Short Title: Small-craft Infection Modes and Effects Analysis

Identifying hazards in complex ecological systems – Part 2: Infection Modes and Effects Analysis for small craft

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Abstract

Risk assessment is a popular environmental management tool. It is used for physical and chemical stressors, and more recently for biological stressors such as invasive species and genetically modified organisms. Hazard identification is the most important part of any risk assessment. In many ecological examples, however, this stage of the analysis is very poor. This paper describes the application of a rigorous and systematic hazard analysis, called Infection Modes and Effects Analysis (named after its industrial counterpart Failure Modes and Effect Analysis), which was used to investigate the potential spread of marine pests by small craft. The analysis was implemented through a series of workshops targeted at fishing vessels, motor cruisers, yachts and trailerable boats operating out of local ports in southeastern Australia. It identified 7 vessel components, which were subsequently divided into sub-components, and 8 infection modes. Each sub-component/infection mode combination represents a possible vector for the spread of marine organisms. The analysis identified a total of 215 sub-component/infection mode combinations for displacement vessels and a further 71 combinations for trailerable vessels. These were then ranked in order of importance using the Risk Priority Number and an area chart. In most cases (73%) the variance associated with the Risk Priority Number is relatively low, indicating reasonable consensus between the participants of the different workshops for most of the sub-component infection modes. This is the first time that Failure Modes and Effects Analysis, or a variant thereof, has been applied to biological invasions. The analysis demonstrates that rigorous hazard identification techniques, originally designed for complex industrial systems, can be modified for use in ecological systems.

Keywords: Ecological risk assessment, biological invasions, non-indigenous species, small boats

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INTRODUCTION

Ecological risk assessment

Risk assessment is a popular management tool for environmental problems. Ecological risk assessment is commonly associated with chemical stressors - indeed much of the terminology associated with this discipline is couched in terms of chemical stressors. This is an unfortunate corollary of the subject origin's (National Research Council, 1983) and its subsequent ecotoxicological emphasis. This perspective does not, however, reflect the much wider application of risk assessment techniques. Quantitative ecological risk assessments have been conducted on animal imports (Keller, 1993; Morley, 1993) and fisheries (Francis, 1992; Meyer and Millar, 1999) for many years. Risk assessment techniques have also been advocated for biological invasions (Richardson *et al.,* 1990, Hayes, 1998, Hayes and Hewitt, 1998) and the release of genetically modified organisms (Fiksell and Covello, 1985).

Biological stressors, such as introduced species or genetically modified organisms, are not governed by the (well-established) decay and dispersion rules that typically characterise chemical stressors. Ecological risk assessments for biological stressors are consequently much more difficult to conduct than their chemical counterparts. Good hazard identification is a critical component in this process – hazards that are not identified in the early stages of a risk assessment are not carried through the assessment, and may seriously undermine the efficacy of the risk assessment. A recent review of ten bio-invasion risk assessments (Hayes, in press) suggests that the initial hazard analysis is usually ad hoc and neither rigorous nor systematic. The aim of this paper is to demonstrate how rigorous hazard analysis techniques can be applied to ecological problems – in this case the use of failure modes and effects analysis for bio-invasions facilitated by small craft.

Marine bio-invasions

Marine organisms are being transported around the world, and introduced to new localities at an unprecedented rate (Walford and Wicklund, 1973; Carlton, 1985, 1995). Introductions of Non-Indigenous Species (NIS) is one of the most important threats to global biodiversity (Baltz, 1991). At least 13 anthropogenic vectors are, or have been, responsible for spreading marine organisms beyond natural bio-geographic boundaries (Table 1). The dominant vectors vary with time and geographical region. Historically, the dominant mode of introduction in Australia is hull fouling, followed by accidental release associated with mariculture (predominately oysters) and ballast water (Thresher *et al.,* 1999). In San Francisco Bay hull fouling and ballast water are the two most important vectors for the introduction of marine organisms, closely followed by mariculture of the Atlantic oyster *Crassostrea virginica* and the Pacific (Japanese) oyster *Crassostrea gigas*, (Cohen and Carlton, 1995). In Britain accidental introductions associated with mariculture are the most important identifiable source of NIS, followed by hull fouling and ballast water (Eno *et al.,* 1997). Mariculture has introduced at least 14 non-indigenous marine plants into the Mediterranean, second only to the Suez canal as a vector in this region (Ribera and Boudouresque, 1995).

Mass oyster movements around the world have by and large ceased. In their place hull fouling and ballast-water have emerged as the most important vector for NIS introductions. The international community is directing considerable effort to managing invasion pathways associated with international shipping, particularly ballast water, but has largely ignored the role of other vessels. Small craft, including ocean going yachts, recreational and commercial fishing vessels (both displacement and trailerable) also play an important role in a) the first introduction of NIS; and b) the subsequent spread of NIS from the site of first introduction.

The black striped mussel *Mytilopsis sp.* is a good example of the first scenario. The mussel was first detected in the Cullen Bay marina, Darwin in March 1999 (Willan *et al.,* 2000). It was most probably introduced on the hull of an ocean-going recreational yacht, and spread to nearby marinas by other local recreational yachts. On-going monitoring has found adult mussels on the hull and in the seawater piping of Indonesian fishing vessels and ocean-going yachts (Willan *et al.,* 2000; *pers comm* A. Marshall, Northern Territory Aquatic Pests Program), confirming the importance of these vectors.

The overland dispersal of the zebra mussel *Dreissena polymorpha* provides a good illustration of the second scenario. The zebra mussel was first introduced into Lake St Clair sometime prior to 1988, most likely as larval stages in the ballast-water of a commercial freighter. Recreational boats and fishing vessels have since spread the mussel between lakes and waterways that are geographically isolated from one another. The mussels are transported as adults attached to the exterior of the boat or trailer, or as larvae in live wells, bilges, bait buckets or cooling systems (Johnson and Padilla, 1996).

METHODS

Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) was developed in the mid-1960s by the aerospace industry to improve safety (McDermott, 1996). It is now widely practised in the petro-chemical industry (Hope *et al.,* 1982) and is specified as a QS-9000 requirement by Chrysler, Ford and General Motors, both as a safety and quality control tool (Palady, 1995).

FMEA examines the components and operating modes of a system. It identifies the failure modes of each component and the effects of failure on other components and the overall function of the system (Ozog and Bendixen, 1987). FMEA is a “bottom-up” hazard analysis tool – it starts with the individual components and assesses the consequences of their failure. In industrial systems, FMEA is formalised in a 6-step procedure (Figure 1):

1. Identify and list all components;

2. Identify all failure modes, considering all possible operating modes;

3. List the potential effects of each failure mode and score their severity;

4. List the potential causes of each failure mode and score their likelihood;

5. List the current controls to prevent the failure mode and score the likelihood of detection; and,

6. Calculate the Risk Priority Number (RPN).

The severity, likelihood and detection ratings are usually scored from 1 to 10, with 1 being the lowest rating and 10 the highest. The RPN is the product of the scores assigned to these three ratings. The RPN is simply a way of priortising failure modes by ranking them from highest RPN to lowest RPN.

