Assessing ecological sensitivities of marine assets to oil spills by means of expert knowledge

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Econometric Institute Report 2014-13 (revised)

Date: 24th December 2014

Abstract

Existing methodologies to assess risk due to vessel traffic often do not fully account for damages to marine resources should an oil or chemical spill occur. While some socio-economic damages can be quantified in monetary terms, expert knowledge is often the only way to assess potential ecological damage to the marine environment. However, the use of expert knowledge introduces a source of uncertainty. A method is proposed to minimize recognized flaws in subjective assessments by eliciting sensitivity ratings from multiple assessors and recognizing their differences of opinion as one source of uncertainty. Various scoring options to best reflect expert opinions are briefly explored. The methodology developed and applied to the Victorian coastline in Australia is believed to have improved assessment which can in turn assist policy-makers of any maritime nation make better-informed risk management decisions.

Keywords: expert knowledge, environmental sensitivities, oil pollution, maritime risk assessement, uncertainty

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1. Introduction

Most maritime administrations or regulatory bodies at national or international level face challenges to assess and estimate potential harm due to maritime activities, such as oil spills, because of the complexity in accounting for all parameters that can influence risk. Total risk exposure for a coastal or port state can best be divided into various risk layers, such as ship specific risk, traffic densities and location-specific physical attributes such as wind, waves, currents, and other bathymetric or geographic features (Knapp, 2013). In theory, each maritime administration has several risk control options (RCO) at its disposal, (e.g. vessel traffic services, pilotage, under-keel clearance, and emergency response activities). Such RCOs are employed proactively to mitigate risk. It is important to consider that there can be various endpoints for risk exposure, including the expected number of incidents in a spatial region, the value of at-risk resources, or the size of potential damages. These latter two are intrinsically difficult to quantify and often rely on the elicitation of expert knowledge. This article is focused on quantifying parameters associated with consequences, such as ecological and socio-economic sensitivities, by recognizing their underlying values.

Worldwide, oil spill risk assessments for coastal waters typically include consideration of shoreline types (e.g. exposed rocky shore, sheltered muddy embayment) following a categorisation developed by the US National Oceanic and Atmospheric Administration (NOAA) (Petersen *et al*. 2002) from the Vulnerability Index of Gundlach & Hayes (1978). The NOAA Environmental Sensitivity Index (ESI) provides a ranking of the sensitivity of shoreline types based on physical characteristics of the location, along with the persistence of oil and ease of clean-up. This shoreline-based approach is now widely accepted (IPIECA/IMO/OGP 2012), although it has been suggested that shoreline ranking should not form the sole basis for an environmental sensitivity assessment (AMSA 2013a, b). NOAA-style ESI maps also indicate the locations of biological and human-use resources (Petersen *et al*. 2002) but do not include them in the ranking process. Other sensitivity assessments considering fate of oil on different types of shoreline typically also take into account aspects of environmental sensitivity such as protected areas, species life cycles or migration routes (e.g. DNV 2011; COWI 2012), scoring on the basis of area affected or degree of impact.

However, understanding of the ecological values of shorelines and shallow water environments is often cursory or general in nature, and in contrast to social or economic resources, natural resources are frequently neither quantified nor valued (Poore 1995, Ponder *et al*., 2002, Carey *et al*. 2007, IMO 2013). For the ecological value of such resources to be considered when assessing the possible consequences of an oil spill, the assessment must either be limited to formally recognised assets, such as listed species or protected areas, or be assessed subjectively.

Basing assessments on subjective judgement, even on that of relevant experts, brings its own difficulties. Subjective judgement is known to be affected by the personal experience and beliefs of individual assessors (Pidgeon *et al*. 1992), by cultural differences in the perception of risk (Rohrmann 1994), and by cognitive biases. This latter category includes framing effects (Kahneman & Tversky 1984), judgement bias (Fischhoff *et al*. 1977) and anchoring or the tendency to be influenced by initial estimates (Tversky & Kahneman 1974). Subjective judgement is a recognised form of epistemic uncertainty (Regan *et al*. 2002); i.e., uncertainty that "stems from a lack of data, understanding and knowledge about the world" (Hayes 2011).

It is essential that risk assessments incorporate uncertainty to minimise the chance of unwelcomed 'surprises' in the future. Strategies for deriving the greatest benefit from a subjective assessment include: 1) involving a group of assessors rather than relying on a single individual (SA/SNZ 2004); 2) allowing assessors the option of assigning a band of sensitivity ratings (i.e. an interval) rather than being constrained to a single rating (Hayes 2011); 3) recognising any differences of opinion among assessors and incorporating such differences in the overall assessment; and 4) recording the discussions of differences of opinion to ensure clarity and transparency in the assessment process, and to inform any management actions based on the assessment.

