuring the impact of the fishery, (i.e. where the proportion of the total fishery catch taken from the community), were found to be high in the majority of high risk communities except the Tasmanian 0-110m and Western Tasmanian Transition 110-250m. These high scores indicate the fishing in concentrated in a few communities. The lowest susceptibility scores were generally for those communities with medium to low overall risk, however, the Tasmanian 0-110m and 110-250m communities, both had low susceptibility scores but were both overall high risk.

Overall, the results for the SESSF case study showed that the communities that might be intuitively considered to be at higher risk due to known fishing patterns, such as the South Eastern 110-250m (high coverage of effort (90%) and the Western Tasmanian Transition 250-565m (high coverage of effort (80%), were also ranked as high risks in the community PSA (**Table 12**). Targeting of blue grenadier and orange roughy (and high reported catches) in the deeper Tasmanian communities resulted in only medium risk to the overall communities in this assessment. The high risk to individual species has been previously captured in the species PSA for the fishery (Wayte e*t al.*, 2007). Communities where effort overlaps were relatively low were generally ranked as low to medium risk.

7.5 Conclusion

The methods for Level 2 community assessment using the Productivity Susceptibility Analysis (PSA) have been developed and applied to a case study.

The methodology we present here is simple conceptually, but the development was operationally complex. The data processing is quite complex and requires good skills in database and processing methods and further application may require specialist knowledge of trophic/functional biology where species still require allocation to functional groups. However, the database query processes are now largely automated and the spreadsheet calculations, while complex, are also in place. Individual species PSA assessments are required for all species identified in the community (i.e. including those species in the community list that were not identified in a Species PSA for the fishery). This necessitates a duplication of the original process but since it is automatic, and some data may have been updated since the original assessments, it is not particularly time-consuming. Further application and review of results and methodology would allow refinement and streamlining of the methodology.

Development of suitable attributes for scoring community risk is challenging. Sainsbury (2008) discussed a range of indicators that have often been used in describing impact from fishing on communities but found little demonstration of actual and practical reference points. As stated previously, many of these indicators could be very useful as reference points particularly in ongoing monitoring e.g. size spectrum (Rice and Gislason 1996) but they were also often very quantitative and available for only a few species. Sainsbury (2008) suggested that composite indicators such as RAPFISH devised by Pitcher and Preikshot (2001), which uses scores of retention of bycatch and numbers of species of bycatch, could track changes through a fishery. This would still rely on quantifiable and reliable catch composition data being recorded within the fishery. This is a challenge, as there is very low coverage by the AFMA observer program (formerly ISMP) in the SESSF and there are still no limits or reference points. The definition of community reference points remains a pressing issue, beyond this project. It would be interesting to compare the SESSF community level 2 results with output from the Atlantis model for the same region. This would provide some much needed "validation" of the method, and could also provide insight into reference points for assessing impact.

We worked with a set of five productivity and seven susceptibility attributes, which overall led to a good spread of risk values in the case study (see **Figure 6**). Some attributes were scored in a narrow range (poor discrimination between communities) (e.g. mean trophic level of community (P3) and possibly the proportion of functional groups with >%50 of species fished or with a high risk rating (S6 and S7)). These attributes were scored in only two of the three ranks (i.e. 1&2 or 2 & 3). Without completing community assessments for a number of other fisheries, it is not possible to tell if these attributes will show more discrimination, and hence be retained in the community PSA.

Attribute values are scored in one of three risk categories (H=3, M=2, or L=1) based on cut-off values, prior to averaging. The selection of cut-offs for ranking of the productivity and selectivity attributes was somewhat arbitrary and further examination and trialling of cut-offs. This can take place as other fisheries are assessed, as occurred for species PSA (Smith *et al.,* 2007b). Selection of cut-off values could also be improved if clear criteria existed for evaluating the attribute in the first place, such as appropriate and robust reference points as described for species (target, bycatch, TEP) (Sainsbury 2008). Such values are missing for communities, as evidenced by our literature review.

The results of the SESSF otter trawl case study showed that the PSA distinguished high, medium and low risk communities. Generally the communities that are known to receive considerable fishing effort were scored as high risk or amongst the highest of the medium risk scores. These were Western Tasmanian Transition 250-565m and 565-820m, South Eastern Transition 110-250m and 250-565m, and Tasmanian 110-250m, 250-565m, 565-820m, and 820-1100m. All of these communities had at least one other susceptibility attribute scored as high (i.e. 3), and represented the highest productivity risk scores, with the exception of the South Eastern Transition 110-250m. Conversely, communities with low effort overlaps were generally classified as low to medium risk, except for the Tasmanian 0-110m and Western Transition 110-250m, however, both these communities had the highest risk productivity scores, and in the latter case, four high-ranked susceptibility attributes.

The SESSF case study completed here was based on 2009 fisheries data. If assessment was based on data collated over a longer period (e.g. 5 years as in the assessments of Level 2 Species in Hobday *et al.,* 2007), the results may have been different. For example, the deeper communities in which orange roughy were targeted in the past might have resulted in those communities being assessed as at high risk rather than the current medium risk. We suggest that in application to other fisheries, several years of recent data be used in assessment.

The PSA community assessment as implemented here reflects the impact of fishing from one fishery only, in this case the Commonwealth otter trawl fishery. There may also be impact on the community from other fisheries, and even other activities (e.g. pollution, oil and gas, pipeline dredging). These other impacts in the same communities may increase the risk (i.e. cumulative) to communities which should also be explored in future work. The work in progress (Zhou *et al.,* FRDC 2011/29) is considering only cumulative impacts on species.

7.5.1 Extension to other fisheries

The methods have been tested on one fishery, which has a focus on teleost fishes and chondrichthyans (Wayte *et al.*, 2007). Lack of detailed data on invertebrates might be a serious shortcoming in other fisheries that focus on invertebrates such as scallop, squid or prawn fisheries. The method can certainly be applied if data exists. If there is insufficient data, then management decisions may need to be made based on level 1 assessment results.

A logical next step is to apply the methods to a number of other fisheries, as has occurred for species and habitats.

7.5.2 Extension to Level 3

At the conclusion of the ERAEF Level 2 assessment, decisions about the action regarding the high risk units are required (**Figure 2)**. Management can respond based on the level 2 results, as has occurred for some species (Hobday *et al.,* 2011), or decide that more detailed assessment is required.

Development of Level 3 community assessment method would enable the quantitative ecological attributes discussed earlier to be used. This method would require quantitative knowledge, which is not always available. Ecosystem models such as Atlantis, which can represent multiple threats and fisheries are an example of a Level 3 approach (Fulton 2010). Less complex models, such as Ecopath, may also be developed for the high risk communities, and then can be used to quantitatively evaluate the impacts of fishing. There are a number of examples of these models for Australia (see Brown *et al.*, 2009 for a recent summary; Bulman *et al.,* 2010)

We suggest that development or application of Level 3 assessments may not be feasible or practical before ERA to ERM community risk management options are considered as detailed in **Section 7** for habitats.

Objective 2 - An ERM framework for the ERAEF Level 2 Habitat assessment

In the following sections, we describe how Objective 2 was achieved. First, an overview of the ERM approach is provided, detailing some of the concepts important to ERA to ERM for habitats (**Section 7.6**). The existing Level 2 habitat results are summarized in **Section 7.7**. Improvements to the habitat assessment are proposed in **Section 7.8**. The remaining steps to complete the ERA to ERM process for habitats are listed in **Section 7.9**. The management options to respond to these risks are described in **Section 7.10**. In the final subsection, issues and the next steps for the habitat ERA to ERM are discussed (**Section 7.11)**.

7.6 ERM habitat approach

7.6.1 The role of the ERA to ERM process

AFMA's ecosystem-based approach to managing Australia's Commonwealth fisheries, and to meeting Australia's international obligations in High Seas fisheries, has broadened the primary focus of sustainable management of target stocks to include the ecological impacts of fishing on bycatch species, threatened and protected species, habitats, and marine communities and food chains. AFMA aims to minimise the impacts of Commonwealth managed fisheries on all aspects of the marine ecosystem, and is developing and implementing an ecological risk management (ERM) framework for this purpose (**Figure. 7**). The framework details a robust and transparent process to assess, analyse and respond to the ecological risks posed by Commonwealth managed fisheries.

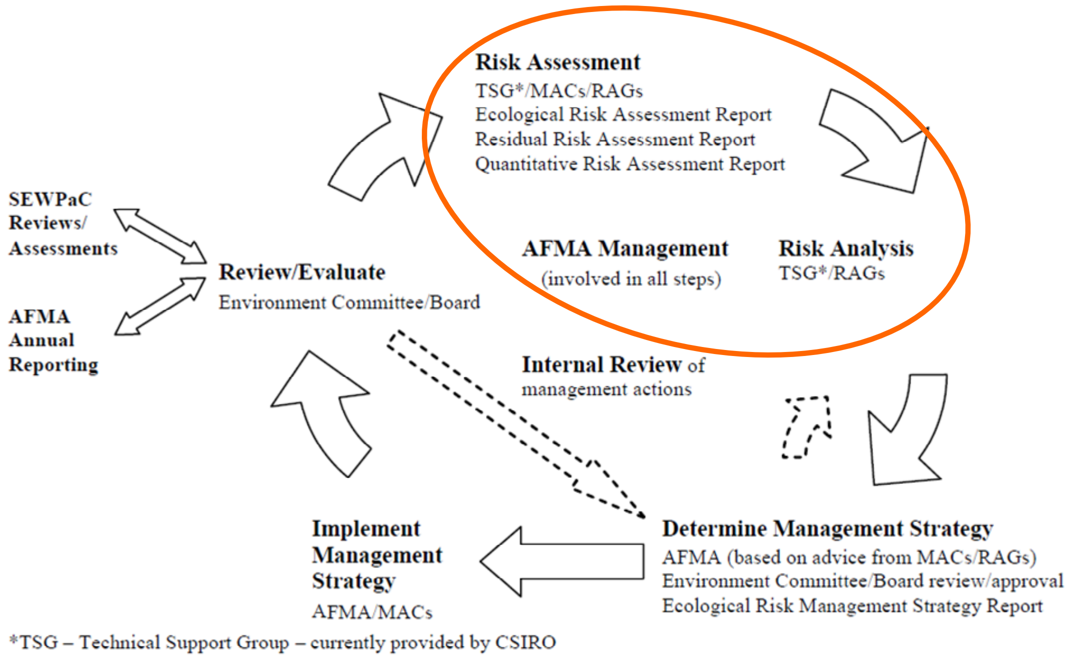

Figure 7. The ERM framework showing the elements considered by this project for habitats. An expanded diagram of the risk assessment and risk analysis steps is provided in **Figure 9**.

The ERM framework involves several steps, including risk assessment, within a hierarchical framework that progresses from a comprehensive but largely qualitative analysis at Level 1 to a quantitative analysis at Level 3 – the Ecological Risk Assessment for the Effects of Fishing (ERAEF) (Hobday *et al.,* 2007; Smith *et al.,* 2007b; Hobday *et al.,* 2011). By screening out low risk activities, a hierarchical approach enables the framework to focus more on the activities assessed as having a greater environmental risk. The results of the risk assessments are now the focus for the development and implementation of ERM strategies.

Risk assessments and risk analysis have been largely completed for fishery species (target, bycatch and TEPs) in all major Commonwealth managed fisheries, but the development of risk assessment and risk analysis methods for habitats has not progressed beyond Level 2 of the ERAEF (Williams *et al.,* 2011a). Thus, while results for habitats have been tested for nine Commonwealth fisheries, there is a need to develop methods to assess residual risk for habitat risk assessment and risk analysis, and to develop the detail of a framework for ERM.

AFMA have specified that the methods for habitat risk assessment and risk analysis, and the habitats ERM framework, provide specific options for appropriate management responses, with the detail provided in non-technical language. These are the aims for Objective 2 of this study.

7.6.2 What are fishery 'habitats'?

Habitats can be simply described as, "the biological and physical environments in which as organism lives" (e.g. Sainsbury 2008). However, 'habitat' exists at multiple spatial scales, and at large scales the term 'habitat' is often used to describe fishery ecosystems. A habitat can therefore be the place where an individual fish lives, a terrain of rocky bottom suited to a mixed assemblage of species, a feature such as a seamount supporting aggregations of specific fishes, or a depth zone with a broad and characteristic community of fishes. This 'hierarchy' of habitats is reviewed by Last *et al.,* (2010), while Williams *et al.,* (2005) describe the relevance of each level to marine resource management. In the context of examining risks posed by bottom fishing, 'habitat' is the seabed and fauna existing at a variety of spatial scales that provide roles or 'services' to the fishery ecosystem.

Ecosystem services provided by habitats may take the form of providing shelter for fishery target species or those linked to target species in food webs; biogeochemical processes such as nutrient cycling, nitrification and mineralization; and by providing energetically favourable places to feed. Establishing the mechanisms underpinning these ecological roles in fisheries relies heavily on inference. However, the ways in which large, erect benthic fauna is important to fishery ecosystem structure in south-eastern Australia has been documented for sponges (Schlacher *et al.,* 2007) and corals (Althaus *et al.,* 2009). Physical refuges created by fauna and physical seabed structures in locations such as submarine canyons, seamounts and rocky escarpments provide energetic advantages which, together with enhanced prey densities, support elevated fishery production (Williams and Bax 2001; Williams *et al.,* 2009b) and create attractive sites for fishing.

7.6.3 Why habitat is a unit of analysis in risk assessment

Negative effects of bottom-contact fishing on marine benthic systems have been well documented. These include reductions in biodiversity and biomass, homogenization of substrates, and disruption of ecosystem processes (e.g. Thrush and Dayton 2002).

Many biological and physical components of habitat are highly vulnerable to degradation or removal by trawling because the recovery times of fauna are typically long, while removal of friable sedimentary rocks and biogenically formed substrata is a permanent impact. Vulnerability is exemplified by the coral matrix-based habitats of seamounts that are completely removed where trawling occurs (Althaus *et al.,* 2009) with effects likely lasting centuries or longer (Williams *et al.,* 2010b).

Level 2 ERAEF results show that when habitat types are described and defined using a variety of physical and biological attributes, large numbers of habitat types are represented in individual fisheries that cover large areas and depth ranges, e.g. the SESSF, and that many habitats can be at high potential risk of impact from bottom fishing methods (**Table 13**). Because the same habitat types may be encountered by different gears that have different impacts, the potential risk can vary between gears. This is illustrated, for example, by the 21 habitat types on the SESSF outer continental shelf encountered by all five main sub-fisheries (gear types) – bottom trawl, auto-longline, gillnet and Danish seine (**Table 14**). Ultimately, understanding the cumulative impacts across gear types is necessary to assess risks, but this is beyond the current project.

Table 13. Habitats described and defined using a variety of physical and biological attributes results in large numbers of types being represented in fisheries covering large areas and depth ranges, e.g. the SESSF. These need a degree of consolidation (i.e. to fewer types) for risk analysis.

Risk Category	Coastal Margin	Inner-shelf	Outer-shelf	Upper-slope	Mid-slope	Total habitats
High	0	0	18	12	16	46
Medium	0	5	5	28	20	58
Low	0	23	31	0	0	54
Total	**Not in fishery**	**28**	**54**	**40**	**36**	**158**

Table 14. Risk categories for a subset of 21 habitats on the outer shelf encountered by all of the five main sub-fisheries of the SESSF fishery as assessed in the ERAEF framework. Sub-fisheries are south-east otter trawl (SE OT), Great Australian Bight otter trawl (GAB OT), Auto-longline (ALL), Danish seine (DS), Shark gillnet (GN) (from Williams *et al.,* 2011).