Teams of four to six people usually conduct a FMEA, with a team leader responsible for coordinating the whole process. Each member of the team must be familiar with one or more aspects of the system in question. For example a typical FMEA team might consist of a team leader, design engineer, process engineer, research scientist, and leading hand. The FMEA is recorded on a spreadsheet with columns headed components, failure modes, effects of failure, severity score, etc. The team is encouraged to complete each column prior to moving to the next. This helps maintain the team's focus and the internal consistency of the scores.

Infection Modes and Effects Analysis

I have coined the name Infection Modes and Effects Analysis (IMEA) to describe a vector hazard analysis tool based on FMEA. The approach is essentially identical to FMEA except that the analyst is seeking to identify bio-invasion hazards – ie how marine (or freshwater) organisms "infect" vectors. In this instance the technique was applied to small-craft operating out of local ports in southeastern Australia, however, it could be applied more generally to any bio-invasion vector. The procedure is formalised in the following steps:

1. Identify and list all the components of the vessel that could be infected by marine organisms;

2. Identify all "infection modes" - how marine organisms survive on each component;

3. Describe the environmental conditions associated with this infection mode and score its suitability for marine organisms;

4. List the causes of each infection mode and score their likelihood;

5. List the current controls to prevent the infection mode and score the likelihood of detection; and,

6. Calculate the Risk Priority Number (RPN)

In a departure from the usual FMEA approach, the suitability, likelihood and detection ratings are simultaneously scored for a minimum and maximum value, on a scale of 1 to 10 (Figure 2). This approach allows the IMEA to highlight differences in the way certain components are used. For example a Danish seine trawler uses a tender to deploy the net. The tender is therefore frequently immersed in the sea and therefore quite likely to become infected with marine organisms. The dinghy or tender of a board trawler, however, is not routinely used and therefore is much less likely to become infected. The IMEA accordingly allows a minimum and maximum RPN for each sub-component to reflect this type of uncertainty.

The IMEA for small craft was implemented through a series of workshops. Eight workshops were held at each of the following locations in southeastern Australia: Apollo Bay, Bairnsdale, Gippsland Lakes, Hobsons Bay, Melbourne, Paynesville, Queenscliff, Sandringham and Eden (Figure 3). The workshops were designed to target each of the vessel types that operate out of these ports (Table 2), distinguishing between displacement vessels - commercial fishing vessels, motor cruisers, ocean-going yachts, dive charter vessels, etc – and trailerable vessels – recreational fishing vessel and “tinnies”. Each workshop was attended by 4 to 8 participants, usually skippers, owners or operators of the vessels concerned. A boat yard manager and marine biologist also attended on two separate occasions. A risk analyst led the workshops with support from a project officer from the Victorian Department of Natural Resources and Environment.

The analysis was completed via a spreadsheet, shown in Figure 4. Each workshop began by identifying the components and sub-components of the vessel(s) in question. The participants were asked to check the sub-components if they had already been derived from a previous workshop, and add any items that were missing. The risk analyst then led the participants through each column of the spreadsheet, asking them to describe the environmental characteristics of each sub-component, then score this using a guide to the environmental severity specifically developed for this analysis (Table 3). The participants where then asked to describe why these sub-components become infected, then score occurrence using a similar guide for the occurrence ratings (Table 4). Finally the participants were asked to describe the controls currently in place to keep the sub-components free of marine organisms, and then to score the probability of detecting marine organisms in these areas given the current practise. Again the participants were supplied with a guide to the detection ratings (Table 5) to assist them in this process. In accordance with FMEA practise each column of the spreadsheet was completed before moving onto the next. The IMEA proved to be very time consuming. Each workshop lasted 2 to 3 hours, during which time two or three components (for example hull and propeller, or fishing gear and deck) were completed depending on how many sub-components were identified for each component.

RESULTS

Sub-components and infection modes

During the workshops the IMEA identified 7 vessel components – hull, deck, internal spaces, fishing gear, propeller, rudder and anchor – for displacement and trailerable vessels, which were then further divided into sub-components – for example surface of the hull (Figure 4). The analysis also identified 8 infection modes; external fouling, internal fouling, borer, refuge, water retention, sediment retention, catch parasites and bait. Each of these was allocated to a sub-component as appropriate. The surface of a timber hull, for example, has three infection modes; external fouling, internal fouling and borer. An anchor well has two infection modes; water retention and sediment retention.

External fouling refers to fouling on a surface that is readily visible when the vessel is either in or out of the water. Internal fouling refers to fouling on a surface that is not readily visible when the vessel is in or out of the water. Borer refers to organisms that bore into wooden or fibreglass surfaces. These organisms thereby create internal surfaces that may also be fouled. Refuge refers to a place on the vessel that may harbour large (ie visible to the naked eye) marine organisms – essentially a place where large marine organisms can hide. Water retention refers to any part of the boat that retains water even when the vessel is out of the water. Similarly sediment retention refers to the areas of the vessel that hold sediment, in and out of the water. These areas are in effect microhabitats that may contain marine organisms that are too small to be seen with the naked eye. Catch parasites refers to the possibility that the parasites of fish, shellfish or any-other catch are NIS. Finally bait refers to the possibility that the bait (or parasites associated with the bait) are NIS.

Risk Priority Number

The IMEA identified a total of 215 sub-component/infection mode combinations for a displacement vessel, and a further 71 combinations for trailerable vessels (not including the trailer). A complete list of the IMEA results showing the components, sub-components, infection modes and their RPNs is provided in Appendix A. The minimum and maximum RPN was calculated as the average of the product of the scores allocated to the environmental severity, occurrence and detection ratings

$$RPN_{\min} = \frac{1}{n}\left[\sum_{i=1}^{n}(MinSevRat_i \cdot MinOccRat_i \cdot MinDetRat_i)\right] \qquad [1]$$

for the i = 1 to n scores allocated at the workshops. Note each workshop resulted in a single minimum and maximum score for the severity, occurrence and detection of the sub-component/infection mode combination. The minimum and maximum score was selected from the individual scores given by the participants at the workshop. During the nine workshops we managed to cover most components (and their sub-components) at least twice (i.e. n = 2). The hull of a displacement vessel, however, was repeated four times.

The RPN is a hazard index – it highlights those parts of a boat that are most likely to be infected with, and sustain, marine organisms. The average RPN is used throughout Appendix A to rank the "strength" of the sub-components of a vessel as a vector for the spread of marine organisms. Alternatively one could rank the sub-components by the maximum RPN. From a management perspective, however, this makes very little difference (see below).