A pilot study performed in cooperation with the Australian Maritime Safety Authority (AMSA) addressed the issue of ecological value while applying recognized methods of dealing with the subjectivity of expert judgment. The study concentrated on assessing ecological (i.e. habitats and species) sensitivities and the aggregation of sensitivity ratings. The assessment process recognized that ecological importance may encompass resources other than those formally listed, and that ecological 'value' should be taken into account even if it cannot be defined in purely monetary terms. Accordingly, the study used the NOAA shoreline classification (Petersen *et al*. 2002) and a similar classification of marine biota as surrogates for the recognized impacts of oil spills on habitats and biota, in conjunction with a subjective measure of ecological value. The developed methodology can enhance risk assessment methodologies at the local and international level such as the Formal Safety Assessment (FSA) Methodology developed by the International Maritime Organization (IMO) where ecological damages are currently not considered. The latest update to that methodology accounts for oil spill clean-up costs (IMO, 2013) based on historical data but not using local ecological values.

2. Material and methods

The pilot study was an update of an oil spill risk assessment conducted in Victoria, Australia for the Victorian Department of Environment and Primary Industries (DEPI) by Navigatus Consulting Ltd. The previous assessment (Navigatus, 2011) considered sensitivities for five resource categories (habitats, species, cultural, economic and social) across 66 coastal cells each of 20 km shoreline length (Appendix A). Only ecological sensitivities were re-evaluated, encompassing the two Navigatus categories of habitats and threatened/iconic species. The present assessment differed from that of Navigatus by allowing local experts in marine ecology to directly assess sensitivity and by explicitly incorporating uncertainty in the sensitivity ratings.

The results are based on two workshops held in June and July 2013 where over 30 marine scientists, agency staff and others with ecological expertise and/or practical experience in Victorian shallow coastal environments (e.g. established eco-tourism operators) were invited to participate. A total of 14 experts attended one or both workshops. To inform discussion during the workshops, various GIS-based resources were compiled and made available on each day, including the Victorian coastal habitat layers of the Oil Spill Response Atlas.

2.1. Bio-physical attributes and ecological values

Due to time constraints, it was not possible to formally rate every shoreline type or species within each of the 66 cells along the coastline. The assessment process had two stages: the identification of key shoreline attributes and biota, followed by a formal rating of the selected attributes. A single coastal cell could be rated for more than one bio-physical attribute (e.g. exposed rock platform and exposed sandy beach) when deemed appropriate by the experts. For the purposes of assigning ratings, ecological sensitivity was broken down into two components: bio-physical attributes and ecological value. Prior to commencing the assessment, possible criteria for the assessment of ecological value were explored.

Bio-physical attributes: This component broadly followed the shoreline types of the ESI (NOAA 2010), but types were limited to those present on the Victorian coastline (Table 1). The shoreline types provided a useful starting point because the rank order of sensitivity reflects much of the existing knowledge about the behaviour of oil and its fate and effects in coastal habitats. Shoreline type was in effect, used as a surrogate for the recognised impacts of oil spills on habitats. However, during the first workshop it became evident that some provision was needed in the ranking process for cases where an important biological attribute could not be readily aligned with an ESI shoreline type (e.g. migrating cetaceans). Accordingly, an alternative to specify a habitat in biological terms (i.e. kelp beds, seagrass beds) or to focus on a specific biological group (i.e. mammals, shorebirds and seabirds, invertebrates and fish, plankton) was provided for the second workshop.

Table 1: Subset of ESI shoreline types (NOAA 2010) present along the Victorian coastline

ESI Shoreline type
Mangrove/Salt Marsh
Sheltered flats
Sheltered rocky
Exposed tidal flats*
Gravel/riprap
Mixed beach
Coarse beach
Fin/medium beach
Exposed platforms*
Exposed cliffs*

** i.e. exposed to wave action*

To avoid ‘double-dipping’ in cases where an ESI shoreline type perfectly matched a biologically-defined habitat type (e.g. salt marsh, mangrove), it was required that either the biological or the physical scale be used. The two are thus alternative scales. They are also independent of one another; i.e. a common rank score does not imply a necessary association between the physical and biotic elements, simply that they occupy similar ranks within their own scales.