Habitat type	Risk Category				
	SE OT	GAB OT	ALL	GN	DS
Fine sediments, subcrop, large sponges	High	High	High	High	Med
Coarse sediments, subcrop, large sponges	High	High	High	High	Med
Gravel, wave rippled, large sponges	High	High	Med	High	High
Sedimentary rock, subcrop, large sponges	High	High	Med	High	Med
Coarse sediments, irregular, small erect fauna	High	High	Med	Med	Med
Coarse sediments, subcrop, small sponges	Med	Med	Low	Med	Low
Mud, subcrop, small sponges	Med	Med	Low	Med	Low
Fine sediments, subcrop, small sponges	Med	Med	Low	Med	Low
Fine sediments, unrippled, small sponges	Med	Med	Low	Low	Low
Gravel, current rippled, bioturbators	Med	Med	Low	Low	Low
Gravel, wave rippled, bioturbators	Med	Med	Low	Low	Low
Sedimentary rock, subcrop, small sponges	Med	Med	Low	Low	Low
Gravel, wave rippled, no fauna	Low	Low	Low	Low	Low
Coarse sediments, wave rippled, no fauna	Low	Low	Low	Low	Low
Coarse sediments, current rippled, no fauna	Low	Low	Low	Low	Low
Fine sediments, unrippled, bioturbators	Low	Low	Low	Low	Low
Fine sediments, wave rippled, bioturbators	Low	Low	Low	Low	Low
Fine sediments, wave rippled, no fauna	Low	Low	Low	Low	Low
Fine sediments, unrippled, no fauna	Low	Low	Low	Low	Low
Fine sediments, irregular, no fauna	Low	Low	Low	Low	Low

7.6.4 Policy drivers for protecting habitats

7.6.4.1 Domestic policy - EPBC Act and EBFM context

Assessing impacts on habitats is a component of evaluating fisheries, or particular fishing methods, against the expectations of EBFM. Australia's Environmental Protection and Biodiversity Conservation Act (EPBC) requires levels of habitat and biodiversity protection, including of benthic fauna. Australian Government requirements for EBFM are detailed in the *Guidelines for the Ecologically Sustainable Management of Fisheries.* These state: *"Fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem"* (Ecosystem impacts – *Principle 2).*

The mechanisms by which these requirements are interpreted and enforced include via a Wildlife Trade Operation (WTO) accreditation which is needed under Part 13A of the EPBC Act before product derived from the fishery can be exported. Accreditation is dependent on a Strategic Assessment process conducted by the Commonwealth Environment agency (currently DSEWPaC) that assesses whether a fishery is being managed in an ecologically sustainable manner. For example, the Strategic Assessment of the SESSF in relation to the 2003 WTO identified, "*the need for more spatial management arrangements, including measures to prevent uncontrolled expansion of fishing effort into new areas*". Subsequently, when reviewing the 2006 WTO, the assessment noted the need for, "*implementation of a structured process to ensure any expansion of spatial fishing effort is suitably controlled and ecologically sustainable*".

The Guidelines focus on threats to species and communities. For example, the 'Protected species and threatened ecological community protection, Objective 2' states, "*The fishery is conducted in a manner that avoids mortality of, or injuries to, endangered, threatened or protected species and avoids or minimises impacts on threatened ecological communities*". More broadly, the Guidelines focus on fishery ecosystems, for example, 'Minimising ecological impacts of fishing operations, Objective 3', states, "*The fishery is conducted in a manner that minimises the impact of fishing operations on the ecosystem generally*". The roles and services provided by benthic habitats to fishery ecosystems (see Section 1.2) also make this objective relevant to assessing and managing risks posed by bottom fishing.

The Threatened Species Scientific Committee (TSSC), established under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, provides advice to the Minister for the Environment and Water Resources on proposed amendments to the EPBC Act with respect to threatened species and threatening processes. Potential risks to habitats are components to assessing both species and processes. Thus, habitat diversity and condition formed part of the basis for evaluating management options to conserve gulper sharks, nominated for threatened species listing (Daley *et al.*, 2010), while an evaluation made in the context of the nomination of "trawling as a key threatening process to marine ecosystems in the area of the Southern and Eastern Scalefish and Shark Fishery (SESSF)", used habitat metrics to estimate trends in trawl footprint and the effectiveness of spatial management (Smith *et al.*, 2011).

7.6.4.2 International obligations

Australia also has international obligations with regard to managing impact on habitats. Australia is required to complete a Bottom Fishing Impact Assessment (BFIA) for Australian bottom fishing vessels operating in High Seas fishery areas; currently these are the South Pacific Ocean (SPRFMO Area), and the southern Indian Ocean (SIOFA Area) (Williams *et al.*, 2011b and 2011c). These BFIAs form part of Australia's response to United Nations General Assembly (UNGA) Resolutions

61/105 and 64/72, the interim measures adopted by participants in negotiations to establish the South Pacific Regional Fisheries Management Organisation (SPRFMO), and the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO 2008). BFIA's evaluate impact, risk and risk management in assessing the potential for significant adverse impacts on vulnerable marine ecosystems (VMEs). VMEs are defined in many cases by benthic habitats characterised by large fauna such as coral and sponges that provide structural habitat for high biodiversity including fishery species.

7.6.4.3 Eco-certification

A final driver for habitat management is eco-certification processes; these will increasingly plan to account for the sustainability of habitat use. For example, accreditation protocols used by the Marine Stewardship Council (MSC) have used ERAEF Level 2 habitat outputs in a 'calibration' process for this purpose. It is a reasonable expectation that demonstrating the sustainable use of habitats will become of greater importance to fishery sectors seeking national and international eco-certification in the future.

7.7 Summary of Level 2 ERAEF results for habitats

7.7.1 Level 2 ERAEF – the 'productivity-susceptibility' (PSA) analysis

At the intermediate Level 2 (PSA) of the hierarchical ERAEF framework, a semi-quantitative approach uses a general conceptual model of how fishing impacts on ecological systems. The PSA is focused at the level of regional sub-fisheries defined by fishing method (gear type). A set of quantifiable attributes for habitats is used to describe the 'susceptibility' of each habitat to damage that may be caused by specific fishing gears; resilience is generalised as a habitat's inherent 'productivity' (ability to recover from damage). In the ERAEF, photographic imagery was used effectively to provide a standardised method to classify habitats, to visualise the attributes assessed, and to communicate with stakeholders (Hobday *et al.*, 2007).

The aim of the Level 2 PSA method in ERAEF is to identify the potentially high risk impacts of fishing on habitats. The SESSF case study (Williams *et al.,* 2011a) illustrated the ability of the generic framework to achieve this for benthic habitats by screening out lower-risk impacts, and identifying priorities for subsequent quantitative assessments (see examples in **Table 13**). Overall, the results captured the contrasts in risks from sub-fisheries (gear types) identified elsewhere, in heuristic assessments (Dorsey and Pederson 1998) and in quantitative comparisons across habitats (Kaiser *et al.*, 2006). Some of the high-risk fishery-habitat interactions have subsequently been verified by findings of long-lasting and potentially irreversible impacts (Althaus *et al.*, 2009; Williams *et al.*, 2010).

7.7.2 Enabling the uptake of Level 2 results for habitats

Assessment of habitats in the ERAEF process has progressed only to the semi-quantitative Level 2 stage (Smith *et al.*, 2007b). At this stage, analysis is limited mostly to defining and classifying 'types', and the potential impacts of individual gear types. Habitat distribution is examined only at coarse spatial scale, i.e. in relation to depth zones and prominent fishery seabed features (seamounts and canyons).

The end point of the ERAEF Level 2 analysis for habitats is therefore information on 'what habitats are' and 'what are the potential impacts by fishing gears'. This information less amenable to management uptake than Level 2 outputs for species, and is the reason why, "AFMA has deferred the development of an ERM strategy for habitats (and communities) until more refined and meaningful results become available".

It is important to understand the Level 2 analysis for habitats posed different challenges to the analysis for species groups such as fishes. In any given fishery there is much less available information on habitats compared to fishes, and, typically, there is no conventional classification of habitats, let alone fishery-wide mapping. In contrast, taxonomy and distributions are usually well established for the great majority of fishes. As a result, the end-points of the Level 2 analysis differ between the species and habitat component – the most important difference being that species have known (or inferred) spatial distributions that allow the potential risks from fishery interactions to be mapped. Therefore, the evolution of habitat risk assessment will require the spatial context (mapping) to be clearly defined so that extent and location of habitat can be incorporated into quantitative metrics for risk analysis and the development of performance measures.

The methods used in the Level 2 PSA assessment result in risk scores of high, medium or low to reflect potential rather than actual risk. An improved estimate of potential risk needs to account for all management measures currently in place in fisheries, without which the actual risk for some habitats may be over-estimated. While quantifying the actual risk for any habitat requires a quantitative (Level 3) assessment, additional steps can be taken to improve or enhance the Level 2 results (**Section 7.8**), and to account for the risks mitigated by existing management arrangements (see **Section 7.8.2**).

In summary, the development and extension from ERAEF Level 2 assessment of habitats – 'what habitats are' and 'what the potential impacts by fishing gears are', requires (1) the consolidation of habitat types into a small number of mappable units, followed by (2) mapping their distributions to show 'where habitats are' and 'how much there is of each type or unit'. This spatial context will enable the subsequent steps of risk assessment and risk analysis to be completed, and management responses formulated within the ERM framework (**Figure 7**).

7.8 Improving Level 2 habitat methods

As well as evolving habitat risk assessment methods beyond Level 2 (**Section 7.9**), there is also scope to refine and improve analysis at Level 2. The scope is greater for fishery habitats than fishery species because there was typically less knowledge of risks to habitats, and because the available information on habitats is growing more rapidly. The SESSF case study (Williams *et al.*, 2011) identified several opportunities to:

- develop Level 2 assessments for smaller or less complex fishery areas, particularly within ecologically distinct depth zones, and for individual sub-fisheries (gear types) (e.g. Clark *et al.*, 2011).
- focus Level 2 assessment at a particular management issue, e.g. regulation of fishing on individual features such as seamounts or submarine canyons (e.g. Clark *et al.*, 2011).
- develop metrics that classify and map habitats in ways, and at scales, that are relevant to management, and may be rapidly and cost-effectively developed. For example, in the GAB, four bottom types (**Figure 8**) were used as the basis for defining and mapping six types of 'important fishery habitat' and eight types of 'vulnerable fishery habitat" (**Appendix 3**).

These improvements are covered in the following sub-sections.

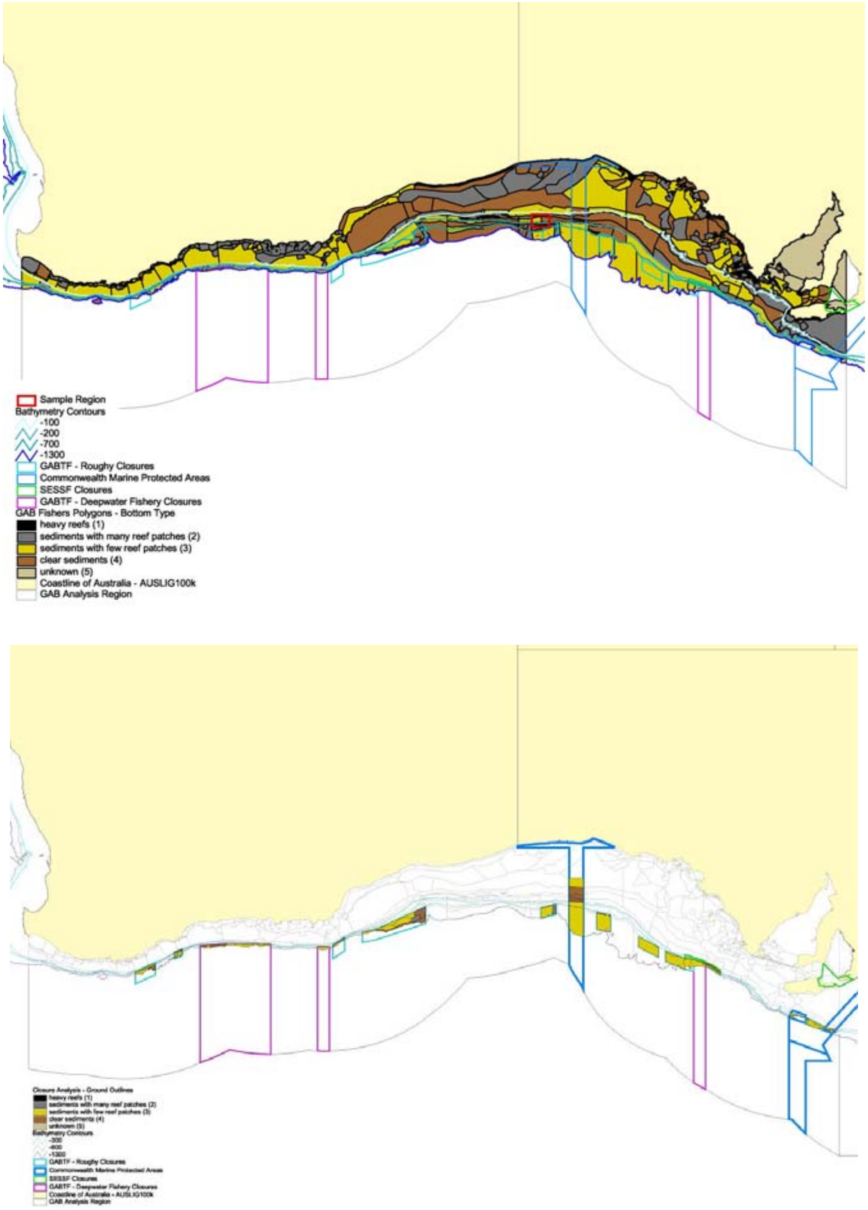

Figure 8. Science-industry mapping of the GAB fishery showing (a) Boundaries of the 484 fishing ground polygons (black lines) within the GAB fishery area with bottom type (terrain) shown to demonstrate how database attributes can be thematically mapped into the polygon template. (b) Boundaries of the 484 polygons (grey lines) within the GAB fishery area showing bottom type (terrain) within existing closed areas to demonstrate how database attributes can be extracted from thematic maps.

7.8.1 Image-based methods to generate habitat lists for assessment

The ERAEF Level 2 PSA results showed that the use of photographic imagery was effective in providing a standardised method to classify benthic habitats and to visualise the attributes assessed. Evaluating potential risks was helped by visualising habitats at the fine spatial scale at which direct impacts of fishing are recognisable. Conversely, we found little useful information on sessile invertebrates, substratum types or impacts in logbook catch records or scientific observer data from commercial fishery operations. The utility of high quality, geo-referenced and quantitative image data for risk assessment purposes is supported by its increasing availability as enabling technology has become simpler and more affordable. For example, photography is increasingly used for non-extractive sampling during observational fishery surveys (e.g. in Australia, Pitcher *et al.*, 2007; Williams *et al.*, 2009; Schlacher *et al.*, 2010).

Notwithstanding the increasing availability of image data, a method based on image-derived data also has drawbacks. The large numbers of habitat types in each risk category generated by our classification – even with the biotic components defined at a coarse level – were not immediately intuitive to stakeholders. Fishers, for example, were familiar with more general definitions based primarily on physical features existing at larger spatial scales, e.g. sand plain, rocky bank, canyon. Multiple 'fine-scale' habitat types were, however, readily aggregated for interpretation and explanation at this intermediate step in the assessment. Finely resolved classifications are most appropriate at Level 3 (fully quantitative) analyses, or where there are concerns about particular species, habitat features or habitat types. Most obviously, quantitative analyses that incorporate physical sampling are needed to determine the impacts of fishing on sediment substrata where effects on small sized and sediment-dwelling biota are unrecognisable in imagery.

In data-poor situations where fisheries areas lack image data, qualitative or semi-quantitative risk assessment can employ an inferential process. This was the case for several areas in Australia's offshore waters where the inferential method was built on image data from adjacent or similar areas, but also incorporated other data from biological collections and bycatch information, GIS mapping of bathymetry, and coarse scale geomorphology ("Method 2" in Hobday *et al.*, 2007). This inferential approach is less satisfactory, partly because some habitat types may remain unidentified, but it is feasible for data-poor situations and is precautionary since it contains habitat types that may be eliminated as additional data is incorporated.