Variance

In most cases the minimum and maximum RPNs reported in Appendix A are averaged across a number of workshops (equation 1). Thus whilst the range between the minimum and maximum RPN provides some indication of variability in the participant's responses, this variability has been masked to some extent. The variance of the scores given to severity, occurrence and detection ratings is the simplest and most accurate guide to the variability in the participant's responses. The variance of a rating is given by

$$\mathrm{var} = \frac{\sum_{i=1}^{m} \left(x_i - \bar{x} \right)}{m-1} \quad , \qquad [2]$$

where m = 2n because each workshop provided a minimum and maximum score for each rating.

The distribution of the variance, for each of the ratings, for the total 286 sub-component/infection mode combinations identified for displacement and trailerable vessels, is shown in Figure 5. In most cases (73%) the overall variance is relatively small (<20) suggesting that the participants at the workshops were broadly in agreement – ie the range between the highest score and the lowest score for the rating was small. Table 6 lists those sub-components with a summed variance greater than or equal to 20. Table 7 summarises the reasons for the high variance of all those sub-components listed in Table 6.

The variance of a particular sub-component/infection mode can be high for two reasons related to differences within and between the workshops:

- there is a large range between the maximum and minimum values assigned to the ratings by the participants at a single workshop – suggesting a diversity of views among the participants or some underlying operational difference for the same sub-component within a vessel type; or,

- the participants at different workshops assigned very different scores to the same sub-component/infection mode combination – suggesting some underlying operational difference for the same sub-component between different vessel types.

The sewage holding tank is a good example of the first scenario. It was addressed once during the Paynesville workshop. The variance is high because the participants scored environmental severity from 1 (minimum) to 10 (maximum). The occurrence rating has a similar range – 1 (minimum) and 9 (maximum), again adding to the variance. In this instance the variance reflects different operational conditions - seawater flush versus chemical flush - within the yachts category.

The closed bilge is a good example of the second scenario. It was addressed three times at Eden (fishing vessels), Paynesville (motor cruisers) and Sandringham (ocean-going yachts). The minimum and maximum environmental severity was scored (1, 8, 3) and (1, 9, 4) respectively. The occurrence and detection are also very different between the three workshops. In this instance the high variance reflects the fact that the bilge in a fishing vessel is very dirty and oily and rarely cleaned, whereas in a motor cruiser it is checked regularly and kept much cleaner to avoid unpleasant odours in the cabin. The bilge of an ocean-going yacht falls somewhere between these two extremes. Overall the closed bilge ranks as an important (Table A2) but nonetheless variable sub-component.

Interpretation

There are two ways to interpret the results of a FMEA (Palady, 1995), and by analogy an IMEA:

- a traditional or "reactive" approach that uses the RPN to prioritise management decisions;
- a "proactive" approach which aims to reduce the occurrence and severity of failure modes (infection modes) before allocating resources to improve detection.

The first approach suggests that managers should address failure modes with high RPNs. In this context, however, what constitutes "high" is entirely at the manager's discretion. Palady (1995) suggests that (on a scale of 0 to 1000) it is reasonable to ignore failure modes with a RPN less than 20. The sub-component/infection modes identified here (displacement and trailerable vessels) are ranked by average RPN and maximum RPN in Appendix B. Approximately 57% of these, 162 out of 286, have an average RPN greater than 20. An additional 28 sub-components have a maximum RPN greater than 20.

There are two problems with this first approach - the RPN cut-off is arbitrary and may cause managers to overlook failure modes that have a relatively high severity and/or occurrence rating but very low detection rating. The second approach aims to avoid these problems by prioritising failure modes on the basis of their severity and occurrence. Each failure mode is priortised as high, medium or low by plotting severity against occurrence on an area chart (Figure 6). Appendix B includes the area chart priority for each of the sub-component/infection modes identified here, using the overall average severity and occurrence ratings. With this approach approximately 29%, 33% and 38% of the sub-components are respectively rated as high, medium and low priority.

Hazard management activities should, in the first instance, be directed to the high priority sub-components, and where practicable, the medium level sub-components. Palady (1995) suggests the four step hazard management strategy outlined below. Its full application, however, will depend on the overall strategic, organisational and risk management context for dealing with primary and secondary introductions of NIS.

1. Eliminate the occurrence;
2. Reduce the severity;
3. Reduce the occurrence; and finally,
4. Improve the detection.

In the IMEA context, *eliminating the occurrence* is equivalent to eliminating the occurrence of marine organisms on small vessels. In most instances, this is not possible as the main management option is to limit vessel movements so that they do not enter infected waters or come in contact with infected vessels or gear.

Reducing the severity is equivalent to ensuring that the sub-components of a vessel are, environmentally less suitable to marine organisms. The management option is for owners/operators of small vessels to keep their vessels clean. For example removing accumulated water and sediment, regularly cleaning fouled surfaces etc. Most of the vessel owners/operators that we talked to follow a regular cleaning regime, although this was a lower priority issue for commercial vessels than recreational vessels. Management agencies could assist by encouraging all vessel operators/owners to clean high priority sub-components as often as is practicable.

Reducing the occurrence translates to reducing infections of a certain group of marine organisms – notably known marine pests. Management options include ‘advisories’ to vessel operators/owners of potential infections, and where on the vessel this is most likely to occur, if the distribution and life cycle of the pest is known. For example species with pelagic larval life-stages that subsequently settle on “hard” surfaces will typically exhibit three infection modes: water retention, internal surface fouling and external surface fouling. Again the results of this analysis will indicate where on the vessel these infections are most likely to occur.

Management options for *improving the detection* of marine pests can include informing vessel operators/owners and small port managers of the risk of pests infecting vessels, gear and ports as well as the risks of cross infection. Voluntary and statutory measures could also be established to assess compliance with the risk abatement measures. In this instance education and extension campaigns would have to include information on the generic risks posed by marine pests, risk abatement strategies and arrangements in the event of vessel, gear or port becoming infected with a pest.

DISCUSSION

To my knowledge this is the first time that FMEA, or a variant thereof - IMEA, has been applied outside of its original (industrial) context. The IMEA has all the advantages of its industrial counterpart:

- it has the potential to identify all the potential hazards associated with the system in question – in this instance the sub-components of small boats that are most likely to harbour marine organisms;

- it quickly prioritises the hazards – the sub-components and their infection modes can be ranked according to the RPN or via an area chart into high, medium and low priority;

- it is easy to conduct –the participants in the workshop were very willing to contribute to the IMEA process despite the fact that, to them, it was a very novel way of thinking about boats and marine pests;

- the process is rigorous, systematic and transparent.

The analysis also suffers the same drawbacks as FMEA – principally the time taken to complete the analysis. The workshops proved to be quite time-consuming. We were therefore unable to repeat the analysis as many times as we had hoped. Ideally each sub-component of each vessel category should be addressed by three or four workshops. We were able to cover most, but not all sub-components three times. It would be useful to return to those sub-components that are not covered three times and those sub-components whose variance is high for reasons which are currently unclear (Table 7).