Ecological value: Basing ecological value solely on species or habitats that have been formally recognised under government legislation or international agreements may be an over-simplification, and provision should be made for more complex or subtle ways in which biota might be valuable to the health or viability of an ecosystem (e.g. keystone species, larval supply, species aggregations). For this reason, ecological value was included as a component of ecological sensitivity that could be assigned a rating in its own right and thus have a direct influence on the final sensitivity rating, rather being relegated to simple listing and a mark on a map. Ecological value was rated on a qualitative five-point scale of ecological value (Very Low, Low, Moderate, High, Very High).

Because the concept of ecological value might be interpreted in various ways, it was conceivable that assessors might apply different criteria when assessing ecological importance or value and thus introduce linguistic uncertainty into the process (Regan *et al*. 2002). To minimise any differences of opinion based solely on differing understanding of what constituted ecological value, participants were asked to first consider criteria which might be applied when assessing value. The following lists were generated for the highest and lowest categories without reference to any existing checklists or reports:

- criteria for **Very High** ecological value: rarity/uniqueness*, nursery area*, species aggregations*, protected area* (e.g. MPA, Ramsar) or species* (e.g. *EPBC Act 1999*, *FFG Act 1988*), high primary productivity*, high biodiversity*, shoreline protection
- criteria for **Very Low** ecological value: highly modified or degraded system (e.g. ports, some metropolitan reefs), high redundancy, resistant to oil

It was notable that those criteria marked with an asterisk correspond to IUCN (International Union for Conservation of Nature) criteria for Ecologically or Biologically Significant Areas (Ardron *et al*. 2009), confirming that the expert assessors had an *a priori* understanding of factors generally associated with ecological importance or value. Participants were not constrained to choose a single rating for ecological value, but were free to instead nominate upper and lower bounds (e.g. low to moderate) if they wished to convey a level of uncertainty in their ratings.

2.2. Rating and scoring options

The ratings of individual assessors were recorded in a spreadsheet in which the qualitative ecological value ratings were subsequently converted to numeric scores for the purpose of combining with shoreline type or biotic category (Fig. 1a). Such conversion to numeric scales also serves as a form of quality control for consistency in rank ordering of the qualitative scales (Hayes 2011).

			Matrix A -Initial scores					Matrix B - Balanced				
Physical	OR	Biological	Ecological Value					Ecological Value				
Characteristics		Characteristics	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
Mangrove/SaltMarsh		Mammals	VL	L	M	H	VH	M	M	H	H	VH
Sheltered flats		Shore/Seabirds	VL	L	M	H	VH	M	M	H	H	VH
Sheltered rocky			VL	L	M	H	VH	L	M	H	H	VH
Exposed tidal flat *			VL	L	M	H	VH	L	M	M	H	VH
Gravel/Riprap		Macroalgae/Seagrasses	VL	L	M	H	H	L	M	M	H	H
Mixed beach			VL	L	M	M	H	L	L	M	H	H
Coarse beach		Invertebrates/Fish	VL	L	L	M	H	L	L	M	M	H
Fine/Med beach			VL	VL	L	M	H	VL	L	M	M	M
Exposed platforms *		Plankton	VL	VL	L	M	M	VL	L	L	M	M
Exposed cliffs *			VL	VL	VL	L	M	VL	VL	L	L	M

* exposed to wave action

			Matrix C - low-end heavy					Matrix D - value emphasis				
Physical	OR	Biological	Ecological Value					Ecological Value				
Characteristics		Characteristics	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
Mangrove/SaltMarsh		Mammals	L	M	H	H	VH	L	M	H	H	VH
Sheltered flats		Shore/Seabirds	L	M	H	H	VH	L	M	H	H	VH
Sheltered rocky			L	M	M	H	H	L	M	M	H	VH
Exposed tidal flat *			L	L	M	H	H	L	M	M	H	VH
Gravel/Riprap		Macroalgae/Seagrasses	L	L	M	M	H	L	M	M	H	VH
Mixed beach			VL	L	M	M	H	L	M	M	H	VH
Coarse beach		Invertebrates/Fish	VL	L	L	M	M	L	L	M	H	H
Fine/Med beach			VL	L	L	M	M	VL	L	M	M	H
Exposed platforms *		Plankton	VL	VL	L	L	M	VL	L	L	M	M
Exposed cliffs *			VL	VL	VL	L	L	VL	VL	L	M	M

Fig. 1: Ecological sensitivity matrices, showing the products of bio-physical characteristic and ecological value. Matrix A (top left) shows the initial scales used during the workshops. Matrices B-D were circulated post-workshop to participants for comment.