7.8.2 Establishing an attribute set to evaluate fishing impacts

Selection of the attribute set was constrained both by the information available for benthic habitats, and by the timelines and scope of the risk assessment being undertaken, i.e. assessment of all Australian Commonwealth fisheries using a consistent methodology for species, habitats and communities (Hobday *et al.*, 2007). By using 11 individual habitat attributes that were neither reliant on complex analysis nor too specialised (focussed on specific fauna or habitats), we were able to generate data sets that represented the potential risk of the fishing-habitat interactions, were reasonably independent, were understood by stakeholders, and had no missing values.

Some individual attributes were well supported with data for some sub-fisheries, e.g. GIS mapping of the extent of fishing effort within the management area, where fishing position was recorded as latitude/longitude at a resolution of degrees and minutes (i.e. geolocation to 1 n.m.) for many consecutive years. Inevitably, given the variety of attributes and the range of fisheries assessed, other attributes were less well resolved and/or relied heavily on expert judgement. Thus, fishing effort distribution was resolved only at coarse grid scale (30 or 60 n.m.) in some sub-fisheries and in many historical data sets. There was some scope to address this kind of technical uncertainty with analytical procedures (e.g. resolving effort distribution at finer scales using bathymetry and knowledge of the depth at which gear is deployed), but most evaluation of gear-habitat interactions and attribute scoring relied on expert judgement by the assessment team with oversight by stakeholders at consultative meetings during ERAEF implementation (Hobday *et al.*, 2011).

Ideally, attribute scoring thresholds would be calibrated and validated before or during the assessment processes, but a paucity of information for some critical attributes cannot be easily remedied (Auster 2001). For example, knowledge of productivity traits for many structural fauna – longevity, growth rate, fecundity, age at maturity, recruitment and dispersal – is limited or nonexistent, or difficult to apply to aggregated faunal groups, even for species within genera for which expert opinions are provided (e.g. Williams *et al.*, 2010).

An acknowledged weakness of our restricted set of relatively simple attributes was the inclusion of only two productivity attributes. These had a disproportionate effect on the overall risk score, and both strongly reflected an assumed relationship between increasing depth and lower productivity (based on great longevity and slow growth reported for deep fauna). While this relationship is supported by data for some taxa (e.g. Clark *et al.*, 2010) and is consistent with patterns reported elsewhere (Kaiser *et al.*, 2006), the use of only two productivity attributes did result in some over-estimates of risk, or 'false-positives'. One example was a score of high risk for bottom trawling interactions with deepwater high rocky outcrops despite a low encounterability score (many of these habitat types are untrawlable). Counter-intuitive outcomes were screened in the stakeholder consultative process where there was the opportunity to over-ride ('down-rank') such cases. Several additional productivity attributes were considered, but they were not easily quantified and/or were not supported by sufficient information in most fishery areas. They included Habitat connectivity (source-sink recruitment dynamics of structural fauna); Chain of habitats (habitat fragmentation); Naturalness (historical level of fishing impact); and Export Production (flux of organic material to benthos). These kinds of additional attributes, some identified at finer resolution, could be used during Level 3 (fully quantitative) analyses, or in a Level 2 framework where concerns are focussed on particular habitats, species or smaller fishery areas, e.g. for seamounts (Clark *et al.*, 2011).

Arguably more important than identifying false positives, is the need to recognise and avoid 'false negatives' where potential risk is underestimated. False assessments of low-risk interactions that remain unidentified may prevent further assessment being undertaken. An obvious example was the low number of shallow (inner continental shelf) habitats in high-risk lists, especially sediment habitats. In most instances the finding of low fishing risk to inner shelf habitats was driven by a range of susceptibility attributes: relatively large habitat areas, low proportional overlap of fishing effort, large areas of relatively invulnerable habitat (dynamic, naturally disturbed sediment plains with little emergent fauna), and a relatively high proportion of inaccessible habitat (e.g. hard, high relief rocky outcrop to bottom trawl). However, false negatives could be generated by the two productivity attributes that assume higher productivity in shallow waters compared to deep, i.e. faster regeneration time of fauna, and adaptation of fauna to a greater degree of natural disturbance. Trawl impacts on shallow fauna vary greatly between major taxonomic groups (Kaiser *et al.*2006), and may be long-lasting (years to decades) for large structural fauna (e.g. Pitcher *et al.*, 2008) and those associated with biogenic habitat (Kaiser *et al.*2006).

The overall result of the PSA for benthic habitat identified a degree of scale-dependence and relativity when applied to fisheries that operate over large areas, or in the Australian case, when applied at a national scale. As habitat heterogeneity increases as a result of increasing the geographical area of assessment, the scope of individual attributes also increases while the options for ranking remain static (3 categories of high, medium and low risk). This can have the effect of reducing the sensitivity of rank scores. Depth is the obvious example because several attributes are strongly influenced by or correlated with it. Thus, sensitivity may be increased if one or a few bathomes (depth ranges characterised by fauna or physical habitat structures) are included within a single assessment (e.g. Clark *et al.*, 2011).

7.8.3 Habitat mapping at relevant scales

Maps of habitat distributions are required to move beyond purely qualitative assessments of fishing risks to benthic habitats (e.g. Astles *et al.,* 2009). Risk assessment for habitats beyond Level 2 requires a clear spatial context to enable the extent and locations of each type to be analysed. Habitats can be usefully defined in a hierarchy such as the one developed for the Australian marine environment by Last *et al.,* (2010). In that framework, the ERAEF Level 2 habitat 'type' (e.g. a sponge bed) is the lowest level – a 'biological facies'. This is nested within higher level habitats, for example, terrains (e.g. an area of rocky bottom), geomorphic features (e.g. a submarine canyon), depth zone or 'bathome' (e.g. the upper continental slope), and a region or 'province' (e.g. southern Tasmania).

However, the need for spatially explicit data is problematic as detailed habitat maps are rarely available at fishery scale. The distributions of finely detailed habitat types may be interpolated to larger spatial scales using surrogates (depth zones or features) as in the ERAEF, or simply be defined at a coarser surrogate scale in the first place (e.g. Auster and Shackell 2000). Multibeam sonar (swath) mapping in conjunction with integrated environmental variables (Kostylev and Hannah 2007) and/or with validation by physical or photographic sampling, has the potential to define and map habitats at finer spatial scales – but is expensive to collect over large areas and in shallow water (Kloser *et al.,* 2007). In the absence of scientific mapping, quality-assured fishing industry data could possibly be used to produce useful fishery-scale maps. For example, the fishery area off south-east Australia (~141,000 km^2 in 25–1300 m depths) was segmented into 516 'fishing ground' polygons resolved at scales of 10s to 100s km^2. A variety of habitat attributes were recorded for each polygon, and confidence levels for habitat types and boundaries reflected the homogeneity of habitat, the distinctness of habitat boundaries, and the degree of validation and/or the corroboration of information (Williams *et al*., 2006). Fishers' knowledge also provided many insights into species-habitat associations and the ecological roles of habitats. There is incentive to provide such information because greater levels of understanding lead to reduced levels of precautionary management, and more predictability in commercial business planning (Auster 2001).

7.9 Completing risk assessment for habitats

7.9.1 ERA to ERM conceptual framework for habitats

In overview, all major Commonwealth fisheries have been assessed for potential risks to habitats up to Level 2 PSA (Hobday *et al.*, 2007), but none have been assessed beyond this. The steps required to move to ERM for habitats are similar to those already formulated for fishery species (**Figure 7**) but differ in some specifics (**Figure 9**). For each fishery, these include the three following inter-linked risk assessment options:

Residual Risk: re-calculating the ERAEF Level 2 scores for habitats at high potential risk to reflect risk mitigation by existing management arrangements and other factors (**Section 7.8.2**). This process incorporates some of the concepts of a Level 3 assessment and is more cost effective than a full Level 3 assessment (**Table 15**). The results from this step more accurately represent overall risk within a fishery and will help clarify if further (Level 3) assessment is necessary

Enhancing ERAEF Level 2 results: Considering whether to update existing Level 2 results to reflect significant advances in knowledge. This step does not require substantial re-analysis for each fishery, but in areas where new information exists, should establish whether new information may identify false positives among habitat types identified as at potentially high risk, or false negatives among medium to low risk types (**Section 7.8**).

ERAEF Level 3 analysis: Establishing whether there are options to undertake a quantitative level risk assessment beyond Level 2, and whether the cost is justified by the potential benefit (**Section 7.9.2**).

When risk assessment is completed, risk analysis evaluates all of the steps undertaken to translate the assessment of risk into clearly defined actions to mitigate risks within the ERM strategy (**Figure 9**).

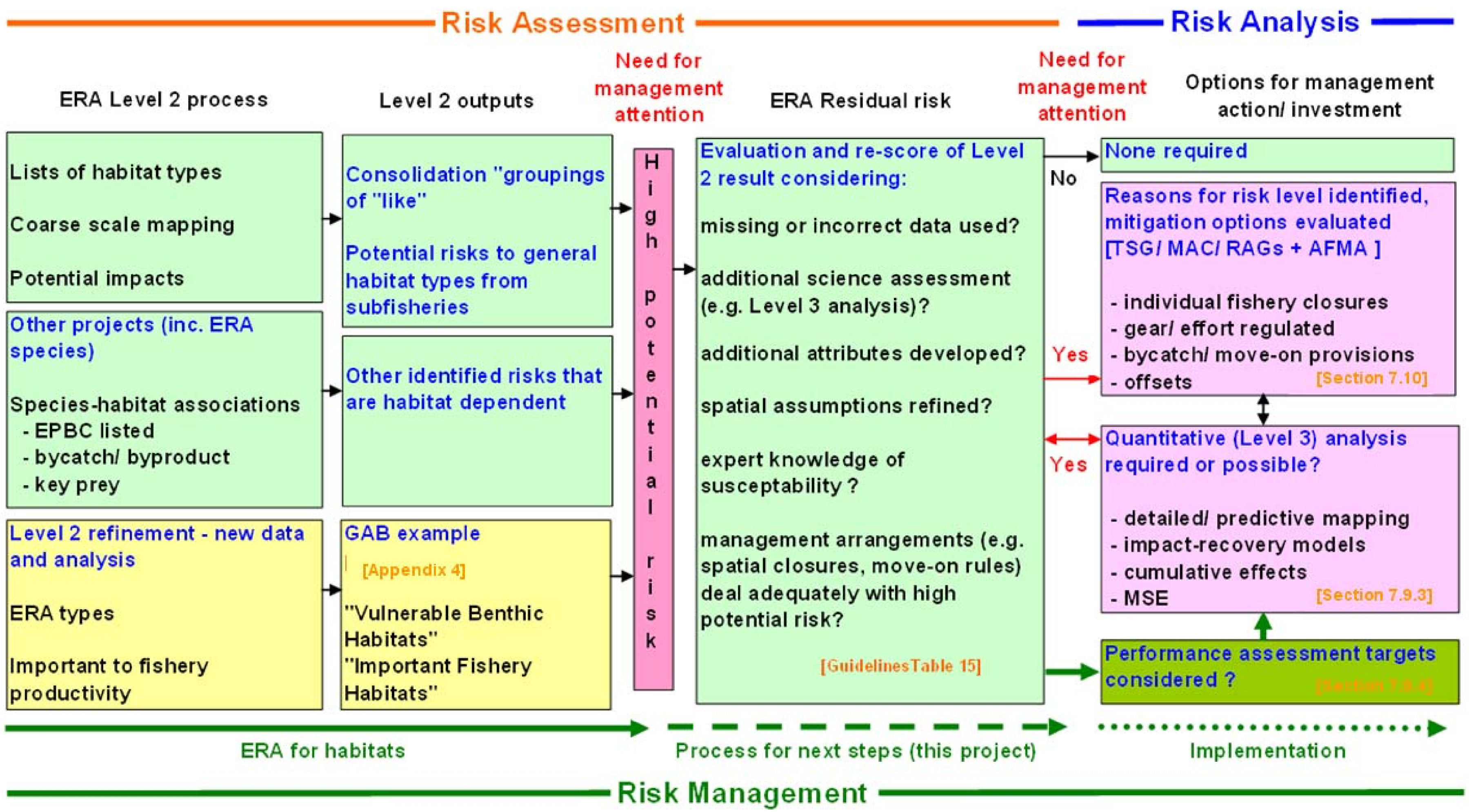

Figure **9**. Diagram showing the components of the risk assessment and risk analysis steps within the ERM framework of **Figure 7**. [References in square brackets are to sections of this report.]

7.9.2 ERAEF Level 2 Residual risk

7.9.2.1 Initial considerations

An improved estimate of potential risk needs to account for all management measures currently in place, and improved knowledge of habitats, for example, based on scientific studies or updated logbook data (**Table 15**). The same list of relevant issues identified for fishery species (AFMA 2010a) is discussed below for habitats.

Improved data

Improved knowledge of habitats may stem from having additional data that affects how individual attributes are scored, in particular because the Level 2 PSA scoring is precautionary and defaults to a high risk ranking for missing attributes. We note, however, that unlike fishery species, no habitat attributes were unscored in the original Level 2 assessments.

Additional information

Since the time of the original ERAEF assessment, additional information may now be available as a result of more detailed risk assessments, such as a Level 3 analysis or alternative approaches. These results could provide a more quantitative analysis than the results from the Level 2 analysis.

Spatial assumptions

The key management measure relevant to habitats is spatial closure of areas within fishery boundaries. While the Level 2 assessment accounts for closed areas in calculating the overlap of fishing effort with habitat types (affecting availability), this is done at only a coarse spatial scale, i.e. depths zones corresponding to the inner and outer continental shelf, upper and lower continental slope.

Interaction and catch data

The extent to which landed bycatch of benthic invertebrate fauna underestimates fishing impact, particularly on habitat forming taxa such as corals and sponges, is unknown but expected to be high and gear dependent. The level of interaction or capture can be more fully scrutinised as part of the Level 2 PSA residual risk process.

Management arrangements

As stated above, the specific benefits of existing management arrangements, e.g. spatial closures, are not taken into account at Level 2 ERAEF even though these arrangements may mitigate risk for some habitat types. The Level 2 PSA residual risk process allows many of these management arrangements to be incorporated into the assessment.

7.9.2.2 Residual risk scoring

In 2007, a set of guidelines was developed by AFMA, CSIRO and stakeholders, to assess the residual risk for species identified as having a high potential risk based on the Level 2 analysis. The guidelines were designed to ensure that a consistent, transparent and repeatable process was adopted across all fisheries. These guidelines have been modified for habitats, where appropriate, and listed below (**Table 15**).

Table 15. Guidelines for assessing residual risk to habitats based on methods used for fishery species.

No.	Guideline	Summary	Differences between guidelines for habitats and species
1	Risk rating due to missing / incorrect information	Considers if susceptibility and/or productivity attribute data for a habitat is missing or incorrect for the fishery assessment, and is corrected using data from a trusted source or another fishery.	There were no missing data for habitats, but attribute correction to be considered.
2	Additional scientific assessment.	Considers any additional rigorous scientific assessment (i.e. rapid level 3 risk assessment, mapping analysis) that calculates the habitat level of risk from fishing, or considers any other scientific published assessments or results.	Quantity and quality of habitat mapping information constantly increasing for many fisheries, and quantitative analysis methods evolving rapidly.
3	At risk due to missing attributes.	When there are three or more missing productivity attributes, considers closely related species within a fishery that have those productivity attributes known.	Level 2 PSA analyses for habitats had no missing values for productivity attributes, but there is scope to develop additional attributes (see Section 7.7.1).
4	At risk with spatial assumptions.	Uses additional information on spatial distribution of habitats to better represent their overlap with the fishery.	Quantity and quality of habitat mapping information constantly increasing for many fisheries, e.g. see GAB case study, Appendix 4.
5	At risk in regards to level of interaction/capture with a zero or negligible level of susceptibility.	Considers observer or expert information to better calculate susceptibility for those habitats known to have a low likelihood or no record of interaction or capture within the fishery.	New information is likely to increase rather than decrease risk (identify false negatives) because bycatch has typically under-estimated the interactions of fishing gear with habitats.
6	Effort and catch management arrangements for target and byproduct species.	Considers current management arrangements based on effort and catch limits set using a scientific assessment for key species.	Management arrangements in high seas fisheries aim to protect Vulnerable Marine Ecosystems (VMEs) which can be characterised by habitats.
7	Management arrangements to mitigate against the level of bycatch.	Considers management arrangements in place that mitigate against bycatch by the use of gear modifications, mitigation devices and catch limits.	Applied only in high seas fisheries at present (in the form of VME evidence reporting and move-on provisions).
8	Limits on associated species through other management arrangements.	Considers the implications of management arrangements for a particular species on other associated species.	Habitats are already defined by groups of co-occurring species in Level 2 PSA analyses, and as VMEs in high seas fisheries – however, formal classification is needed.
9	Management arrangements relating to seasonal, spatial and depth closures.	Considers management arrangements based on seasonal, spatial and/or depth closures.	Together with guideline #4, the most relevant to assessing residual risk for habitats.