The IMEA is also very reliant on having the right people at each workshop. This means attracting experienced vessel owners/operators to the workshops who are able to "represent" the class of vessel being addressed. We found a simple phone call to the local fishing co-operative, port manager's office or sailing club was enough to identify suitable participants. Furthermore we found owners/operators were very willing participants. The workshops also provided an excellent opportunity to draw on practical knowledge about small vessels operating from local ports, and raise awareness about marine pest issues. This will help ensure that management activities are practical and acceptable to the community.

The RPNs are internally consistent – they provide a meaningful measure of hazard when compared against each other. For example this analysis suggests that the internal fouling of the seawater or grey-water inlets/outlets of a displacement vessel is more important as a vector than water retention in the bilge. The analysis also suggests, however, that in certain cases the sewage holding tank of a vessel is more important than the seawater or grey-water inlets/outlets. The RPNs, should not, however, be used a surrogate measure of bio-invasion risk. The probability of bio-invasion is site- and species-specific and cannot be gauged with an analysis as simple as this. They are most useful as a tool to managers seeking to minimise the spread of marine organisms via small-vessel traffic. For example, the Victorian DNRE intends to use the results of the analysis as the basis for a set of guidelines designed to deal with the potential spread of marine pests between small ports. The guidelines will encourage vessel owners to keep their vessels free of marine pests by identifying those parts of their boats that are most likely to be "infected" with marine organisms. The RPNs can also be used as a basis for vessel inspection protocols – management agencies can maximise the effectiveness of field resources by targeting those parts of the vessels that are most likely to harbour marine organisms.

The results of this analysis seem to agree with the (albeit limited) empirical evidence gathered to date on small-craft transmission of marine pests. Routine inspections of ocean-going yachts visiting Darwin continue to retrieve marine organisms from the vessel's seawater inlets and outlets (Willan *et al,* 2000). This analysis identifies sea/grey-water inlets and outlets as one of the most important vectors on displacement vessels, but also suggests that vessel inspectors should target sonar tubes, sewage holding tanks, outboard sail drive legs, skin fittings and plate cases. Similarly Johnson and Padilla (1996) found mussel larvae in live wells, bilges, bait buckets and cooling systems of trailerable vessels. This analysis identifies berley (bait) buckets, anchor wells, open bilges and bilge pumps, floatation pods and heat exchangers as the most important vectors on trailerable vessels, along with sea/grey water inlets and outlets, and transducers.

Ecological risk assessment must strive to be systematic and rigorous if it is to be successful. This is particularly important during the early hazard identification stage of the assessment. In practise this means identifying all hazards, including those beyond the professional experience of the analyst(s) immediately involved in the assessment. The analyst must use rigorous hazard analysis tools to capture the experience of those people who are most intimate with the system in question. In most cases this will require more than the usual literature search. This analysis demonstrates that it is possible to apply rigorous hazard analysis tools originally developed for industrial systems to ecological systems. I recommend risk analysts adopt these techniques more generally in a continuing effort to improve best practise in ecological risk assessment.

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Table 1 Anthropogenic vectors responsible for the spread of marine organisms around the globe

Anthropogenic vectors
Ships: accidental with vessel fouling (including boring into wooden hulls)
Ships: accidental with solid ballast (rocks, sand, etc)
Ships: accidental with ballast water
Fisheries: deliberate translocations of fish and shellfish to establish or support a new fishery
Fisheries: accidental with deliberate translocations of fish and shellfish (particularly oysters)
Fisheries: accidental with seaweed packing for bait and fishery products
Plant introductions: deliberate translocation of plant species (e.g. for erosion control)
Plant introductions: accidental with deliberate plant translocations
Biocontrol: deliberate translocation as a biocontrol agent
Biocontrol: accidental translocation with deliberate biocontrol release
Canals: natural range expansion through man-made canals
Individual release: deliberate and accidental release by individuals (e.g. aquarium discards)
Scientific release: deliberate and accidental release as a result of research activities

Table 2 Vessels operating out of the small ports and sailing clubs where the IMEA workshops were completed

Vessel type	Port/Sailing club
Commercial fishing vessels	
Abalone	Gippsland Lakes
Shark	Apollo Bay,
Cray	Apollo Bay, Gippsland Lakes, Eden, Queenscliff
Scallop	Apollo Bay, Gippsland Lakes, Eden, Queenscliff
Squid	Apollo Bay, Gippsland Lakes, Eden Queenscliff
Danish/purse seine	Apollo Bay, Eden
Board trawler (fish and prawn)	Apollo Bay, Eden, Queenscliff
Long-liner (tuna)	Eden
Recreational vessels	
Motor cruisers	Apollo Bay, Paynesville, Queenscliff
Yachts	Apollo Bay, Hobsons Bay, Eden, Sandringham, Queenscliff
Tinnies	Eden
Other vessels	
Dredge	Apollo Bay, Gippsland Lakes, Queenscliff
Charter (eg dive, tourist)	Apollo Bay, Bairnsdale, Gippsland Lakes, Eden, Queenscliff
Ferries	Gippsland Lakes
Tugs	Eden
Tankers (gas and fuel)	Eden

Table 3 Environmental severity ratings (SevRat) provided to each participant at the IMEA workshops

Description	Score
The environment is not suitable for survival of any marine organisms	1
The environment is only suitable for the survival of resistant diapause/resting stages	2
The environment is only suitable for the survival of very tolerant species	3
The environment is suitable for the survival of tolerant species	4
The environment is suitable for the survival of a lot of species	5
The environment is suitable for the survival of most species	6
The environment is suitable for the survival and growth of tolerant species	7
The environment is suitable for the survival and growth of most species	8
The environment is suitable for the survival, growth and reproduction of tolerant species	9
The environment is suitable for the survival, growth and reproduction of most species	10

Table 4 Occurrence rating (OccRat) provided to each participant at the IMEA workshops

Description	Score
The infection is extremely remote, highly unlikely	1
The infection is remote, unlikely	2
There is a slight chance of infection	3
There will be a small number of occurrences each year	4
An occasional number of infections are expected each year	5
The infection has a moderate occurrence frequency per year	6
The infection occurs frequently each year	7
There is a high occurrence of the infection each year	8
There is a very high occurrence of the infection each year	9
The infection is certain	10

Table 5 Detection ratings (DetRat) provided to each participant at the IMEA workshops

Description	**Score**
Almost certain to detect	1
Very high probability of detection	2
High probability of detection	3
Moderate chance of detection	4
Medium detection	5
Low chance of detection	6
Slight chance of detection	7
Very slight chance of detection	8
Remote chance of detection	9
Almost impossible to detect	10

Table 6 The variance of each of the ratings for those sub-components whose combined variance is greater than 20