Ecological sensitivity (ES) was then calculated as the product of shoreline type or biotic category, and ecological value scores (EV), using interval arithmetic (Young 1931, Moore *et al*. 2009, Hayes 2011) to propagate any uncertainties:

$$[ES_{lower}, ES_{upper}] = (Shoreline\ or\ Biota) \times [EV_{lower}, EV._{upper}]$$

The sensitivity scores of individual assessors were then converted back to categorical ratings for display. Overall ratings for each attribute were generated by combining the ratings of the individual assessors. Where more than one shoreline type or biotic category was assessed within a coastal cell, overall ratings were further combined to produce a single rating for each coastal cell. Intervals were used to propagate any uncertainties within the individual ratings in envelope fashion (Hayes 2011) as the lowest of all Lower bounds and the highest of all Upper bounds.

The conversion of qualitative ratings to numeric scores and back again also provided an opportunity to explore different scoring options (Fig1b-d) for both bio-physical attributes and ecological value. It should be noted that the scores have no absolute meaning, but are simply a tool for adjusting the relationships of the different categories and their products in much the same way as is routinely done with likelihood and consequence scores in conventional risk assessments (SA/SNZ, 2004).

Following the workshops, three variations on the initial scoring scheme were presented to the experts involved to find out which variation best matched their expectations for given combinations of shoreline type or biotic category combined with ecological value. Matrix B attempted a balanced approach in terms of the numbers of VL/L and H/VH cells. Matrix C aimed to avoid undue alarms and was thus ‘low-end heavy’, while Matrix D placed slightly more emphasis on ecological value than on the impacts of oils on different habitats and species. The experts were consulted in terms of their preference for the scoring options.

3. Results and Discussion

3.1. Recognition of Uncertainty

In 14 of the 66 coastal cells along the Victorian coastline, more than one habitat or species group was assessed, leading to a total of 85 cases of a habitat or species group within a single cell requiring assessment. Results clearly showed the effect of allowing multiple experts to make their own assessment of ecological importance without being constrained to a single rating category (Table 2).

Table 2: Summary of rating of ecological value by individual assessors

	Upper Bound (worst case)					
	Very	Low	Moderate	High	Very	Total No.
Count of Assessments	0	25	72	119	135	351
Percentage	0%	7%	21%	34%	38%	
	No. of rating categories spanned					
	1	2	3	4	5	Total No.
Count of Assessments	180	165	5	1	0	351
Percentage	51%	47%	1%	<1%	0%	

Collectively, the experts made 351 assessments of individual cells and the selected habitats or biota within each. In 49% of cases, the experts took the opportunity to register their own uncertainty by nominating a band of categories (e.g. Very Low to Moderate) rather than a single category. When the ratings of individual assessors were combined in a manner that propagated those uncertainties, 74% of coastal cells received overall ratings which spanned more than one category (Table 3). The uncertainty represented at the coastal cell level reflects both that of the individual assessor and any differences of opinion between assessors.

Table 3: Summary of ecological sensitivity at level of coastal cell

	Upper Bound (worst case)					
	Very	Low	Moderate	High	Very	Total No.
Count of Coastal Cells	3	14	20	8	21	66
Percentage	5%	21%	30%	12%	32%	
	No. of rating categories spanned					
	1	2	3	4	5	Total No.
Count of Coastal Cells	17	32	10	6	1	66
Percentage	26%	48%	15%	9%	2%	

Of the 66 coastal cells, in only 10 cases (15%) was there complete agreement both within and between assessors over ecological value, with no uncertainty about the specified ratings. In other words, individual assessors each nominated a single rating without the need for different upper and lower bounds, and all assessors were agreed on that single rating. In a further 15 cases (18%), individual assessors each gave upper and lower bounds, and all assessors applied the same bounds.

Agreement among assessors in the rank order of their ratings was tested by applying Kendall's coefficient of concordance (Kendall & Babington Smith 1939; Legendre 2005; IMO 2013) to the scores corresponding to the ecological value ratings (Table 4). Because the test does not allow for missing data, it was not possible to apply the test to the full data set. Therefore, two smaller subsets of data were generated by discarding some assessors and/or cells/habitats/biota.

Because of the natural ordering inherent in upper and lower bounds, the two types of bound were examined separately to avoid any artificial inflating of the level of agreement. Notwithstanding the low level of *complete* agreement noted above, there were significant levels of agreement in the *rank order* of ratings applied to the cells/habitats/species groups by the experts.