Guideline 2 was most commonly used for residual risk assessment of fishery species. We anticipate Guidelines 2, 4 and 9 will be most useful for assessing residual risk for habitats. Clear decision rules will need to be developed that can be applied to a habitat (if relevant) to calculate the Level 2 PSA residual risk. Decision rules should be developed during the initial residual risk evaluations. Each of the guidelines will be applied on a habitat-by-habitat basis to determine the Level 2 PSA residual risk within the fishery.

When determining the Level 2 PSA residual risk for habitats, all considerations included in the calculation process must be recorded. These include the individual guidelines applied, and a clearly stated and detailed justification. This ensures that a transparent process is maintained. In review of the ERAEF results, the guidelines will be applied to all high risk species by managers in consultation with MAC members and experts. Broadly, the application process involves the following steps.

- Sort the ERAEF habitat results by potential risk, then group the high risk habitats by general type depth zone and area within the fishery
- Create a list of all management arrangements not included in the Level 2 PSA results for reference when applying the guidelines
- Consider each management arrangement relevant to high risk habitats
- Collate spatial information from experts, observers, and logbook data for all high risk habitats for reference when applying the guidelines
- Decide which guidelines (if any) applies to each of the high risk habitats by conducting a habitat-by-habitat application
- Make changes to the necessary attributes, productivity and susceptibility scores to calculate the Level 2 PSA residual risk score
- Record all workings, guidelines used, how they have been applied and a justification for the Level 2 residual risk score
- Provide preliminary Level 2 PSA residual risk results to MACs for feedback
- Finalise the Level 2 PSA residual risk results for release

7.9.3 Quantitative (ERAEF Level 3) assessment

At the conclusion of the Level 2 PSA assessment, and/ or following Residual Risk assessment, habitat units may remain at high risk from fishing impacts. At this stage a quantitative Level 3 analysis for habitats may be warranted (**Figure 2)**, and, as for species, this can take various forms. While quantitative risk assessments already exist for many species in the form of stock assessments, there are not equivalent analyses for habitats.

Level 2 of the ERAEF considers risks to habitats from fishing by detailing the vulnerability of habitat types classified at fine scale, but with habitat areas and distributions quantified at relatively very coarse spatial scales. This alone may be sufficient for precautionary and pre-emptive management action within an EBM framework (Astles *et al.,* 2009), or to regulate fishing within conservation reserves – as has been the case with deepwater benthic ecosystems off temperate Australia. However, quantitative analyses are typically required as the basis for implementing management actions.

Quantitative analyses for habitats can be built into management frameworks using large spatial scale mapping of impact from fishing (Sharp *et al.*, 2009) or climate (Game *et al.*, 2008); by predicting habitat distributions (Kostylev and Hannah, 2007; Clark and Tittensor, 2010); mapping habitat sensitivity (Hiddink *et al.*, 2007); or species and assemblage recovery rates (e.g. Hiddink *et al.*, 2006; Pitcher *et al.*, 2008). Alternatively, models of benthic impact may form part of integrated management planning or management strategy evaluation (Sainsbury *et al.*, 2000; Dichmont *et al.*, 2008; Ellis *et al.*, 2008; O'Boyle and Worcester, 2009; Bustamante *et al.*, 2010). Ecosystem models provide the opportunity to integrate habitat analysis with analyses of species or communities, e.g. Atlantis – Fulton *et al.,* 2007; Ecospace - Bulman *et al.,* 2006).

However, the ‘data-poor’ reality for most fisheries means that mapping habitats may be limited to estimating their associations with features and depth zones (bathomes). In data-poor cases, precautionary decisions need to be made about risks of localised extinctions of certain habitat types, and fragmentation leading to the associated loss of connectivity between types. For all areas, irrespective of data density, there is a need to account for cumulative impacts of different sub-fisheries (as well as other human pressures), and their combined impacts through time (e.g. Foden *et al.*, 2010), because, at Level 2, the ERAEF method assesses sub-fisheries independently. In cases where extensive data exist, risk assessment will more ideally be based on understanding the roles of habitat for individual species (e.g. Bustamante, *et al.*, 2010) and for broader ecosystem functions such as maintaining population connectivity and trophic relationships. Establishing habitat role and value requires integrating many ecologically relevant data sources, and then building the concept of ecological resilience into management planning (Thrush and Dayton, 2010).

Before proceeding to a fully quantitative Level 3 assessment, investigation of suitable existing information to further understand the risk scores for high risk units should be identified. This may help to overcome some of the constraints of the Level 2 PSA results (outlined above in **Section 8.2**) prior to proceeding to a more costly Level 3 analysis for the remaining high risk units. Science-industry collaborations, such as those developed for Commonwealth fisheries off temperate Australia (Williams 2006, 2010a), have the potential to provide low-cost mapping information at relevant scales (moderate resolution over large areas), and derived metrics for habitat vulnerability or ‘fishery value’, to support risk management for habitats.

7.9.4 Reference points

A recent review by Sainsbury (2008) considered best practice reference points for Australian fisheries using the same ecosystem elements included in the ERAEF framework: target, bycatch and TEP species, habitats and communities. Sainsbury defined reference points as, “the operational or measurable benchmarks that identify targets to be achieved on average, limits to be avoided, or triggers to initiate specific management responses”. A fishery is expected to approach or fluctuate around a target reference point, to have a very high probability (at least 90%) of not violating a limit reference point, and to have trigger reference points and planned management responses that achieve these two outcomes.

Sainsbury noted that direct management of fishery impacts of habitats is at an early stage of development and implementation, and that there is no widely agreed approach to the selection or use of reference points for habitat management. He provides a simple theoretical outline for the likely limits of habitat modification to sustain a tropical continental shelf fishery (based on Sainsbury 1991), and noted that examples of best practice are emerging. For example, Link (2004) suggested that the area covered or occupied by long-lived seabed biota (such as corals) could provide a good indicator of habitat functionality and disturbance. Link suggests that reduction to 70% of the natural level is an appropriate ‘warning threshold’ and that a reduction to 50% of the natural level should be a limit reference point.

Sainsbury (2008) suggests “the best practice target reference point for habitat impacts is for no impact on relevant seabed habitats, modified as appropriate to include acceptance of minimal and temporary impacts. This is consistent with the theoretical predictions that yield from a habitat-dependent target species is reduced if the relevant habitat is reduced, and that reduction of the habitat to less than 0.6 of the unfished areal extent could result in the target species becoming excessively depleted.” Thus, achieving and maintaining high yield from a habitat-dependent target species requires minimal loss of its habitat.

In the context of 'best practice', Sainsbury notes the need to identify 'critical habitats' for species of interest, and to ensure such habitats are exposed to no more than minimal and temporary impacts. Defining critical habitats needs to consider that different life history stages of individual species may use different habitats (a 'chain of habitats', e.g. Naiman and Latterell (2006)), and that individual habitat types may support a range of species, each with a different level or type of dependence on the habitat. If a wide enough range of species is considered this effectively becomes a 'no net loss' requirement from the unfished habitat coverage because all habitats are likely to be critical to one species or another.

Sainsbury notes that, "in a fishery management context, the ecosystem service of interest is usually the productivity and persistence of fish populations, so the habitat usage by these populations defines the relevant level in the hierarchy of habitats. Additionally it is usually not feasible to manage fishing activities on very small space scales, because of the movement patterns of the target species, the large area affected by the fishing gear or the costs of fishing constraints and compliance." In practice, this means (1) that the relevant scales of habitat definition for fishery management are typically at scales of 10s to 100s of kilometres – the intermediate levels of the Last *et al.,* (2010) hierarchical framework – and, (2) that there is a need to specify the habitat 'type' at a specific scale within the hierarchy. Using the example above (**Section 7.8.3**), sponge beds on rocky bottom in an upper slope canyon will differ in their role for fishery productivity compared to, for example, sponge beds on the continental shelf, or in a different region. This classification is critical because, as Sainsbury also notes, the full spatial range of the habitat type should be included in calculating the proportions of the unfished areal extent of habitats, and because, in some circumstances, it may be appropriate or necessary to consider habitat quality rather than simply areal extent. This raises another challenge for habitat management because, as Sainsbury points out, "indicators of habitat disturbance are very weakly developed, so there is little agreement on what to measure and what would constitute disturbance."

In summary, Sainsbury states that the best practice limit reference point for habitat impacts is a reduction to no more that 0.3 of the pre-fished areal extent, i.e. ≥30% of the habitat type remains unimpacted. This will avoid excessive depletion of habitat-forming organisms, and of habitat-dependent fish species that are not subject to fishing mortality. However, there are additional theoretical grounds for regarding 0.3 as inadequate for protecting habitat-dependent fishes that are also subject to significant fishing mortality (i.e. approximately FMSY or greater). Further, as some habitat-dependent by-catch species may have low productivity, and consequently a low FMSY, significant fishing mortality may result from relatively small catches. In cases where the species is exposed to significant fishing mortality in addition to habitat loss, Sainsbury notes that a more appropriate limit reference point would be reducing relevant habitats to no less than 0.6 of their unfished areal extent. Overall, Sainsbury notes there is justification in using an approach similar to that applied to account for trophic dependencies when harvesting key prey species, but where the exact nature of the habitat dependencies are not fully understood or explicitly modelled. That is, in the absence of explicit models of the relevant system to provide specific guidance, habitats should not be reduced to less than 75% of their unfished areas.

A pragmatic alternative to mapping and modelling habitat types is to develop derived metrics based on ecological 'valuation'. In a case study in the Great Australian Bight (**Appendix 4**), 'vulnerable benthic habitats' and 'important fishery habitats' were defined during a consultative process. These provide the basis for fishery-scale mapping thematic and simple performance evaluation, i.e. against a reference point, but lack specificity because many different habitat types are aggregated into a relatively small number of categories for mapping (i.e. 6 VBH types and 8 IFH types – **Appendix 4**).

7.10 Risk analysis and management responses for habitats

7.10.1 Context

Despite the legislative and policy requirements to manage habitats in ways that maintain the integrity of fishery ecosystems (**Section 7.6.4**), there are still substantial implementation challenges for Commonwealth and international fisheries. These stem both from the currently incomplete level of development of risk assessment methods for habitats, and from the generally poor knowledge of the ways in which habitats support fishery ecosystems and fishery productivity.

Assessment of habitats in the ERAEF process has, in most fisheries, progressed only to defining and classifying habitat types, mapping their distributions at coarse spatial scales, and assessing the potential impacts by fishing gears. This information is less amenable to management uptake than ERAEF outputs for species (**Section 7.7**). Because there is much less available information on habitats compared to fishes, and typically no fishery-wide mapping, the evolution of ERA and ERM is therefore dependent on methods that more clearly define habitat distributions (mapping). However, even where high quality mapping exists, experience shows there may be strong resistance by fishers to habitat protection measures that result in the loss of access to particular fishing areas. In some cases it can be legitimately argued that habitat-management actions may have unintended consequences, for example that area closures may redistribute and/ or concentrate fishing effort on other vulnerable habitats. However, there is a need to clarify, and ideally quantify, the ecosystem services provided by habitats beyond simply conserving biodiversity.

With this context, we use the following sections to briefly outline:

- options for managing fishery habitats in the context of an ERM framework (**Section 7.10.2**)
- a suggested summary of actions (**Table 16**),
- specifying the role of Technical Support Groups (as have been established for species) (**Section 7.10.4**), and
- a outline of ERM reporting requirements for habitats (**Section 7.10.5**)

7.10.2 Management options

7.10.2.1 Area closures

Area closures have the potential to mitigate risks of fishing impacts to vulnerable habitats by limiting the availability of habitats to the fishery, and to influencing (reducing) encounterability. However, closures are typically implemented in response to fishery species issues without considering the effectiveness of closures for mitigating impacts on habitats (e.g. SESSF closures for ling spawning aggregations). When habitat protection has been articulated as a goal of closures, habitat information may not have been used to define either where closures occur, or how it could be used to evaluating the effectiveness of closures, e.g. deepwater closures for orange roughy in the SESSF CTS and GABTF.

It should be noted that many fishery closures and marine reserves function as ‘managed areas’ that provide no permanent protection for habitats. This is either because they are temporary or voluntary (e.g. SESSF ling closures), or because they permit regulated fishing (orange roughy closures, gulper shark closures, multiple-use areas of reserves).

Options for habitat protection can provide ‘contrast’ between conservation and socio-economic objectives in a qualitative management strategy evaluation (MSE) framework. One example, although in a species context, was the development of a closure network to protect gulper sharks (Daley *et al.,* 2010; Williams *et al.*, 2011d). In that example, the criteria used to assess the suitability of candidate closed areas for gulper sharks were developed from EPBC guidelines for assessing threatened species and included habitat diversity, extent and condition. MSE frameworks transparently capture the trade-offs between (often competing) conservation and economic imperatives and therefore have a potentially important role in the evolving ERM process for habitats. The opportunity to establish this link exists because the development of MSE models is a continuing activity that supports AFMA's adoption of EBFM approaches (Smith *et al.,* 2007a).

Determining the availability of vulnerable habitat types to the fishery should, more ideally, involve a synoptic (fishery scale) inventory of habitats and closures, (1) in relation to their roles for sustaining fishery ecosystems, biodiversity and economic returns, (2) at appropriate spatial scales (e.g. terrains and features within depth zones, and (3) against reference points. Fishery-scale inventory is possible where Commonwealth Marine Reserves have been implemented during the roll-out of Australia's National Representative System of Marine Protected Areas (NRSMPA). Currently this is only the South East Region (the CTS region of the SESSF), but the NRSMPA will be complete by 2012.

In fisheries where the inventory of high risk habitats against reference points indicates the need for area closures, the options considered should take account of dynamic effects including the possible responses to changing climate (e.g. Hobday 2011), and the scope for restoration initiatives.

7.10.2.2 Gear restrictions

Gear restrictions have the potential to mitigate risks of fishing impacts to high risk habitats, primarily by moderating the encounterability of gear types (sub-fisheries) with habitats. Because impacts on high risk habitats are expected to be long-lasting in most cases, gear restrictions will need to be long-term initiatives and spatially regulated. As a consequence, gear-related management options form a sub-set of the considerations for area closures.

7.10.2.3 Altered fishing patterns

Management actions that alter fishing patterns, similarly to gear restrictions, have the potential to mitigate risks of fishing impacts to vulnerable habitats by limiting the encounterability of gear types (sub-fisheries) to the habitats. As for gear restrictions, impacts on high risk habitats are expected to be long-lasting in most cases, and so altered fishing patterns will need to be long-term and spatially regulated. Again, management options for altering fishing patterns form a sub-set of the considerations for area closures.

7.10.2.4 Bycatch limits and move-on rules

Management measures to limit habitat bycatch (predominantly fauna such as corals and sponges, but including biogenic substrates such as those formed by stony corals) are well developed for Australian vessels fishing in international waters but are not applied in domestic Commonwealth fisheries. Measures include recording evidence of interactions with vulnerable habitats, move-on provisions triggered by bycatch of benthic fauna, and spatial management initiatives explicitly focussed on habitat protection. In these respects, AFMA's international habitat management measures provide important signposts for ways to influence encounterability and to develop the ERM framework for habitats.