Sub-component: infection mode	SevRat	OccRat	DetRat
Sewage holding tank: Water retention	40.50	32.00	0.00
Sewage holding tank: Sediment retention	40.50	32.00	0.00
Sewage holding tank: Refuge	40.50	32.00	0.00
Bilge - closed: Water retention	11.87	14.97	7.77
Bilge - closed: Sediment retention	11.87	14.97	7.77
Bilge - closed: Refuge	11.87	14.97	7.77
Propeller surface: External fouling	18.41	12.79	0.13
Propeller shaft: External fouling	18.41	12.79	0.13
Zinc blocks: Internal fouling	14.13	15.13	0.57
Skin fittings: External fouling	10.70	2.41	13.64
Echo sounder booth: Internal fouling	1.13	12.21	13.27
Skin fittings*: External fouling	1.67	1.67	21.67
Sea/grey-water inlet/outlets: Internal fouling	10.27	2.79	10.21
Traps - octopus: Water retention	18.00	0.50	4.50
Traps - octopus: External fouling	18.00	0.50	4.50
Traps - octopus: Refuge	18.00	0.50	4.50
Traps - octopus: Catch parasites	18.00	0.50	4.50
Outboard sail drive legs: External fouling	13.10	3.77	5.07
Zinc blocks: External fouling	12.29	9.43	0.21
Stabilisers/trim tabs - folding: External fouling	10.57	9.84	0.55
Stabilisers/trim tabs - folding: Internal fouling	10.57	9.84	0.55
Net reels: Water retention	1.67	12.33	6.92
Net reels: External fouling	1.67	12.33	6.92
Net reels: Refuge	1.67	12.33	6.92
Net reels: Catch parasites	1.67	12.33	6.92
Stern tubes cover/stern gland: External fouling	13.47	6.97	0.17
Marlin board: External fouling	10.97	9.07	0.17
Marlin board: Sediment retention	10.97	9.07	0.17