Table 4: Tests of concordance among assessors in the rank order of ecological sensitivity ratings.

Subset of data	Kendall's W	χ^2	df	probability
7 assessors x 12 cells/habitats/biota – Upper bounds	0.862	66.336	11	$P < 0.001$
7 assessors x 12 cells/habitats/biota – Lower bounds	0.857	65.955	11	$P < 0.001$
3 assessors x 66 cells/habitats/biota – Upper bounds	0.963	187.847	65	$P < 0.001$
3 assessors x 66 cells/habitats/biota – Lower bounds	0.971	189.246	65	$P < 0.001$

3.2. Visualization of results

Assessment results can be visualized in GIS format and Figure 2 provides a map of the Victorian coastline with the results based on the scoring option initially presented to participants (Fig. 1A). Cell colour is used to indicate the upper bound of sensitivity and a number to indicate the level of uncertainty in the assessment for the cell.

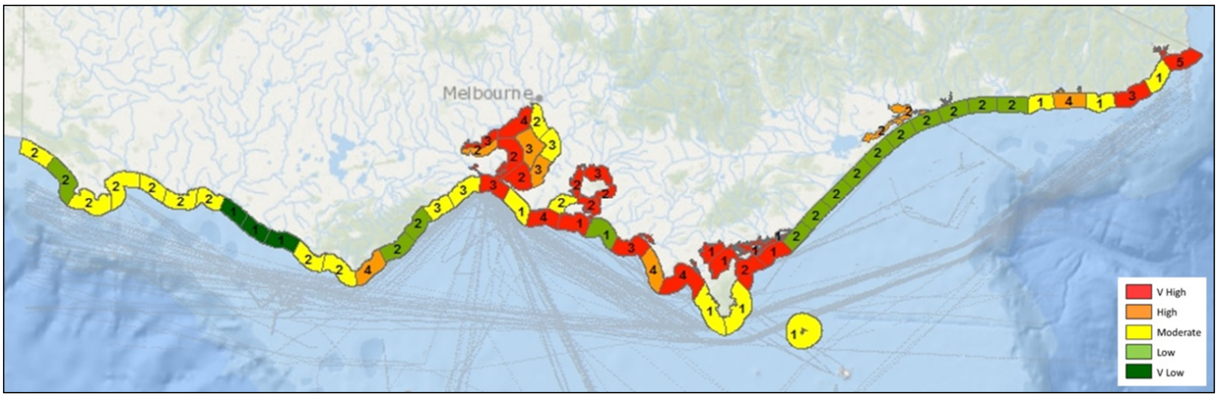

Fig 2. Map of the Victorian coast showing the upper bound of ecological sensitivity ratings (i.e. worst case) using the initial scoring scale, together with an indication of the level of uncertainty in the assessment for each cell. '1' indicates no uncertainty in the rating (i.e. upper and lower bounds spanned only a single rating), while '5' indicates a maximum difference between upper and lower bounds (i.e. bounds span 5 ratings).

3.3 Comparison of assessment styles

Figure 3 shows a reworking of the earlier Navigatus assessment to combine what had been separate resource categories of habitats and species into a single ecological category. This was done in a manner consistent with the Navigatus approach, i.e., by taking the higher of the two Navigatus ratings for each cell.

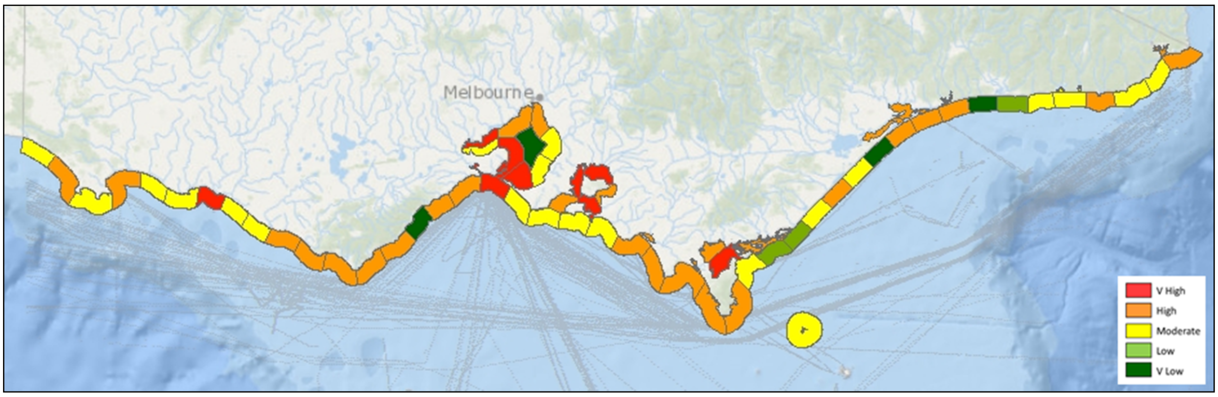

Fig. 3. Map of the Victorian coast showing combined sensitivity ratings for the two Navigatus resource categories of habitats and species (based on data from Navigatus 2011).