7.10.2.5 Offsets

Although there may be limited opportunities to use offsets to reduce risks to habitats, the potential of artificial reefs to enhance the areas or quality of specific habitat types is worthy of desk-top examination. For example, seabed oil and gas industry infrastructure and shipwrecks frequently support attached epifauna such as sponges. Discarded 'hard surfaces' or scientifically designed artificial reefs, if strategically located, may have the potential to enhance some habitat types by maintaining connectivity between isolated populations. A good example is southern Australia's very narrow but productive upper continental slope (200-700 m depths) where fishing impacts are widespread in some areas (e.g. the SESSF CTS area – Smith *et al.*, 2011), and where hard-bottom habitat is apparently very limited in other areas (e.g. the GAB).

7.10.3 ERM Action List for habitats

Here we suggest a summary of actions that can be taken to assess and advance the ERA-ERM framework for habitats, showing the individual tasks, their goals and the processes required to complete them (**Table 16**). This table should form the basis of discussions for AFMA in implementing responses to habitat risks indentified in the ERAEF.

7.10.4 The role of an expert Technical Support Group

A key component of the ERA to ERM process for species was the formation of expert Technical Support Groups (TSG) to provide advice and analysis during both the risk assessment and risk analysis phases. For example, the Chondrichthyan Working Group identified mitigation measures that might be effective for sharks and rays, and in what circumstances they should be used

An equivalent group focussed on mitigating risk to fishery habitats could progress at least three key areas: (1) developing the science to underpin the establishment of references points and identifying performance measures by determining what are acceptable levels of impact and what constitutes an 'undesirable' consequence for habitat; (2) determining what monitoring is required to assess recovery from impact-related change and differentiate this from broader environmental change, e.g. climate related changes; and (3) defining ways to increase habitat-specific data collection to map spatial distribution of higher-risk habitat types – for example, by improving habitat bycatch recording by fisheries observers, or capturing habitat classifications in a form that can be readily assimilated into existing frameworks.

7.10.5 ERM reporting for habitats

The outputs from risk assessments relate to individual fisheries, but there is scope for considering integrated risk assessment and risk analysis across sub-fisheries, across fisheries and across components (see **Section 9**). Integration in this way, which is effectively the same as a cumulative assessment, offers the prospect of being cost-effective, and is intuitive when a habitat type is impacted by more than one sub-fishery, and/ or where the distribution of a type extends across fisheries. There is also scope to simultaneously assess risks across components when species have strong habitat associations, and/or when habitat types are co-located with ecological communities.

Integrated or cumulative outputs may be necessary to develop reference points, and measure performance against them (**Section 7.9.4**). The time required to develop operational reference points and assess performance means that it will be necessary to define both near-term and longer-term management aims. Accordingly, ERM will need periodic update that reviews mitigation measures in the light of technical developments in the assessment framework, as well as results from ongoing monitoring.

Table 16. A tabulated action list for advancing the risk assessment and risk management approach for habitats showing individual tasks, their goals and the expected outcomes.

Action	Task	Goal	Outcome
1	Establish a Technical Support Group	Review the options for advancing all aspects of ERA and ERM for habitats, including defining specific needs for methods of individual fisheries, and key personnel needed to contribute to the work.	Developing the ERA to ERM framework for habitats is fully specified.
2	Review and summarise the status of data and new research for individual fisheries as the first step in residual risk assessment.	Advance ERA Level 2 risk assessment for habitats by commencing residual risk assessment and scoping the opportunities and difficulties for individual fisheries – including those assessed outside the ERA process (e.g. sub-Antarctic and international fisheries).	ERA risk assessment for habitats is comprehensive across the Commonwealth jurisdiction, and the ERA-ERM process is advanced to the next major step.
3	Complete a full inventory of habitat types available/ unavailable to individual fisheries when Commonwealth Marine Reserves have been implemented (2012).	Complete the risk assessment for habitats.	Completion of risk assessment enables risk analysis and management responses to be formalised.
4	Develop reference points for habitats.	Explore the opportunities to develop quantitative management strategy evaluation frameworks for habitats (emulating, to the extent possible, those developed for fishery species).	Explicit and assessable measures of habitat health and management performance supports Australia's obligations to domestic (EPBC) and international (UNGA) ecosystem based management.
5	Finalise the review, evaluation and reporting processes.	Establish a parallel process for habitats as exists for species.	A formal reporting structure and process enables Australia to meet its domestic (EPBC) and international (UNGA) obligations with respect to managing habitats in an ecologically sustainable manner that avoids significant adverse impact.
6	Implement bycatch monitoring and reduction measures already established for Australian vessels in international fisheries to domestic Commonwealth fisheries.	Expended, standardised, systematic and quality assured collection of habitat data by seagoing observers, e-monitoring and by using other enabling technology (e.g. compact sensors on fishing gear).	A refined spatial context for risk assessment, analysis and responses to mitigate impacts to vulnerable (high risk habitats) is provided. Informed and specific management responses (e.g. move-on provisions) are enabled. Key uncertainties, such as the degree to which landed habitat bycatch underestimate impacts are reduced.

Development and review of ERM strategies will rely principally on existing reporting mechanisms and frameworks in place within management policies and mitigation strategies. These would include, for example, details (including aims and performance measures) of closed areas or other spatial management measures, and by-catch reduction measures.

The form of the ERM output will need to specify the outcomes of ERM strategies and measures in a way that facilitates their incorporation into a number of processes. These include annual reporting to DSEWPaC, periodic fishery assessments for WTO accreditation, and assessments for Regional Fishery Management Organisations (RFMO) or equivalent agencies to which Australia has reporting obligations in regard to high seas fishing (currently the South Pacific and Indian Oceans).

Reporting should describe the appropriate management arrangements developed to address the high priority habitats remaining after the risk assessment phase (including evaluation of residual risk) is completed. As for species, the ERM framework will need to tie into current fishery management processes and structures so that additional measures to address high risks can be easily implemented. Again, following ERM development for species, the risk management response for each fishery will need to be fully documented to ensure transparency in the process and allow for easier co-ordination within and between fisheries. The ways in which management responses address the requirements of the EPBC Act, and the expectations of EBFM, will need to be explicit.

7.11 Conclusions

The impacts of Australia's domestic and international fisheries on habitats need to be assessed against the expectations of EBFM, because of requirements under the EPBC Act, and obligations to United Nations General Assembly (UNGA) Resolutions 61/105 and 64/72, and for eco-certification purposes. In the context of examining risks posed by bottom fishing, 'habitat' is the seabed and fauna existing at a variety of spatial scales that provide roles or 'services' to the fishery ecosystem.

Assessing the potential risks to fishery habitats in the ERA process has, in most fisheries, progressed only to defining and classifying habitat types, mapping their distributions at coarse spatial scales, and assessing the potential impacts by individual fishing gears – the Level 2 (PSA) assessment. Level 2 outputs for habitats are less amenable to management uptake than equivalent outputs for species because there is much less available information on habitats, and typically no fishery-wide mapping. The evolution of ERA and ERM is therefore dependent on risk assessment methods that more clearly define habitat distributions (mapping), and that fully account for existing mitigation measures and new data (residual risk assessment). Guidelines for assessing residual risk are provided. At the conclusion of the Level 2 PSA habitat assessment, and/ or following residual risk assessment, a quantitative Level 3 analysis may be warranted for habitats remaining at high risk; as for species, this can take various forms (see **Section 7.9**).

The management options available for ERM of habitats are outlined (**Section 7.10.2**). In regard to spatial (area) closures, we draw attention to the fact that many fishery closures and marine reserves provide no permanent protection for habitats, either because they are temporary or voluntary, or because they permit regulated fishing. We suggest the ERM framework should consider developing best practice reference points for managing and monitoring habitats. Reference points will need to specify the spatial scales at which habitats are defined, and clarify the fishery ecosystem services provided by habitats, particularly to high risk species and high priority species with strong habitat dependencies. A suggested summary of actions (**Table 16**) is provided to enable the further develop of ERA to ERM for habitats. These include specifying the role of Technical Support Groups (as have been established for species) (**Section 7.10.4**).

The outputs from risk assessments relate to individual fisheries, but there is scope for considering integrated risk assessment and risk analysis across sub-fisheries, across fisheries and across components (see **Section 9**). Integration in this way, which is effectively the same as a cumulative assessment, offers the prospect of being cost-effective, and is intuitive when a habitat type is impacted by more than one sub-fishery, and/ or where the distribution of a type extends across fisheries.

The time required to develop integrated or cumulative outputs, or operational reference points, means that it will be necessary to define both near-term and longer-term management aims. Accordingly, ERM will need periodic update that reviews mitigation measures in the light of technical developments in the assessment framework, as well as results from ongoing monitoring. We briefly discuss ERM reporting requirements for habitats (**Section 7.10.5**).

8 Benefits

The purpose of this project was two-fold: (1) to complete and test the Level 2 habitat assessment approach for the Ecological Risk Assessment for the Effects of Fishing, and (2) develop the approach to allow Level 2 habitat risk results to be actioned by management (ERA to ERM). These objectives were achieved as planned in the project application.

The direct beneficiaries of this research will be the fisheries management agencies of Australia, as they can complete adoption of ERAEF results and meet national and international obligations associated with fisheries management. Beneficiaries include all Commonwealth fisheries, as they must demonstrate compliance with the EPBC Act and undergo strategic assessment. Outcomes will include improved information for fishery managers to determine management responses to habitat and community issues, leading to clear benefits in allowing fisheries to meet EPBC criteria and pass strategic assessment. Indirect benefits also accrue for fisheries, via clear processes for risk identification and management, which makes business operation more certain. Eco-certification prospects also enhanced, for example, the Marine Stewardship Council recognizes the ERAEF approach as worlds-best practice, and is seeking to incorporate some elements in it's own assessment process. Eco-certification of fisheries, such as through MSC, will be directly facilitated by the Level 2 ERAEF methods and results which meet the needs for Principle 2 assessment (non-target species, habitats, and communities) using the new MSC risk-based approach (which is derived from the ERAEF approach).

The ERAEF tools developed by CSIRO and AFMA can be applied to all fisheries with sufficient data. In the absence of data, the method guides the collection of suitable data. The ERAEF approach allows fisheries to demonstrate knowledge of risks to sustainability and focuses management actions (Ecological Risk Management, ERM).

9 Further Development

These ERAEF methods are evolving over time, and improvements being suggested or implemented around the world (e.g. Patrick *et al.*, 2010; Arrizabalaga *et al.*, 2011; Tuck *et al.*, 2011). Ecological Risk Assessments in general are now considered important tools in the fishery management toolkit (Smith *et al.*, 2007a; Plaganyi *et al.*, 2011). Thus, continued improvement will be business-as-usual for the coming years, as was the case with stock assessments, and is the ongoing case with harvest strategy development. Data used in this project are stored at CSIRO Marine and Atmospheric Research, Hobart, and as for previous ERAEF projects the species database is updated regularly, and used to provide extracts for other applications in Australia and elsewhere. The project team (specifically Mike Fuller as data custodian) can facilitate access to these data for other projects, and the databases are established to accept data for assessment of other fisheries using the methods developed in this project.

The full set of ERAEF methods have been developed over the course of two projects (**Figure 10**). The community methods are now tested and have been applied though to Level 2 for the SESSF. Cumulative methods for species (FRDC 2011/29) have been initiated as an addition to the ERAEF hierarchy, and should be considered in future for the habitats and communities components.

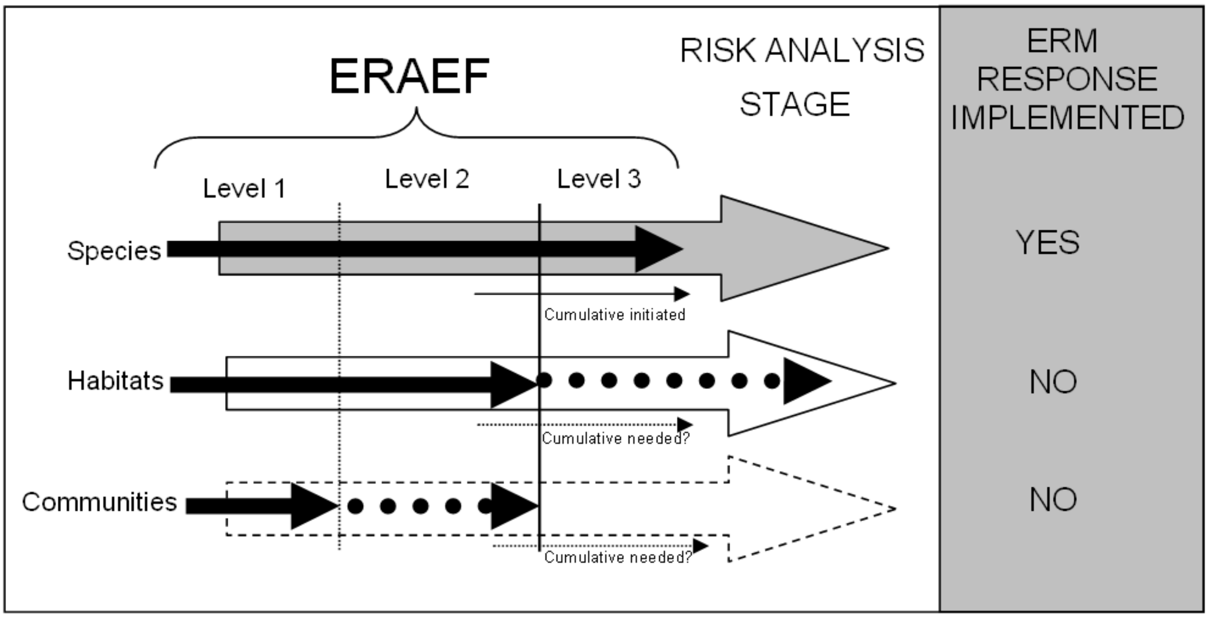

Figure 10. Development of the ERAEF, risk analysis, and ERM management response within the ERM framework – an adaptive management loop. The ERAEF methods have been developed over the course of two projects (Stage 1; Hobday *et al.,* (2007), solid arrows; Stage 2 (current project) dotted arrows).

The ERAEF forms part of a fisheries management loop (**Figure 3**). The process describing the risk analysis stage of the ERM cycle has been completed for species in most major fisheries (AFMA reports provided at http://www.afma.gov.au/managing-our-fisheries/environment-and-sustainability/Ecological-Risk-Management/). The current project has shown how ERAEF habitat results from Level 2 (in this case) would proceed through to an ERM management response. Level 2 community results also need to proceed through a similar process, pending discussion with AFMA. While results from any level in the ERAEF can move to the risk analysis stage, operationally AFMA has used the Level 2 (PSA) or Level 3 (SAFE) results. The next step in ERM is implementation of the risk assessment and risk analysis findings, which AFMA has completed for the species components for most major fisheries. Completion of this project now enables the habitat component to proceed similarly by providing a set of residual risk guidelines and potential management responses, and a table of suggested actions. However, a number of additional steps should also be considered for both the community and habitats (**Section 7)** components in the ERAEF approach, as detailed in the following sub-sections.

9.1 Next steps for development of Level 2 community assessments

9.1.1 Extension to other fisheries

The Level 2 methods have been tested on one fishery in this project, which mainly captures teleost fishes and Chondrichthyan species (Wayte *et al.*, 2007). A logical next step is to apply the methods to a number of other fisheries, as has occurred for species and habitats.

Lack of detailed data on invertebrates might be a serious shortcoming in other fisheries that focus on invertebrates such as scallop, squid or prawn fisheries, as the method can certainly be applied if data exists. If there is insufficient data, then management decisions may need to be made based on level 1 assessment results.

Overall, improved data gathering for a range of species as a result of fisheries monitoring coupled with improved databases from non-fishery sources (e.g. fishbase, OBIS) will improve the ability to assess potential community impacts resulting from fishing for a range of gears, geographic regions, and species mixes.

9.1.2 Extension to Level 3

At the conclusion of the ERAEF Level 2 assessment, decisions about the action regarding the high risk units are required (**Figure 2)**. Management can respond to risks based on the Level 2 results, as has occurred for some species (Hobday *et al.*, 2011), or decide that more detailed assessment is required.