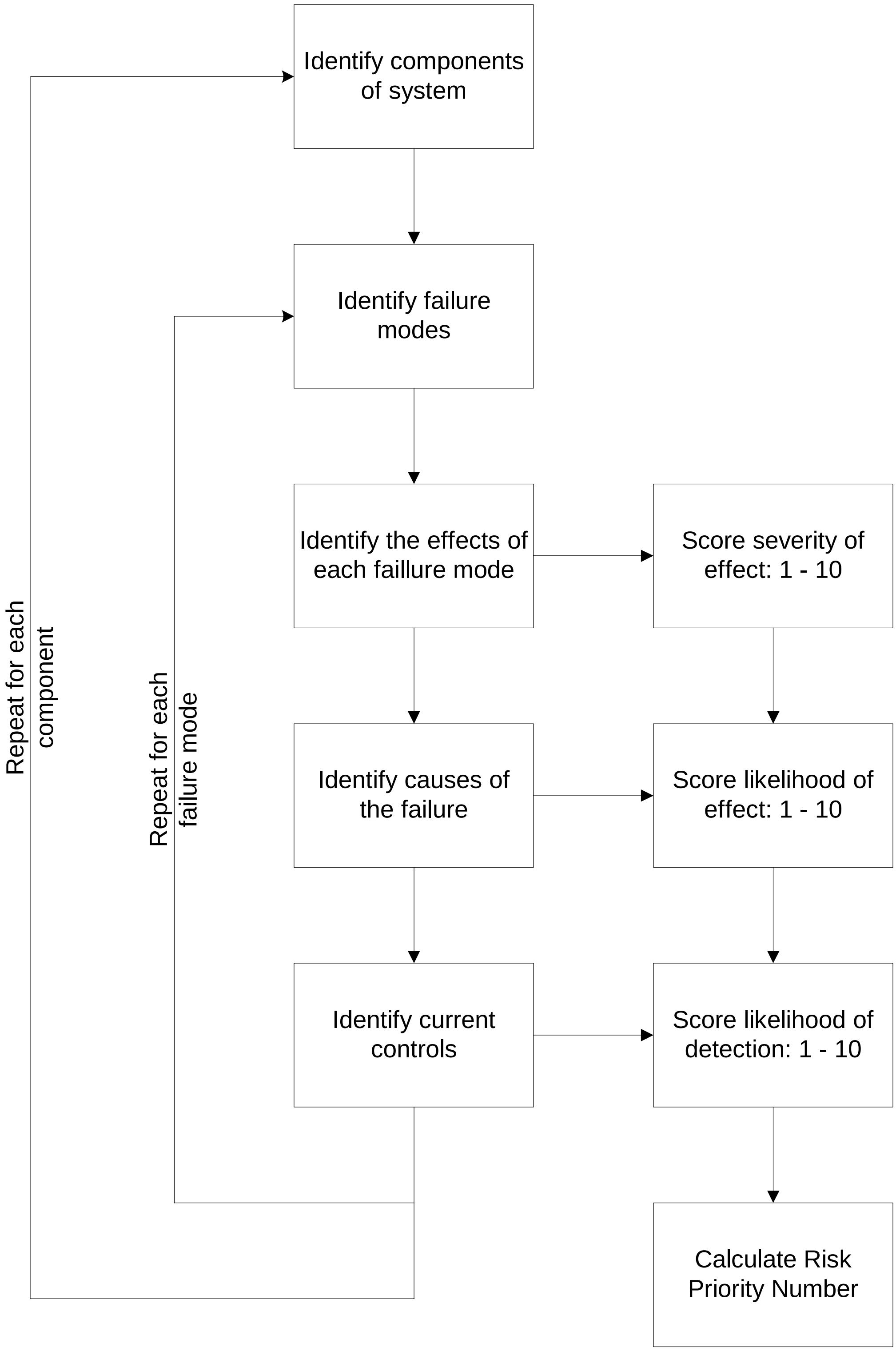
* indicates trailerable vessel

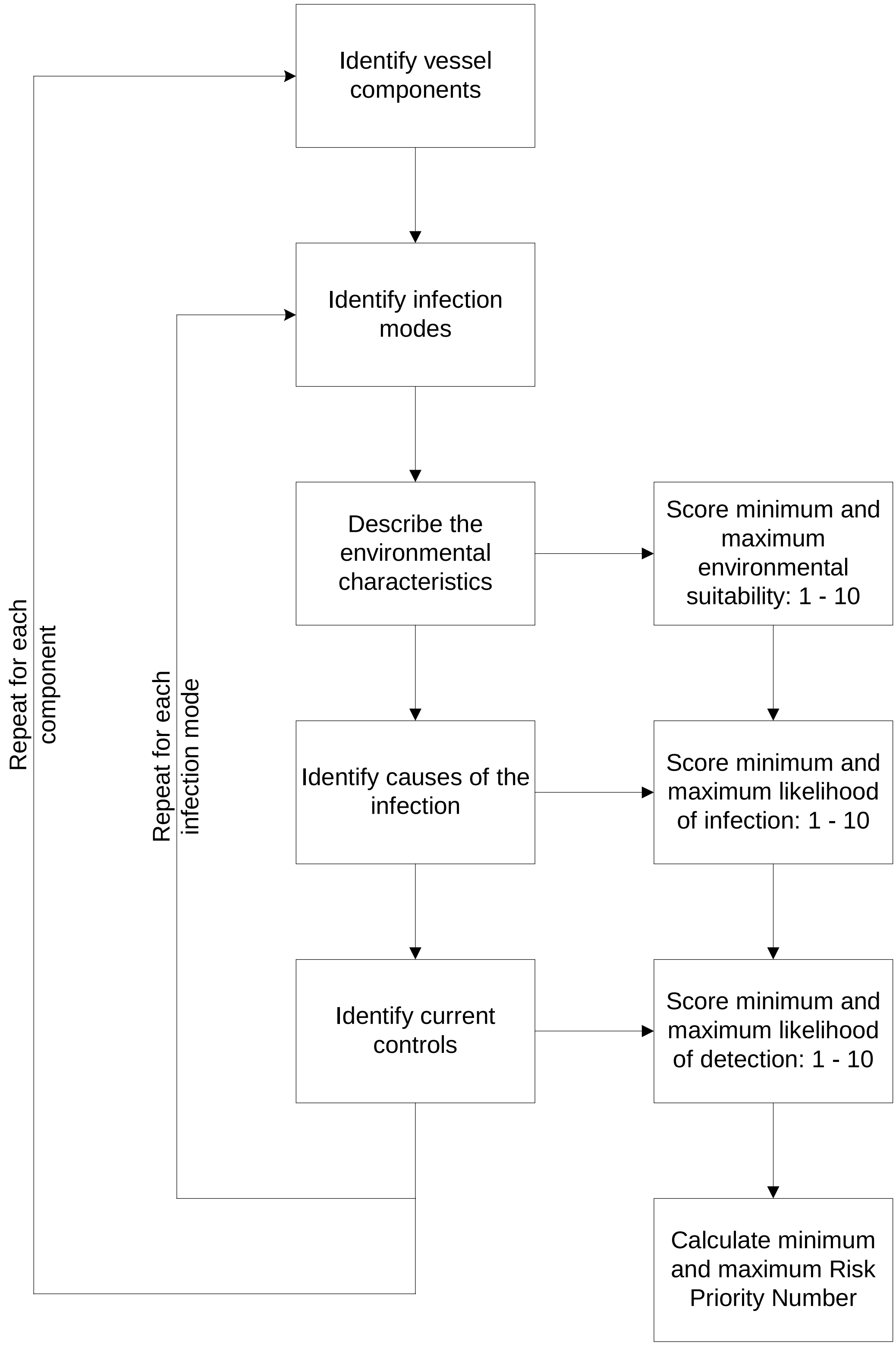
Table 7 The reasons for the high variance for those sub-components/infection modes whose combined variance is greater than 20.

COMPONENT - INFECTION MODE	REASONS FOR HIGH VARIANCE
Sewage holding tank: Water retention Sewage holding tank: Sediment retention Sewage holding tank: Refuge	Wide range given to environmental severity and occurrence ratings. Range reflects difference between the effects of seawater versus chemical flush on marine organisms.
Bilge - closed: Water retention Bilge - closed: Sediment retention Bilge - closed: Refuge	Non-consensus between scores given to all the ratings. Disagreement reflects operational difference between fishing vessels (bilge is very dirty and inaccessible) and motor cruisers (bilge is kept clean and is largely accessible).
Propeller surface: External fouling Propeller shaft: External fouling	Non-consensus between scores given to environmental severity and occurrence. Disagreement reflects the extent to which the propeller and shaft are stationary. For fishing vessels this is rare, for yachts this is more common.
Zinc blocks: Internal fouling	Zinc blocks on some vessels are bolted directly onto the hull. On other vessels they are bolted onto a bracket leaving a small space behind the block. Variance reflects disagreement between scores given to environmental severity and occurrence due to different interpretation of "internal" in this context.
Skin fittings: External fouling Skin fittings*: External fouling	Non-consensus between scores given to detection rating for displacement and trailerable vessels – reasons for this are unclear.
Echo sounder booth: Internal fouling	Non-consensus between scores given to occurrence and detection – reflects the fact that some booths are recessed and some are not, and possible confusion over the term "internal" in this context.
Sea/grey-water inlet/outlets: Internal fouling	Non-consensus over current controls between fishing vessels and yachts, and consequently scores allocated to detection rating. Fishing vessel operators reported no current controls unless blocked (hence low detection ratings). Yachts reported regular cleaning (hence higher detection ratings).
Traps - octopus: Water retention Traps - octopus: External fouling Traps - octopus: Refuge Traps - octopus: Catch parasites	Wide range given to environmental severity and detection rating. Severity range reflects a) different construction material – steel, terracotta, poly-pipe and b) how long the traps are left in the water – this varies between fisheries. Detection range reflects different construction material – e.g. the fisherman cannot see inside the terracotta pot design
Outboard sail drive legs: External fouling	Non-consensus over environmental severity – reasons for this are unclear
Zinc blocks: External fouling	Non-consensus on environmental severity and occurrence – disagreement on severity seems to centre on the extent to the zinc blocks are toxic to marine organisms. Reasons for disagreement on occurrence are unclear
Stabilisers/trim tabs - folding: External fouling Stabilisers/trim tabs - folding: Internal fouling	Non-consensus over environmental severity and occurrence between fishing vessels, yachts and other vessels – results for fishing vessels indicate that the folding stabilisers are periodically dry, results for all other vessels suggest that the stabilisers are in an ambient environment.
Net reels: Water retention Net reels: External fouling Net reels: Refuge Net reels: Catch parasites	Non-consensus over occurrence between Eden and Gippsland Lakes workshops – reasons for this are unclear.
Stern tubes cover/stern gland: External fouling	Non-consensus over environmental severity and occurrence reflecting a) operational differences – in some instances the stern tube is seawater lubricated, in others it is lubricated with grease; and, b) interpretation problems – some workshops took internal to mean internal to the vessel, other took internal to mean inside the stern cover tube. The small tolerance in this tube, and its rotating parts, reduce the probability of infection.
Marlin board: External fouling Marlin board: Sediment retention	Large range given to environmental severity because some marlin boards are retractable and therefore periodically dry, whilst some are not

* indicates trailerable vessel

List of Figures


Identify components of system
Identify failure modes
Identify the effects of each faillure mode
Score severity of effect: 1 - 10
Identify causes of the failure
Score likelihood of effect: 1 - 10
Identify current controls
Score likelihood of detection: 1 - 10
Calculate Risk Priority Number
Repeat for each component
Repeat for each failure mode