Visual comparison of Figures 2 and 3 shows the present bounded approach produced generally lower sensitivity ratings along the outer parts of the coast and high ratings in much of the central area including the bays and inlets. Consider cell 7 (west coast) as an example of how the different assessment styles produce different results. The presence of the Merri Marine Sanctuary rated highly under the Navigatus process, and the cell was similarly scored for ecological value in the present study. However, the exposed rocky platforms of the sanctuary are by their nature less sensitive to oil spills than some other habitats (e.g. sheltered tidal flats) and this factor combined with the high ecological value to produce an upper ecological sensitivity of only Moderate for the present study. A similar logic explains the abundance of Very High upper bounds in Victorian bays and inlets from the present assessment. Not only are the habitats sheltered and thus somewhat sensitive to any oil spill that may occur, their ecological sensitivity is boosted by the high ecological value placed on them because, for example, seagrasses are ecosystem engineers which stabilize the environment and increase productivity.

The greater frequency of Very High ratings is examined in a different form in Table 5. While overall there were more than twice as many Very High ratings in the present study than in the Navigatus project, it can be seen that in less than one third of cases (6 out of 21) was the Very High rating unequivocal (i.e. with lower and upper bounds identical). For the remaining 15 cases, it was acknowledged that although a Very High rating was possible, some lower rating was also possible. The flow-on effects to overall environmental sensitivity including the other layers originally evaluated in the Navigatus project (economic, cultural, social) besides the ecological layer are also reflected in Table 5. For the combined sensitivities, all the Very High ratings were qualified by greater uncertainty (i.e. lower bounds were all one or more levels lower than the matching upper bounds).

3.3. Other factors possibly influencing the assessment

Because the workshop spread over two days, with little overlap in assessors from one to the other, a small number of cells was re-assessed to roughly gauge what differences might arise in such situations. Two contrasting cells were chosen and it was found that while there were some differences between assessors, the overall ratings and scores for the two days were identical with for the two chosen cells (Table 6). While the very small sample size does not permit a rigorous comparison of scores and ratings, it is evident that a change of personnel does not necessarily produce outcomes more divergent than would otherwise be the case.

Table 5: Frequency of sensitivity ratings for coastal cells from the present study compared to Navigatus

Sensitivity Rating		Ecological			Overall (i.e. Environmental)		
		Current Study		Navigatus	Current Study		Navigatus
Upper	Interval	Freq.	Sum of Freqs.	Freq.	Freq.	Sum of Freqs.	Freq.
Very High	VH - VH	6	21	9	0	23	11
	H - VH	6			3		
	M - VH	5			14		
	L - VH	3			5		
	VL - VH	1			1		
High	H - H	0	8	29	0	16	34
	M - H	3			4		
	L - H	2			6		
	VL - H	3			6		
Moderate	M - M	7	20	21	5	27	21
	L - M	10			5		
	VL - M	3			17		
Low	L - L	4	14	3	0	0	0
	VL - L	10			0		
Very Low	VL - VL	3	3	4	0	0	0

Table 6: Repeat scoring of coastal cells.

Coastal Cell	Habitat	Workshop	Variation between assessors	Overall Sensitivity	
				Score	Rating
2 Discovery Bay (east)	Exposed cliffs	1	H – H x 1 M – H x 1 M – M x 5	7 - 20	V Low - Low
		2	M – H x 1 M – M x 1	7 - 20	V Low - Low
19 Port Phillip (Queenscliff)	Sheltered flats	1	VH – VH x 1 H – VH x 5 H - H x 1	180 – 450	High – V High
		2	VH – VH x 2 H – VH x 2	180 - 450	High – V High

The assessment benefitted from the interaction among experts during the course of the workshops, as individuals shared knowledge which then stimulated discussion or informed the assessments of others in the room. This information (recorded but not reported in detail here) not only provides a useful resource for future updates of the assessment, it also provides transparency by making the reasoning behind the subjective judgments of the assessors available to interested parties.