Development of Level 3 community assessment methods would enable the quantitative ecological attributes discussed earlier to be used. This method would require quantitative knowledge, which is not always available. Ecosystem models, such as Atlantis, which can represent multiple threats and fisheries are an example of a Level 3 approach (Fulton 2010). Less complex models, such as Ecopath, may also be developed for the high risk communities, and then can be used to quantitatively evaluate the impacts of fishing. There are a number of examples of these models for Australia (see Brown *et al.*, 2009 for a recent summary; Bulman *et al.*, 2010).

We suggest that development or application of Level 3 assessments may not be feasible or practical before ERA to ERM community risk management options are considered as detailed in **Section 7** for habitats. These steps are detailed in **Table 17**, and would form the basis of research project as completed for Habitats in **Section 7** of this report.

Table 17. Summary table of actions required to complete up to the ERM process for communities.

Action	Task	Goal	Outcome
1	Apply methodology to more (selected) fisheries, preferably those with high priority due to high risk species and communities identified from SICA analyses	To evaluate and compare results across a range of fishery (gear) types	Community analyses for selected fisheries (highest priority fisheries across range of gear types) available for step 2 (review of methodology)
2	Review the methodology in terms of stated community objectives and ecological principles particularly with reference to AFMA's obligations, ease of application, availability of data, and any other constraints	To re-develop or streamline both the data collation and the application of methodology across the range of assessed fisheries	A more efficient and robust methodology and application
3	Review existing Level 2 community analyses if necessary and analyse remaining fisheries as required.	To complete community assessments of all fisheries (as required)	Identify all communities at high risk of impact from fishing (for step 4)
4	Review and summarise the status of data and new research for individual fisheries as the first step in residual risk assessment	Commence residual risk assessment and scope the opportunities and difficulties for individual fisheries - including those assessed outside the ERA process (e.g. sub-Antarctic and international fisheries)	ERA risk assessment for communities is comprehensive across the Commonwealth jurisdiction, and the ERA-ERM process is advanced to the next major step
5	Develop reference points for communities	Explore the opportunities to develop quantitative management strategy evaluation frameworks for communities	Explicit and assessable measures of community health and management performance supports Australia's obligations to domestic (EPBC) and international (UNGA) ecosystem based management
6	Finalise the review, evaluation and reporting processes	Establish a similar process for communities as exists for species	A formal reporting structure and process enables Australia to meet its domestic (EPBC) and international (UNGA) obligations with respect to managing communities in an ecologically sustainable manner that avoids significant adverse impact

9.2 Next steps for the operationalisation of the habitat results

The process outlined in **Section 7** for habitats identified the next steps that need to be taken in going from ERA to ERM, particularly in choosing between different management options to reduce risk for habitats identified as potential high risk. These steps are provided as a table (**Table 18).**

Table 18. Summary table of actions required to complete the ERM process for habitats.

Action	Task(s)	Goal(s)	Outcome(s)
1	Establish a Technical Support Group	Review the needs and options for advancing all aspects of ERA and ERM for habitats, including defining specific needs for methods or individual fisheries, and key personnel needed to contribute to the work	The process to develop the ERA to ERM framework for habitats is fully specified
2	Summarize the existing Level 2 information available for all Commonwealth fisheries and identify the scope to enhance Level 2 outputs before progressing to Residual Risk Assessment	Prepare and summarise the existing habitat outputs for Commonwealth fisheries. Contextualise this information by reviewing recent methodological developments, e.g. CCAMLR; New Zealand's ERA-based approaches, and clarifying the fishery ecosystem services provided by habitats	Synthesis of existing work and aggregation to management scale is completed. Australia's ERA/ERM methods are calibrated with international approaches to fishery risk assessment. Shared understanding of habitat role in fishery ecosystems held by fishery managers and stakeholders
3	Review the status of data and new research for individual fisheries as the first step in residual risk assessment	Advance ERA Level 2 risk assessment for habitats by commencing residual risk assessment and scoping the opportunities and difficulties for individual fisheries - including those assessed outside the ERA process (e.g. sub-Antarctic and international fisheries)	ERA risk assessment for habitats is comprehensive across the Commonwealth jurisdiction, and the ERA-ERM process is advanced to the next major step
4	Complete a full inventory of habitat types available/ unavailable to individual fisheries when Commonwealth Marine Reserves have been implemented (2012)	Complete the risk assessment for habitats	Completion of risk assessment enables risk analysis and management responses to be formalised
5	Develop reference points for habitats	Explore the opportunities to develop quantitative management strategy evaluation frameworks for habitats (emulating, to the extent possible, those developed for fishery species)	Explicit and assessable measures of habitat health and management performance supports Australia's obligations to domestic (EPBC) and international (UNGA) ecosystem based management
6	Finalise the review, evaluation and reporting processes	Establish a parallel process for habitats as exists for species	A formal reporting structure and process enables Australia to meet its domestic (EPBC) and international (UNGA) obligations with respect to managing habitats in an ecologically sustainable manner that avoids significant adverse impact
7	Implement bycatch monitoring and reduction measures already established for Australian vessels in international fisheries to domestic Commonwealth fisheries	Expanded, standardised, systematic and quality assured collection of habitat data by seagoing observers, e-monitoring and by using other enabling technology (e.g. compact sensors on fishing gear)	A refined spatial context for risk assessment, analysis and responses to mitigate impacts to vulnerable (high risk habitats) is provided. Informed and specific management responses (e.g. move-on provisions) are enabled. Key uncertainties, such as the degree to which landed habitat bycatch underestimates impacts, are reduced

9.3 Cumulative impacts and assessments

The five ERAEF components (note "Species" here includes the "Target", "bycatch/byproduct" and "TEP" species components) are currently assessed separately at Level 1, Level 2 (PSA) and Level 3 (e.g. SAFE for species, quantitative habitat analyses). There may be interactions between components that are overlooked if assessment focuses only on a single component. Ecosystem models such as Ecopath (Bulman *et al.*2006) or Atlantis (e.g. Fulton 2010; 2011) offer the potential to jointly consider risk at Level 3, to say, habitats and communities, or species and communities, or even all three together. This is illustrated in **Figure 11**. Individual components are assessed at Level 1 and Level 2, but at Level 3 cumulative assessment might be more effective.

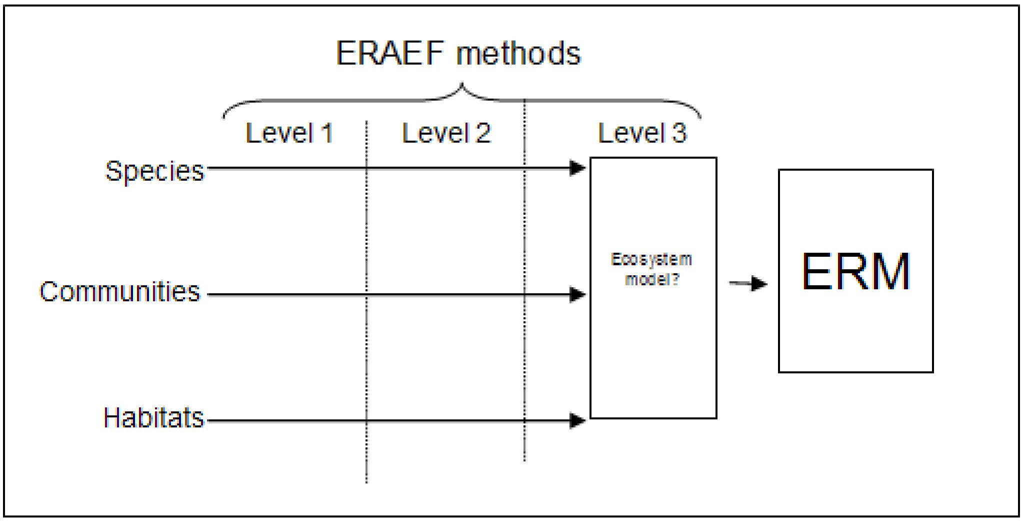

Figure 11. Potential integration of components within the ERAEF framework.

Integrating all components also allows cumulative impacts from multiple fisheries to be considered. For example, in the case of habitat-dependent effects, feedbacks might become important. Examples include invasive species that degrade habitat types (e.g. urchins and barrens; Ling *et al.*, 2009), or where critical habitat is important for reproduction. Changes to habitat for example, might change the species and hence the community in a location (e.g. Ling 2008). The integrated Level 3 results would also then proceed to the Ecological Risk Management (ERM) step – which would need to be described as at Level 2 for species, habitats and communities.

Cumulative assessment could take several forms, and determining what is the appropriate scale for fisheries risk assessment is an important preliminary step before commencing work in this area. As indicated in **Figure 12**, the complexity of cumulative analysis increases as more factors are considered. The least complex option is to consider just the overlapping sub-fisheries (gears) in an area, which may be sufficient for cross-sector management;, cumulative assessment of all the sub-fisheries and fisheries that capture a given species would assist whole species management. Formal stock assessment usually accounts for a range of non-fishing mortality for example, although recreational fishing mortality is one example where additional external impacts need to be considered in a cumulative assessment. Ecosystem management might be advanced by considering impacts across all components, while whole of system management would also include non-fishery impacts on species, habitats and communities (**Figure 12)**. Development of the cumulative assessment options as part of ERAEF is an area deserving future attention.

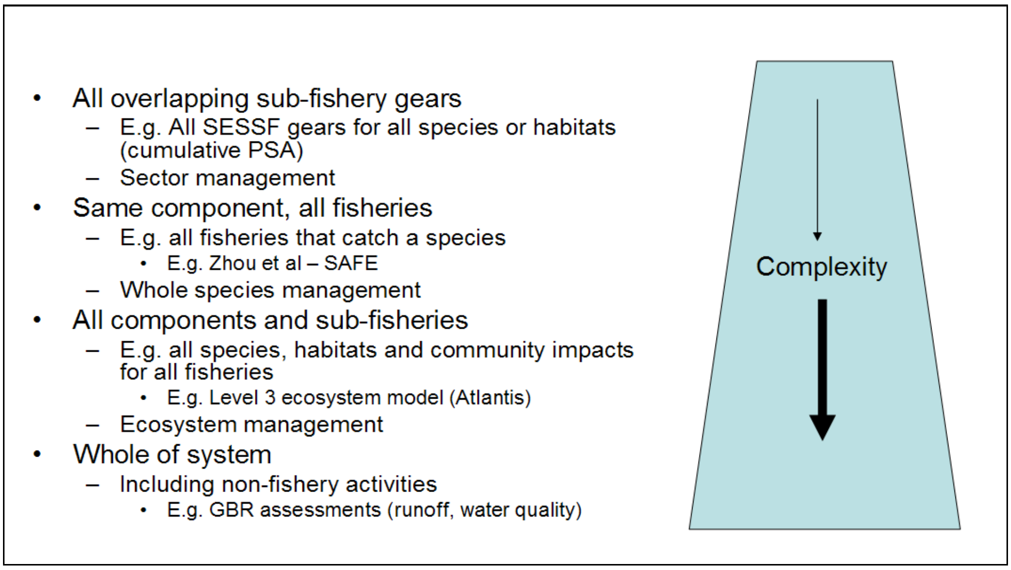

Figure 12. Levels of cumulative assessment in ecological risk assessment.

10 Planned outcomes

The purpose of this project was two-fold: (1) to complete and test the Level 2 habitat assessment approach for the Ecological Risk Assessment for the Effects of Fishing, and (2) develop the approach to allow Level 2 habitat risk results to be actioned by management (ERA to ERM). These objectives were achieved as planned in the project application. As detailed in Section 9, the Australian Fisheries Management Agency (AFMA) can complete adoption of ERA results and meet national and international obligations associated with fisheries management.

A process for generating improved information for fishery managers to determine management responses to habitat and community issues, leading to clear benefits in allowing fisheries to meet EPBC criteria and pass strategic assessment. The final methods and preliminary case study results have been communicated to AFMA managers at fishery meeting such as the SESSF research advisory meeting (Aug 2 2011, Melbourne), and in briefings to senior AFMA staff. AFMA have also indicated to Tony Smith (CSIRO) that they are planning to implement results of this project and extend the methods to other fisheries. This decision will be made after the conclusion of the Cumulative ERA project (2011/029 “ERA extension to assess cumulative effects of fishing on species”) led by Dr Shijie Zhou.

11 Conclusion

This project has met both objectives. The methods for Level 2 community assessment using the Productivity Susceptibility Analysis (PSA) have been developed and applied to a case study, while the ERA to ERM process for habitats has been detailed in a simple, flexible, and practical fashion.

With regard to the first objective (**Section 7**), development of Level 2 community assessment methods, the methods are simple in concept, and follow the approach developed for species and habitats. Execution of the methods, however, as illustrated in the SESSF case study, is operationally complex. Selecting attributes that can be used to indicate the impacts of fishing on ecosystems is difficult given lack of theory, absence of accepted reference points, and conflicting results from the limited case studies. The data processing is quite complex and requires good skills in database management and data processing methods. Application to other fishery region outside the SESSF will likely require specialist knowledge of trophic/functional biology before the species present in the communities can be allocated to functional groups and the attribute scores generated. That caveat noted, the database query processes are now largely automated and the spreadsheet calculations, while complex, are also in place. Further application to additional fisheries is the logical next step, and will result in further refinement and streamlining of the methodology, as occurred when species and habitat PSAs were conducted for a range of fisheries. We suggest that development or application of Level 3 community assessments should not be pursued at this time, until ERA to ERM community risk management options are considered as detailed in this project for habitats under the second objective.

As described in **Section 7**, under the second objective, assessing the potential risks to fishery habitats in the ERAEF process has, in most fisheries, progressed only to defining and classifying habitat types, mapping their distributions at coarse spatial scales, and assessing the potential impacts by individual fishing gears using the Level 2 (PSA) assessment. Level 2 outputs for habitats are less amenable to management uptake than equivalent outputs for species because there is much less available information on habitats, and typically no fishery-wide mapping. The evolution of ERA and ERM is therefore dependent on risk assessment methods that more clearly define habitat distributions (mapping), and that fully account for existing mitigation measures and new data (residual risk assessment). The guidelines for assessing residual risk for habitats provide a way forward. The management options available for ERM of habitats will be important (**Section 7.10.2**), and include spatial closures, gear modifications, and, potentially, offsets. In regard to spatial (area) closures, it is critical to note that many fishery closures and marine reserves provide no permanent protection for habitats, either because they are temporary or voluntary, or because they permit regulated fishing for a limited range of species – they are not explicit in protection for habitat. Like communities, established reference points for habitat management do not yet exist. The ERM framework should consider developing best practice reference points for managing and monitoring habitats. Reference points will need to specify the spatial scales at which habitats are defined, and clarify the fishery ecosystem services provided by habitats, particularly to high risk species and high priority species with strong habitat dependencies.

The outputs from each ERAEF level for species, habitats and communities currently apply to individual fisheries, but in future there is scope for developing cumulative risk assessment and analysis that will integrate across sub-fisheries, fisheries, components, and other threatening processes. Cumulative assessment will be particularly cost-effective at Level 3 in the ERAEF hierarchy, and ecosystem models offer one solution to the challenge. The time required to develop cumulative assessments, or operational reference points, means that it will be necessary for AFMA to define both near-term and longer-term management aims for both habitats and communities. Finally, ERM will need periodic update that reviews mitigation measures in the light of technical developments in the ERAEF approach, as well as results from ongoing monitoring.

Ecological Risk Assessments in general are now considered important tools in the fishery management toolkit (Smith *et al.*, 2007a; Plagányi, *et al.*, 2011). Improvements being suggested or implemented in Australia and around the world (e.g. Patrick *et al.*, 2010; Arrizabalaga *et al.*, 2011; Tuck *et al*., 2011). Thus, continued improvement will be business-as-usual for the coming years, as was the case with stock assessments, and is the ongoing case with harvest strategy development.

Overall, the ERAEF approach allows fisheries to demonstrate knowledge of risks to sustainability and an Ecological Risk Management approach will focus management actions. Together these elements will assist Australian fisheries to be recognized domestically and internationally for meeting the EBFM mandate and providing sustainable methods for supplying seafood.