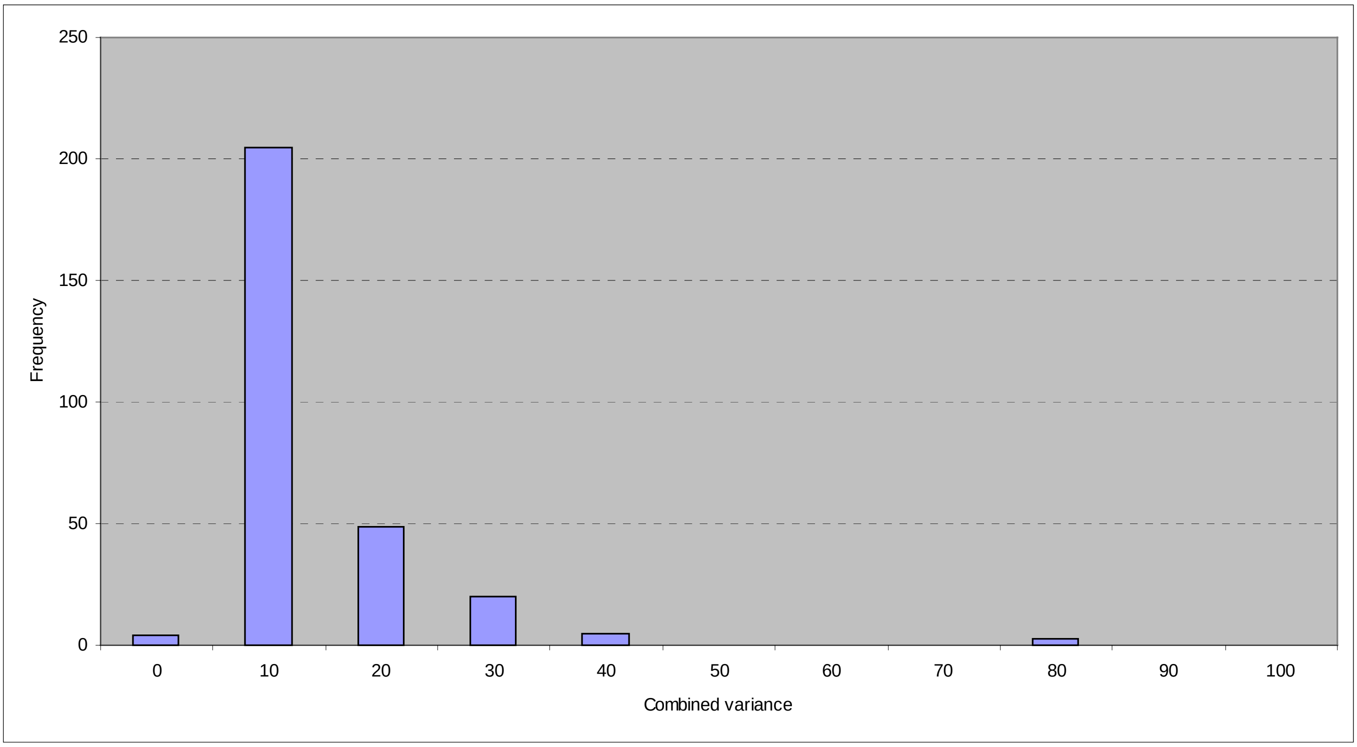


Identify vessel components
Identify infection modes
Describe the environmental characteristics
Score minimum and maximum environmental suitability: 1 - 10
Identify causes of the infection
Score minimum and maximum likelihood of infection: 1 - 10
Identify current controls
Score minimum and maximum likelihood of detection: 1 - 10
Calculate minimum and maximum Risk Priority Number
Repeat for each component
Repeat for each infection mode

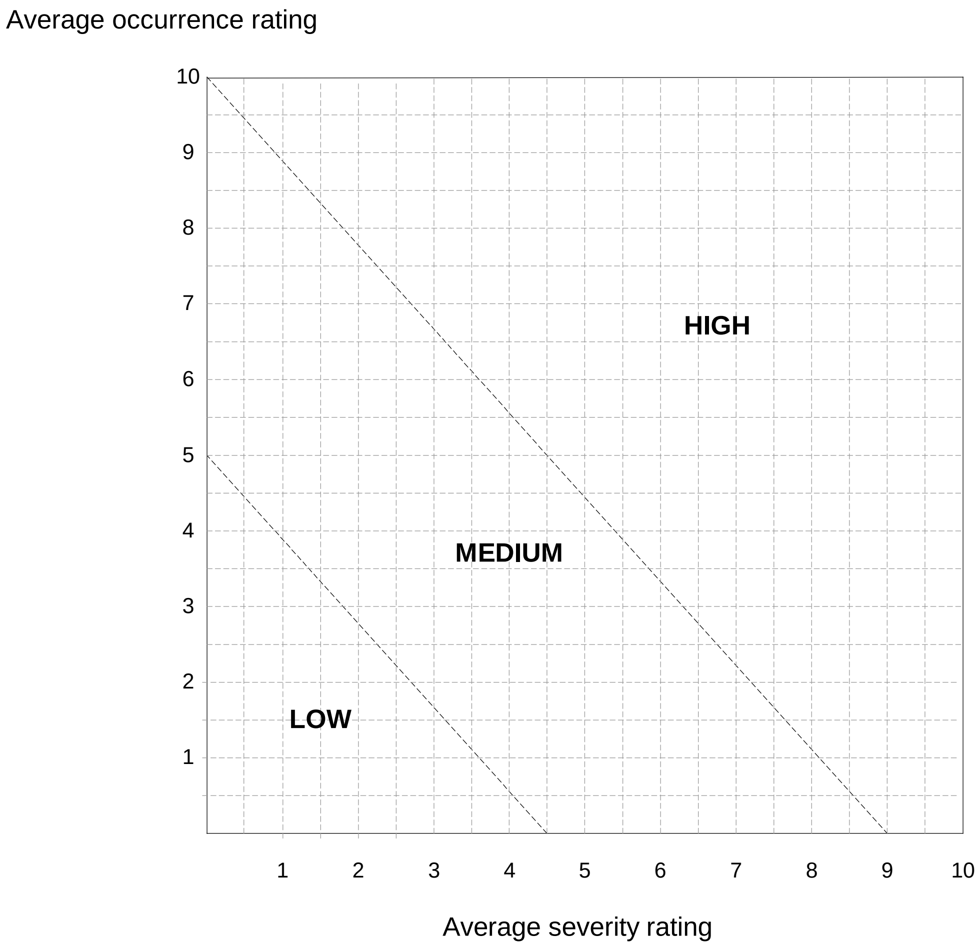

VIC
Melbourne
Hobsons Bay
Sandringham
Queenscliff
Apollo Bay
Eden
Lakes Entrance
Bairnsdale
Paynesville