The different scoring options (Fig. 1) generated some marked differences among the sensitivities, with less than one third of cells having identical ratings identical across all four scoring options (Table 7). This indicates that the selection of numeric scores associated with qualitative ratings is an important issue. When presented with the alternative scoring systems after the workshops, four experts expressed a preference for Matrix D with its emphasis on ecological value. Reasons cited include that matrix representing a more precautionary approach than the other alternatives. Larger numbers of high value attributes were seen as appropriate for the Victorian coast which was noted as being in generally good or excellent condition, especially when compared to highly modified marine environments found in other parts of the world. In contrast, one expert preferred the low-end heavy Matrix C because it best reflected his views at the extreme ends of the value scale. He also noted that distinctions were harder to make in the middle of the scale. In a practical sense, Matrix C also had the advantage of not creating a situation where limited resources might be spread very thinly over more Very High sensitivity cells that might be the case using another matrix. It was notable that matrix preferences corresponded to the affiliations of the responding experts. Those preferring the emphasis on ecological value (Matrix D) were all engaged in protected area management, while the remaining expert who opted for the low-end heavy matrix (Matrix C) was responsible for oil spill response coordination.

Table 7. Summary of differences among assessment outcomes across 4 different scoring options.

	Differences among Lower Bounds	Differences among Upper bounds	Differences among Ranges of rating categories	Ratings identical in all ways
Count of Coastal Cells	38	27	42	21
Percentage of Coastal Cells	58%	41%	64%	32%

3.4. Recommendations and future additions

The results of this pilot workshop confirm that expert assessors are unlikely to be in complete agreement over the subjective rating of ecological importance in coastal waters. Three key strategies to address the uncertainty inherent in subjective risk assessment are as follows: 1) engage with multiple experts to minimize the effects of individual cognitive biases; 2) employ methods such as interval analysis to explicitly incorporate uncertainty into the assessment, rather than simply ignoring it; and 3) allow for revision of ratings following discussion to resolve any language-based misunderstandings that may have artificially inflated uncertainty

The corollary to this multi-expert workshop approach is that additional measures are required to minimize the effects of group-based biases such as 'group think' (Janis 1982) and 'halo effects' (Thorndike 1920). Careful facilitation is required to avoid domination of the group by extroverts (Bonner *et al*. 2007).

The incorporation of uncertainty should always be a priority where data is sparse and the assessment must rely on subjective judgment in order to proceed, regardless of the category of resources under consideration (i.e. social or economic as well as ecological). Options for representing the uncertainty associated with an ecological sensitivity rating to better visual effect in a GIS layer could be explored. Ideally, within any given rating category, the preferred option would make ratings with lower uncertainty more conspicuous on a map than those with higher uncertainty. In the future, the GIS layers could also be combined with other relevant information about the cell so that oil response services could have easy access to plan for emergencies if they arrive.

Depending on the length of coastline to be considered and the amount of background information available, it seems that two days is a more realistic timeframe for a workshop of this nature. For any future workshops, particularly if they occupy two days, attendance might be improved by offering some incentive for experts to forego their usual activities in order to participate. Additional time could be utilized to alleviate group-based biases by adopting a Delphi-style approach (Schmidt 1997) to the workshop where an initial rating of cells is carried out privately before the group discussion and possible individual revision of ratings. Further development and refinement of criteria by which ecological value might be assessed is desirable to provide further guidance to experts when making their assessments. Finally, whether the approach is being used for a local or regional assessment or as one workshop across a wider (perhaps national) assessment, continuity of the facilitator and some of the key assessors across workshops should be considered to limit inter-temporal, geographic or ecological expertise biases.

4. Conclusions

The results of this pilot workshop confirm what is known from previous studies – that uncertainty pervades subjective risk assessments – and that with appropriate design, uncertainty can be better identified and addressed

Yet, many risk assessments, including oil spill sensitivity assessments, fail to consider uncertainty. When quantitative data are lacking and the only option is subjective judgement, there are relatively simple ways to incorporate uncertainty and thus produce a more 'honest' outcome. These include using multiple assessors and simple mathematical tools like interval analysis. Applying such methods to the Victorian coastline, many instances of differences of opinion between assessors were identified, as was uncertainty within the assessments of individual assessors. Nonetheless, there was still a high level of agreement overall among the expert assessors, with their differences 'averaging out'.