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13 Appendices

Appendix 1: Staff engaged on the project

Alistair Hobday, Research Scientist, CSIRO Marine Research

Cathy Bulman, Research Scientist, CSIRO Marine Research

Mike Fuller, Research Scientist, CSIRO Marine Research

Alan Williams, Research Scientist, CSIRO Marine Research

Appendix 2: Preliminary set of attributes for community PSA

Table A2.1. Original set of community scoring attributes from Hobday *et al.*, 2007. These were considered for calculating productivity and susceptibility scores for each foodweb in the community component. The selection of the final set is discussed in the main text.

Property	Component	Attribute	Rationale
Productivity	Life-history	Mean growth rate (H_0: high, more productive)	High mean growth rate of community members means higher productivity.
		Mean length at maturity (Jennings *et al*., Fig 12.10). (H_0: low, more productive)	Low mean length at maturity would suggest species higher growth rates and therefore more productive.
	Diversity/Species Composition	Species richness (S) (H_0: high richness, more resilience)	Higher species richness means higher productivity or higher resilience to perturbation. Could indicate also redundancy in functional groups.
		Taxonomic distinctness (presence/absence data) Δ^+ (H_0: high richness, more resilient)	Low phylogenetic biodiversity indicates significant impact or higher risk of loss of biodiversity from impact. This index is independent of sample size. Can be monitored for loss of Δ^+ from impact (of fishing)
	Trophic structure	Mean trophic level (H_0:low, can also indicates change)	Low mean trophic level would indicate species probably of smaller size and higher growth rates.
		% of functional groups with total number of members per group> 5 or 10 (H_0: more groups, less susceptible)	Redundancy guards against impact.
		Number of top predators (n predators <2) (H_0: high number, more stable)	High number of top predators means productive system supporting them, therefore not significantly impacted.
		Attack sensitivity (H_0: low AS, high resilience to impact)	Calculated from topological analysis see Hobday *et al.*, 2007
		Error sensitivity (H_0: low ES, high resilience)	Calculated from topological analysis see Hobday *et al.*, 2007
		Key players (H_0: high value, high risk)	Calculated from mean of influence and fragmentation dominator tree analysis metrics see Hobday *et al.*, 2007
		Number of high risk species which eat high risk prey	The more high risk predators relying on high risk prey lessens the resilience to effects of perturbation
Susceptibility	Trophic structure	% of functional groups fished (total all gear types) (Ho: higher the number more susceptible the community is)	If high number of functional groups is fished, then community structure and diversity at risk.
		% of functional groups with high proportion of species fished i.e. >50% species (H_0: high % means community structure susceptible)	If high number of functional groups have more than half species membership fished, then community structure and diversity susceptible.
		% of mean functional group risk rating (H_0: higher; higher risk)	If species within functional groups have high risk ratings then functional group is at risk.
	Fishery specific	% jurisdictional overlap of fishery with community (H_0; high overlap, more vulnerable)	High overlap, more of community available, high risk
		% actual effort overlap of effort in fishery with community (H_0; high overlap, more vulnerable)	High effort overlap, more of community available, high risk
		Mean trophic level of catch from sub fishery (Ho: lower trophic level, higher risk)	Monitor; can be calculated directly from catch stats
		% of functional groups fished by sub fishery/gear (H_O: higher the number more susceptible the community is)	If high number of functional groups is fished, then community structure and diversity at risk.

Table A2.1. Continued

Property	Component	Attribute	Rationale
		Number of trophic levels captured by gear (H_O; more trophic levels , less discriminating, higher susceptibility of community)	If a gear is indiscriminate in selectivity of fishes and trophic levels, then community is more susceptible to impact
		% sub fishery catch of total catch overall all gear types (H_0: high proportion of total catch, more impact of fishery on community)	High proportions of fishery catch of total catch considered to indicate high selectivity therefore risk from sub fishery. Could also be a proportion of cumulative risk in future iterations
		% of fished species with high PCM from species PSA (H_0: higher number, higher risk)	If high proportion of species have high Post-capture mortality, risk to community is higher

Appendix 3: Development of Community Data Processing

The processing of data to generate the Level 2 community assessment is described in this section, with particular detail on the database support.

"Fish Central"

The database developed for data processing, "Fish Central" (Figure A3.1), consists of a:

- Species Table based on all species for which we have "bioregionalisation" distributions and which occur in the catch and effort database. These species form the core data set from which "community assemblages" will be generated. Community assemblages are the unit of analysis for the Level 2 Community PSA.
- Attributes Table for all species identified in the ERAEF process to date including those that have not been identified from fishery–specific PSA analyses loaded from list of species with distributional information (see 1. in following list of external databases).
- Taxonomy files that provide detailed hierarchical taxonomy for taxonomic distinctness analyses.
- Functional group listings that allocate each species into a functional group for analysis – not complete for all CAAB species but for most of the southern Australian species.
- Pelagic and Demersal community spatial layers which generate the set of PSA attributes as detailed in **Section 7.3,** such as:
  - Species presence in a community lists
  - Species area and % of total range of the species within a community
  - Fishing effort by sub-fishery in a community including spatial overlap and other effort metrics as required
  - Overlap of fishing effort with species range within a community.

The data processing application uses the above community information integrating it with data from the following external databases to generate fishery specific community PSA data:

- Species distributions are generated from "string" distributions maintained by the Taxonomic lab which are provided as "C-Squares" (1/2 degree) resolution grids. Data processing methods have been developed to generate new or updated distributions from the source data at the refined spatial resolution used by the analysis (1km) to the depth ranges included in the modelled distributions using best available bathymetry information (Geoscience Australia Bathymetry - 2009).

Fine scale (1km grid) fishing effort mapping generated from the AFMA logbook database. Overlaps of fishing effort on community and species distributions are generated from the fine scale logbook data for the community analyses.

Fishery license boundaries, processed for integration with fishery community analysis (1km grid).

ERAEF spreadsheet extracts from the new EcoBase database allow PSAs to be run on each "community assemblage" (species list).

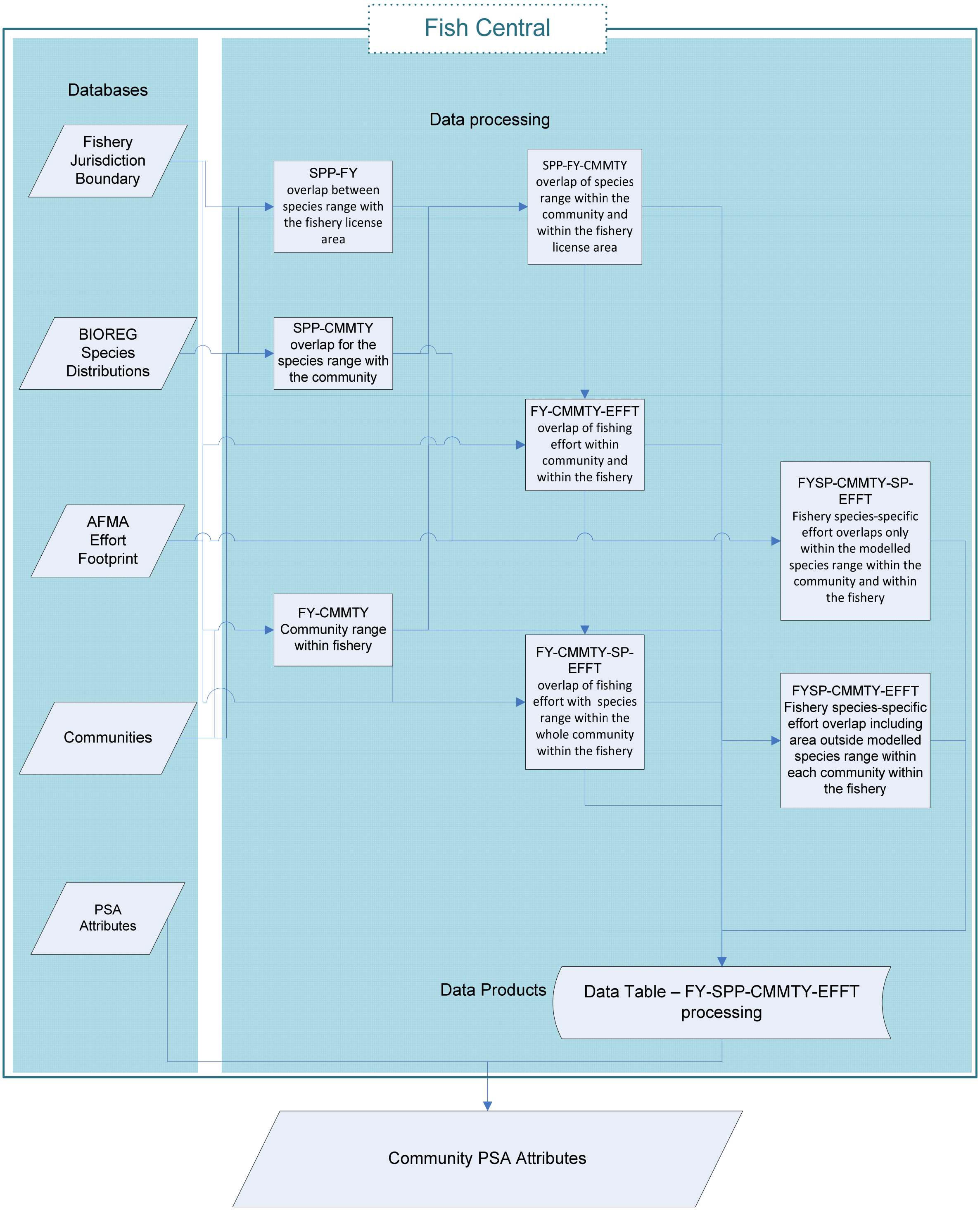

Figure A3.1. “Fish Central” components and the data processing flow between them. NB Fishery Jurisdiction boundary and Communities are in fact datasets within larger databases i.e. AFMA Jurisdictional Boundary database and the ERAEF database respectively.

Generation of species distributions from source information:

Species distributions were provided from "bioreg" (=bioregionalisation) species mappings. These consist of locations along the Australian coastline and depth distributions. These are then mapped onto 1/2 degree C-Squares distributions (pers.comm. Tony Rees, CSIRO). The 1/2 degree distributions are then further refined using the best available bathymetry data (Geoscience Australia ausbath_09_v4) mapped onto a 1km grid for the Australian EEZ. For each species - grid cells are then selected based on the 1/2 degree distribution, and the depth range the species is distributed within.

Logbook Catch and Effort Data:

AFMA commercial logbook data is used for generating fishery effort distribution information. Fishing operations (start-end locations for trawl methods) are mapped onto the 1km grid and effort allocated (shot length, shot time, number of operations) to each grid cell. These can then be used to generate data summaries of catch, effort and spatial overlap for the analysis layers used.

Community Distributions:

Community distributions are mapped onto the 1km index. Each grid cell is allocated to an ERAEF community.

Overlap Generation:

Overlaps between the species, fishery and communities are generated by SQL queries in Oracle. A Java application and Oracle database have been developed to automate the process of generating the different overlap values used in the community analyses.

Data Processing Modules:

Data processing for community PSA generation has been developed with the aim of being able to easily process a sub-fishery. Generic processing methods have been developed enabling application to any ERAEF sub-fishery where AFMA logbook data is available.

Existing catch and effort datasets generated from AFMA logbooks mapped onto fine scale grid (1km) have been used for defining fishery-species-community interactions. The 1km grid used for logbook mapping forms the basis for the spatial data processing used here.

Brief descriptions of the modules follow:

- calcSPP_CMMTY: Calculate overlap of the species with communities.
- calcSPP_FY: Calculate overlap between species range with the fishery license area.
- calcSPP_FY_CMMTY: Calculate overlap of species range within the community within the fishery license area (needed if fishery doesn't overlap entire community).
- calcCMMTY_EFFT: Calculate overlap of fishing effort with the whole communities.
- calcFY_CMMTY_EFFT: Calculate overlap of fishing effort with communities and within the fishery license area (needed if fishery doesn't overlap entire community).
- calcFY_CMMTY_SP_EFFT: Calculate overlap of fishing effort with (modelled) species range within communities and within the fishery license area.
- calcFYSP_CMMTY_EFFT: Fishery species-specific effort overlap including area outside modelled species range within each community (i.e. those records which actually caught the particular species as opposed to all effort records).
- calcFYSP_CMMTY_SP_EFFT: Fishery species-specific effort overlaps only within the modelled species range within the community and within the fishery (i.e. those records which actually caught the particular species as opposed to all effort records).

Oracle SQL Summary tables:

Additional data summaries are also generated based on detailed data tables. The aggregated data generated are used for the full PSA extract. Additional data were:

- total area of each community, and
- area of each community within fishery.

Final data summaries are then generated joining the intermediate tables to provide the overlap information required for community PSA generation. Spatial summaries are then joined to the species life history information required for the PSA analysis. PSA data resides in the ERAEF Microsoft Access database and export tables are generated for use in the Excel PSA worksheets.

Appendix 4: GAB mapping case study

Important Fishery Habitats (IFH)

The rationale for defining IFH in the GAB

The concept of "important fishery habitats" in the context of this study is used to define habitat areas that appear to provide ecological services linked to production of the fishery. The detail of the ecological linkage may remain unknown, and 'importance' is most often inferred simply from the fact that particular habitats support commercial species of marketable size and in sufficient abundance to support commercial catches. The previous section notes that spatial overlays of catch on maps of habitat, in conjunction with fishers' knowledge, provide an effective way to determine spatial relationships at coarse scale over a large fishery area. In the context of this project, the interest of the Steering Committee was in defining and better understanding distributions of IFHs to assist with the long term sustainability and spatial management of the GAB fishery.

It is worth noting that the comparable concept of 'Essential fish habitat' is defined under the primary United States fisheries legislation as: "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (U.S. Magnuson-Stevens Act, 16 U.S.C. 1801 et seq). However, this definition is so general that it is unlikely to assist managers in making decisions on marine resource management. It also continues an overly species-centric approach to conservation that is increasingly seen as less valuable in comparison to the conservation of spaces or landscapes (Simberloff 1998, Roff and Taylor 2000).

Because the GAB is vast and the data available to map habitats is patchy and sparse, proxies are needed to extrapolate from mapped areas to those that remain unmapped. Integrating fishers' knowledge with science data is an effective way to do this at regional scale for the depth range that is fished (depths to ~1300 m) (e.g. in the SEF, Williams *et al.*, 2006). Alternative methods to map habitats or species at fishery scale are not generally available, even for relatively intensely used areas, and there is no other alternative for the GAB. Geomorphology is a proxy that has had widespread use in marine resource planning in Australia (Harris 2007; Heap and Harris 2008) but typically does not classify and map habitat at fine-enough scales to be relevant to the distributions of fishery habitats or their use during fishing (Williams *et al.*, 2009a).

In the integration of data during this project, fishers knowledge was used to refine maps of bathymetry and geomorphology, primarily by mapping finer scale features – albeit mostly at a rather coarse resolution for bottom type and with a need to define many different types of boundaries around and between habitat types. However, mapping at this scale and resolution is highly suited to defining productive ('important') areas for the fishery. There were a number of habitats that were repeatedly and independently identified by different fishers and observers during our mapping process. Based on this, and from a considerable amount of other science data from the temperate Australian seabed used for fishing (e.g. Williams *et al.*, 2006; Williams *et al.*, 2000b), we defined six important fishery habitat types (IFH) represented in the fishery.

It is important to understand that IFH types are generalised descriptions, and while some of these are mappable at fine spatial scales, the mapping completed by this project was limited to the resolution of fishing ground polygons that have an average size of 745 km^2. Thus, IFHs were not individually mapped into the fishing grounds even where finer scale data were available. Rather, the distribution of IFHs was assessed using qualitative spatial analysis that scored each polygon based on whether each IFH was present or abundant there, and the confidence we had in that assessment. The polygon score for IFH was the sum of the scores for each individual IFH.

IFH summary

'Important Fishery Habitats' (IFH) are descriptions of six classes of habitat important for fishery production that are:

- defined by integrating the knowledge of fishers, scientific observers and scientists on species-habitat associations and habitat distributions;
- represented at a spatial scale that is coarse relative to the real distributions of habitat types by using polygons with an average area of some 745 km^2;
- located spatially by using expert judgement to combine empirical evidence and inference about the presence and abundance of each IFH within fishing ground polygons; and,
- mapped by developing a simple metric that sums IFH scores within each polygon.

List and descriptions of six IFHs within the GAB

IFH type 1. Structured inner shelf habitats.

Structured habitats on the inner shelf (~<80 m depths) are provided by seabed communities (mainly sponges and bryozoan) which are often associated with hard bottom – variously coarse or cemented sediments; low relief rocky pavement – often with sediment veneers; and outcrops of rocky reef. These habitats are different to 'equivalent' structured habitats at the shelf edge where they support a different mix of fishes, life history stages, and community structure. They provide structural refuges, and probably higher prey densities, for a variety of key issue species:

- Typical inner shelf species, and other species that may have a shallow life history stage before adults migrate to deeper waters ('bigger-deeper'): Broadnose Sevengill Shark, School Shark, Dusky Shark, Rough Flutemouth, Latchet
- Highly mobile species that traverse the inner shelf and greater depths as adults: School Shark, Whiskery shark, Shortfin Mako, whaler sharks, hammerhead sharks, Grey Nurse Shark, White Shark

<u>Additional comments:</u>

Of the six IFH types described, structured inner shelf habitat is the most simplistic because it generalises over a variety of habitat types characterised by many different fauna and flora, and to some extent masks the importance of structured habitats associated with sediment bottom types.

Although no subdivision of the IFH 1 was attempted in the analysis, it is important to note that several distinct areas or general locations important for fishery productivity were identified, and these are referred to elsewhere, e.g. School Shark.

- Areas of prominent reefs or areas of reef patches ('cray weed') and adjacent sediment plains in coastal waters (<25 m depth) at the Head of the Bight where fishers' believe warm water from 'springs' enhances productivity
- Areas of sand or few reef patches with low epifauna off the Venus – Streaky Bay area where enhanced chlorophyll appears to improve benthic productivity

- Areas of prominent reefs or areas of reef patches on the deep inner shelf (~80 m depth), particularly those west of the Eyre Peninsula.

None of these habitats are identified as vulnerable by the ERA. This is for a variety of reasons including that the inner shelf is large and large areas are not fished, e.g. because there is low availability of rocky bottoms to trawl gear, and because shallow fauna are more resilient than deep fauna. However, the habitats are impacted in places by gillnets and trawls that remove sponge and bryozoans (mostly in the eastern GAB). Large areas of inner shelf closed to trawling may provide refuges for species that are trawled on the outer shelf but distributed across the entire shelf. However, while this is a commonly cited connection, it is yet to be substantiated by data on connectivity and abundances (biomass) of particular species such as Bight redfish.

Inner shelf IFH needs to be considered in the context of providing continuity (corridors) across the shelf for species with bigger-deeper patterns of distribution, and in terms of 'comprehensiveness' – providing protection across the GAB, i.e. within each of the major bioregions, especially where species exploited offshore may rely on connections to the inner shelf. This is likely to be important where the shelf is wide leading to inner and outer shelf habitats being further apart. However, fishers believe strong currents enhance food supply and produce productive fishing grounds in narrow areas of shelf, e.g. adjacent to the Eyre Peninsula and Kangaroo Island. These areas provide opportunities to protect connected cross-shelf habitats in relatively small closures. Where currents favourable for fish production occur on the shelf, productive (important) fishery habitats are likely to occur across all shelf depths, and on the adjacent slope, e.g. where deflected shelf currents and upwelling occur in the eastern GAB (~Port Lincoln to Kangaroo Island).

IFH type 2. Paleo-coastline

This is roughly mapped by the 100 m contour, and is a persistent, although not continuous, feature around much of Australia associated with historical sea-level low stands. It is often a subtle feature, but frequently characterised by many reef patches. Fishers describe areas of ledges and drop-offs which are important for a variety of sharks and scalefish – consistent with fishers' knowledge and scientific mapping of the same feature off SE and NW Australia.

- Morwong, Melbourne Skate, short-tailed torpedo ray, Whiskery Shark, School Shark

<u>Additional comments:</u> this important fishery feature does not appear on maps of GAB geological features because the scale of mapping is too coarse.

IFH type 3. Structured shelf edge habitats (deep shelf - shelf break in 150– 300 m)

Similar to structured habitats on the inner shelf (~<80 m depths), IFH at the shelf edge is provided by seabed communities (mainly sponges and bryozoans, but also seapens and crinoids), which are often associated with hard bottom. They provide aggregations points – probably linked to higher prey densities – and structural refuges for a variety of key issue species:

- Species characteristic of the shelf edge, and shelf species that extend to the shelf edge, possibly in their adult life history stage: deepwater flathead, Bight redfish, morwong, Spotted Wobbegong, Gulf Catshark, Juvenile Mako shark, Smooth Hammerhead, Spikey Dogfish, Greeneye Dogfish, Ornate angel shark, southern fiddler ray, swallowtail, Yelloweye Redfish, Gulf Gurnard Perch, Thetis Fish, Latchet, Hapuka, (Boarfish)
- Highly mobile species that traverse the inner shelf and greater depths as adults: School Shark, Whiskery shark, Shortfin Mako, whaler sharks, hammerhead sharks

Additional comments: the ERAEF identified these habitats as vulnerable (e.g. *VBH types 1-6*) with habitats and fauna altered by trawling in some heavily used areas – despite consistent catch rates of key species such as deepwater flathead. There is a potential impact from multiple gear types, but the effects of cumulative impacts, and the distribution of impacts at the scale of the fishery, needs to be better understood.

IFH type 4. Heads of large canyons cutting the upper slope and shelf edge

These occur at the shelf edge and on the slope where relatively high catches indicate they provide areas of elevated productivity and fishery production. The size and extent of canyons appears to be important, with large features that extend from deep waters beyond the slope up to the shelf edge being most important to fishery production (and likely to have the greatest degrees of structural fauna). They provide aggregations points – probably linked to higher prey densities – and structural refuges for a variety of key issue species:

- Ling, Hapuka, Greneye Shark, Blueye, Sevengill Shark, Sawtail Catshark, Shortfin Mako, School Shark, Southern Dogfish, Platypus Shark, Lantern Shark, Greeneye Spurdog, Bight Skate, Grey Skate, Southern Chimaera, Tusk

Additional comments: some large canyon heads remained un-mapped (e.g. by the geomorphic feature mapping for regional marine planning by DEWHA), and there is no between-feature differentiation that identifies valuable from non-valuable canyons in a fishery perspective. Their structural fauna is identified by the ERAEF as vulnerable (e.g. *VBH types 4, 5 and 6*).

IFH type 5. Upper slope terraces

Where the upper slope is particularly narrow and steep, and between large canyons, it is typically more structured and provides IFH for several key issue species:

- Gemfish, Blue Grenadier, Southern Dogfish, Greeneye Spurdog, Bight Skate, Grey Skate, Sawtail Catshark, Lantern Shark, Southern Dogfish, Tusk, Hapuka, Blueye,

Additional comments: These productive fishery areas are limited in areal extent. Their structural fauna is identified by the ERAEF as vulnerable (e.g. *VBH types 4, 5 and 7*). The narrow upper slope (~300-700 m depths) resembles an escarpment, and off SE Australia provides a disproportionately high amount of the total offshore fishery catch by trawl and non-trawl sectors. The level of effort and catch is at a much lower level in the GAB.

IFH type 6. Seamounts (hill-like features) on the mid-slope (~700-1500 m depths)

Many, probably all, of these features have been recorded and mapped, but they make up tiny fractions of the mid-slope seabed at individual fishing ground scale. Fishers report that muddy bottom makes up the vast majority of mid-slope grounds, estimated to be often 95% or more, with seamount features making up the remaining small percentages of seabed area. However, several fishes including the conservation dependent Orange Roughy, preferentially aggregate around seamount features.

- Orange Roughy, Black Shark, Brier Shark, Platypus Shark

Additional comments: a considerable body of evidence shows that seamounts are among the most vulnerable benthic habitats (*VBH types 7 and 8*) because their structural fauna is fragile, long-lived and completely removable by trawling. There are relatively few seamounts in the GAB and it is not yet known whether they are important stepping stones to maintain connectivity between the biological communities, such as deep sea corals, that make up the structural habitat on them.

Vulnerable benthic habitats (VBH)

The rationale for defining VBH in the GAB

The concept of "vulnerable benthic habitats" in the context of this study follows the methodology of the Ecological Risk Analysis for the Effects of Fishing (Hobday *et al.,* 2007). This process was used to define habitat types that are at risk from activities linked to fishing. In most cases, risk to habitat means damage, degradation or removal, and the relevant fishing activity is the direct impact of the gear on the seabed. In the context of this project, the interest of the Steering Committee was in defining and better understanding distributions of VBHs to assist with the long term sustainability and spatial management of the GAB fishery.

Initially, habitat types were identified using photographic data using the ERAEF methodology. Classification of habitats was based on substratum (what the seabed is made of), geomorphology (what the seabed looks like), and the dominant faunal type associated with the seabed. The detailed lists of habitat types generated by this process are subsequently rationalised into a smaller set of types that are relevant to the scales and context of the fishery.

As was stated in the previous section for IFH, it is important to understand that VBH types are generalised descriptions, and while some of these are mappable at fine spatial scales, the mapping completed by this project was mostly limited to the resolution of fishing ground polygons that have an average size of 745 km^2. Thus, while finer scale mapping data on habitat types were often available (either from scientific mapping or fishers data) VBH were not individually mapped into the fishing grounds. Rather, the distribution of VBHs was assessed using qualitative spatial analysis that scored each polygon based on whether each VBH was present or abundant there, and the confidence we had in that assessment. The polygon score for VBH was the sum of the scores for each individual IFH,

Summary outcomes of the ERAEF in the GAB

A key issue to emerge from the Ecological Risk Assessment for the Effects of Fishing (ERAEF) analysis (Hobday *et al.,* 2007) was the direct impact of the trawl, auto-longline and gillnet sub-fisheries on certain vulnerable benthic habitats (Table A4.1, Hobday *et al.,* 2007).

- Habitats at potential risk from trawling occur across a range of depths, mainly on the outer shelf and the upper slope. Most trawling currently occurs on the outer shelf but there is increasing exploration of the upper slope and mid slope waters of this developing fishery.
- Habitats at potential risk from gillnet fishing occur on the outer shelf, but because most gillnet fishing is now at less than 80-m depth (i.e. on the inner shelf) the threat to habitats from this method is reducing.
- Habitats at potential risk from auto-longline fishing occur mostly on the upper-slope. Auto-longline fishing can target bottom types not fishable by trawling, but there is no empirical data that shows the effect of movement of the main line on large, erect and fragile epifauna.

The ERAEF report concluded that some form of spatial management (specific spatial closures) may be an appropriate way to protect vulnerable habitats from the impacts of all gear types. In many instances, informed placement of closed areas for habitats would also mitigate the impacts on high risk by-product and by-catch species, e.g. closures on the upper slope should be effective both for habitats and for species such as gulper sharks at risk from auto-longline fishing

Table A4.1. Summary outcomes from the ERAEF analysis for Trawl, Autoline and Gillnet sub-fisheries in the GAB in relation to habitats; no. of potentially high risk habitat types in each major depth zone shaded pink.

Trawl	Inner-shelf	Out-shelf	Upper-slope	Mid-slope	Total
High	0	8	5	8	21
Medium	5	17	5	5	32
Low	6	16	1	1	24
Total	11	41	11	14	77
Autoline					
High	0	2	15	0	17
Medium	0	21	13	0	34
Low	0	50	11	37	98
Total	0	73	39	37	149
Gillnet					
High	0	22	0	0	22
Medium	10	8	0	0	18
Low	19	43	0	0	62
Total	29	73	0	0	102

Trawl

Of the 77 habitat types encountered by trawl, 21 were assessed to be at high risk, 32 medium, and 24 low. Of the high risk habitats, none were found on the inner shelf (0-100m), 8 were on the outer shelf (100-200m), 5 were on the upper slope (200-700m), and 8 were on the mid slope (700-1500m).

- High risk mid-slope habitats include several categories of hard bottom (but still accessible to trawl gear) with large, erect or delicate epifauna consisting of octocorals, and sedentary animals. There are also three types of soft bottom habitat that support large, erect or delicate epifauna. Habitats of seamounts occur at this depth zone.
- High risk habitats on the upper slope include types of low-relief hard bottom, in this case dominated by large sponges not seen on the mid slope, and also several soft bottom habitats characterized by octocorals and sedentary animals, as well as an additional soft seabed type based on bryozoan communities which are restricted to a narrow zone near the shelf break. Habitats of canyon features occur at this depth zone.
- High risk habitats on the outer shelf are mainly soft sediment seabed types characteristically dominated by large sponges and mixed epifauna, with bryozoan communities at the shelf break. Sedimentary, sub-cropping rock with communities of large sponges also scored at high risk.

Gillnet

Of the 102 habitat types encountered by the gillnet subfishery, 22 were assessed to be at high risk, 18 medium, and 64 low. All high risk habitats occur on the outer shelf; these were 13 hard bottom types (low relief, gravels or outcrops) covered with large, erect or delicate epifauna and 9 soft bottom habitat types covered with large, erect or delicate epifauna. The epifauna consists of sponges, crinoids, octocorals, sedimentary animals, or communities of mixed fauna.

Auto-longline

Of the 149 habitat types, 17 were assessed to be at high risk, 98 medium, and 34 low. Of the high risk habitats, 2 were on the outer shelf (100-200m) and 15 on the upper slope (200-700m).

- High risk upper slope habitats include several categories of hard bottom (but still accessible to trawl gear) with large, erect or delicate epifauna consisting of octocorals, crinoids, large sponges, and mixed epifaunal communities. Also ranked high are sediment veneers over hard bottom and sediment bottoms characterized by large sponges and sedentary epifauna. Habitats of the shelf break, and canyon features occur at this depth zone.
- High risk habitats on the outer shelf include soft sediment seabed types over hard bottom characterized by sediment veneers interspersed with sub-cropping, friable sedimentary rocks or cobbles characterized by large sponges.

List and description of the eight VBHs in the GAB

It is possible to summarise the habitat types at potentially high risk to all the offshore gear methods by aggregating similar types. The relatively large number of habitat types defined by details of substratum, geomorphology, and the dominant faunal type can be summarised for each major depth zone as follows:

Outer continental shelf (100-200 m)

VBH type 1. Fine or muddy sediments, unrippled, wave rippled or forming veneers over sub-cropping rock, supporting large sponges or mixed epifaunal communities including gold corals or sedentary animals such as seapens. Occur across shelf, including at shelf-edge (>160 m depth).

VBH type 2. Gravel sediments, often wave or current rippled, supporting bryozoan-based communities or large sponges. Typically at shelf-edge (>160 m depth).

VBH type 3. Rocky bottom, existing as outcrop or subcrop, supporting large sponges and mixed faunal communities including crinoids. Occur across shelf, including at shelf-edge (>160 m depth).

Upper-continental slope (200-700 m)

VBH type 4. Fine or muddy sediments, unrippled or forming veneers over sub-cropping rock, supporting large sponges or sedentary animals such as seapens. Associated with gentle slopes, terraces and canyons.

VBH type 5. Coarse sediments, unrippled, supporting sedentary animals such as seapens. Typically near shelf-edge (200-300 m depths).

VBH type 6. Rocky bottom, existing as outcrop or subcrop, and supporting communities of gold corals, and other large erect fauna such as sponges. Typically associated with steep slopes, e.g. in canyons.

Mid-continental slope (700-1500 m)

VBH type 7. Coarse sediments, current rippled or irregular or scoured, supporting mixed faunal communities including sponges, seawhips, ascidians or encrusting or small erect forms such as bryozoans or sedentary animals such as seapens. Typically associated with current-exposed slopes and narrow terraces.

VBH type 8. Cobble or boulder bottom forming debris flows or rubble banks supporting sedentary fauna such as seapens. Rocky bottom existing as low outcrop or subcrop and supporting communities of stony and gold corals, and other large erect and sedentary fauna. Typically associated with steep slopes, e.g. in canyons, and seamount-like features.

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