The approach of the present assessment produced generally lower ecological sensitivity ratings along the outer parts of the coast and higher ratings in much of central Victoria than the habitats and species component of the Navigatus project. This appeared to be a result of ecological value ratings having a modifying effect on the relatively straightforward habitats and species sensitivities that appeared to be the basis of the Navigatus project, but which formed only one part of the present assessment. In the bounded approach, the flow-on effects to overall environmental sensitivity were also evident (with more Very High ratings and fewer High ratings) than in the comparable Navigatus version. There was at least some uncertainty associated with all such ratings.

Alternative scoring options produced different assessment outcomes. While there were substantial differences at the lower end of the ecological sensitivity scale, ratings at the upper end of the scale were slightly more consistent across the four alternatives. Further exploration of options is desirable to identify a scoring option that best represents the participants understanding of the ratings applied.

The developed methodology can enhance risk assessment methodologies at the local and international level such as the Formal Safety Assessment (FSA) Methodology developed by the International Maritime Organization (IMO) where ecological values (potential damage) are currently not considered.

Acknowledgements

We thank the Australian Maritime Safety Authority and the Victorian Department of Transport, Planning and Local Infrastructure as well as the experts who gave of their time to participate in the workshops.

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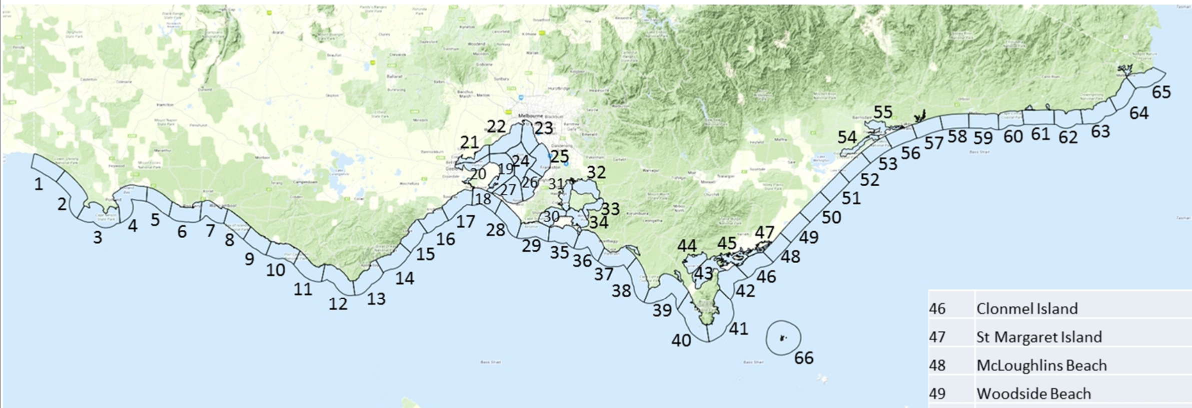
Appendix A: Key to Coastal Cells



1	Discovery Bay (west)
2	Discovery Bay (east)
3	Cape Neslon
4	Portland Bay (west)
5	Portland Bay (east)
6	Port Fairy
7	Warrnambool
8	Childers Cove
9	Bay of Islands
10	Port Campbell
11	Moonlight Head
12	Cape Otway West
13	Apollo Bay
14	Cape Patton
15	Lorne
16	Anglesea
17	Torquay
18	Port Phillip Heads
19	Port Phillip (Queenscliff)
20	Geelong approaches
21	Geelong Port
22	Altona Bay
23	Melbourne
24	Port Phillip (central)
25	Port Phillip (Frankston)
26	Port Phillip (Mornington)
27	Port Phillip (Sorrento shore)
28	Mornington Peninsula (SW)
29	Mornington Peninsula (S)
30	Westernport
31	French Island / Crib Point
32	French Island (north)
33	French Island (east)
34	French Island / San Remo
35	Phillip Island (south)
36	Kilcunda
37	Venus Bay
38	Cape Liptrap (NW)
39	Waratah Bay
40	Wilsons Promontory (west)
41	Wilsons Promontory (east)
42	Snake Island (south)
43	Corner Inlet (south)
44	Port Welshpool
45	Sunday Island
46	Clonmel Island
47	St Margaret Island
48	McLoughlins Beach
49	Woodside Beach
50	Seaspray
51	Golden Beach
52	Ocean Grange
53	Lakes Entrance (west)
54	Lake Victoria
55	Lake King / Metung
56	Lakes Entrance
57	Lake Tyers Beach
58	Corringle
59	Marlo
60	Cape Conran
61	Sydenham Inlet
62	Point Hicks
63	Croajingolong (west)
64	Croajingolong (east)
65	Cape Howe / Mallacoota
66	Hogan Group

Source: Navigatus (2011)