VESSEL TYPE: Recreational vessels - displacement

COMPONENT	SUB-COMPONENT	INFECTION MODES	ENVIRONMENTAL CAHARACTERISTICS	Min SevRat	Max SevRat	CAUSES	Min OccRat	Max OccRat	CURRENT CONTROLS	Min DetRat	Max DetRat	Min RPN	Max RPN
Hull	Surface												
	timber	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
		Internal fouling	ambient sheltered	8	10	in the water	2	3	antifoul once per year, regular in water scrub	1	1	16	30
		Borer	ambient sheltered	8	10	in the water	2	3	antifoul once per year, regular in water scrub	1	1	16	30
	steel / alloy	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
	fibreglass	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
	Block spaces	External fouling	ambient	8	10	in the water	7	10	regular in water scrub, nil antifoul	1	3	56	300
	Keel - fixed	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
		Internal fouling	ambient, sheltered	8	10	in the water	2	3	antifoul once per year, regular in water scrub	1	1	16	30
		Borer	ambient, sheltered	8	10	in the water	2	3	antifoul once per year, regular in water scrub	1	1	16	30
	Keel cooling pipes	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
		Internal fouling	ambient, sheltered	8	10	in the water	7	10	difficult to clean	1	3	56	300
	Echo sounder booths	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub, sometimes diff a/foul	1	1	40	100
		Internal fouling	ambient sheltered	8	10	in the water	2	2	usually sealed	10	10	160	200
	Paddle wheel & booth	External fouling	ambient	8	10	in the water	5	10	remove & clean per week	1	1	40	100
		Internal fouling	ambient sheltered	8	10	in the water	5	10	remove & clean per week	1	4	40	400
	Garboard plank	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
	Zinc blocks/anodes	External fouling	ambient	8	10	in the water	2	10	replace when used	1	1	16	100
		Internal fouling	ambient sheltered	8	10	in the water	5	10	difficult to clean	1	3	40	300
	Trim tabs - folding	External fouling	ambient	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100
		Internal fouling	ambient sheltered	8	10	in the water	5	10	antifoul once per year, regular in water scrub	1	1	40	100



250
200
150
100
50
0
Frequency
0
10
20
30
40
50
60
70
80
90
100
Combined variance


Average occurrence rating
10
9
8
7
6
5
4
3
2
1
HIGH
MEDIUM
LOW
1
2
3
4
5
6
7
8
9
10
Average severity rating

Appendix A IMEA results

Table A1 Hull of a displacement vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Sonar tubes: Internal fouling	432	504	468
Skin fittings: External fouling	219	395	307
Plate case: Internal fouling	81	400	241
Echo sounder booth: Internal fouling	190	265	227
Keel cooling pipes: Internal fouling	153	291	222
Water inlet/outlet cover plates: Internal fouling	102	291	196
Echo sounder booth: External fouling	140	249	194
Bob-stay fitting: Internal fouling	40	300	170
Bob-stay fitting: Refuge	40	300	170
Paddle wheel and booth: Internal fouling	78	261	170
Block space: External fouling	54	235	145
Transducer: External fouling	81	200	141
Paddle wheel and booth: External fouling	78	174	126
Keel - retractable: External fouling	64	180	122
Keel - retractable: Internal fouling	64	180	122
Keel - retractable: Borer	64	180	122
Keel cooling pipes: External fouling	61	141	101
Keel - fixed: External fouling	52	125	89
Surface - fibreglass: Internal fouling	48	126	87
Surface - fibreglass: Borer	48	126	87
Surface - timber: External fouling	54	118	86
False keel: External fouling	42	126	84
False keel: Internal fouling	42	126	84
False keel: Borer	42	126	84
Surface - steel / alloy: External fouling	52	115	84
Surface - fibreglass: External fouling	52	115	84
Stabilisers/trim tabs - folding: External fouling	47	120	83
Stabilisers/trim tabs - folding: Internal fouling	47	120	83
Rolling chock - fixed: External fouling	51	106	79
Rolling chock - fixed: Internal fouling	51	106	79
Head fitting: External fouling	56	100	78
Head fitting: Internal fouling	56	100	78
Head fitting: Sediment retention	56	100	78
Garboard plank: External fouling	46	108	77
Keel - fixed: Internal fouling	47	101	74
Keel - fixed: Borer	47	101	74
Surface - timber: Internal fouling	48	95	71
Surface - timber: Borer	48	95	71
Bob-stay fitting: External fouling	40	100	70
Marlin board: External fouling	28	75	52
Marlin board: Sediment retention	28	75	52
Zinc blocks: Internal fouling	20	72	46
Exhaust outlet: External fouling	9	32	21
Zinc blocks: External fouling	4	23	13
Exhaust outlet: Internal fouling	9	10	10
Exhaust outlet: Refuge	9	10	10

Table A2 Internal spaces of a displacement vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Seawater/grey-water inlet/outlets: Water retention	352	685	519
Seawater/grey-water inlet/outlets: Internal fouling	348	642	495
Sewage holding tank: Water retention	10	900	455
Sewage holding tank: Sediment retention	10	900	455
Sewage holding tank: Refuge	10	900	455
Bilge - closed: Water retention	59	159	109
Bilge - closed: Sediment retention	59	159	109
Bilge - closed: Refuge	59	159	109
Engine cooling water filter: Water retention	38	146	92
Engine cooling water filter: Sediment retention	38	146	92
Engine cooling water filter: Refuge	38	146	92
Engine cooling water filter: Internal fouling	38	146	92
Anchor well: Water retention	40	128	84
Anchor well: Sediment retention	40	128	84
Ballast tanks/brine storage tanks: Water retention	35	96	66
Ballast tanks/brine storage tanks: Sediment retention	35	96	66
Ballast tanks/brine storage tanks: Internal fouling	35	96	66
Heat exchanger: Internal fouling	40	69	54
Live catch storage - wet well: External fouling	42	56	49
Live catch storage - wet well: Catch parasites	42	56	49
Live catch storage - circulation tank: External fouling	42	56	49
Live catch storage - circulation tank: Catch parasites	42	56	49
Heat exchanger: Sediment retention	21	63	42
Rudder control room: Water retention	15	49	32
Rudder control room: Internal fouling	15	49	32
Live catch storage - wet well: Water retention	18	42	30
Live catch storage - circulation tank: Water retention	18	42	30
Ice makers (sea water): Water retention	8	10	9
Shower holding tank: Water retention	4	12	8
Storage rooms - gear: Water retention	3	10	7
Storage rooms - gear: Sediment retention	3	10	7
Storage rooms - gear: Refuge	3	10	7
Storage - boxes: Water retention	3	10	7
Storage - boxes: Sediment retention	3	10	7
Storage - boxes: Refuge	3	10	7
Cockpits: Water retention	1	8	5
Cockpits: Sediment retention	1	8	5
Focastle/accommodation: Water retention	3	6	4
Dead catch storage - freezer: Catch parasites	1	4	3
Dead catch storage - freezer: Bait	1	4	3
Dead catch storage - ice room: Catch parasites	1	4	3
Dead catch storage - ice room: Bait	1	4	3
Dead catch storage - spray room: Water retention	1	4	3
Dead catch storage - spray room: Catch parasites	1	4	3
Dead catch storage - spray room: Bait	1	4	3
Dead catch storage - insulated: Catch parasites	1	4	3
Dead catch storage - insulated: Water retention	1	4	3
Dead catch storage - insulated: Bait	1	4	3
Bilge - open: Water retention	2	3	3
Bilge - open: Sediment retention	2	3	3
Bilge - open: Refuge	2	3	3
Toilet/shower: Water retention	1	1	1
Wheelhouse: Water retention	1	1	1
Wheelhouse: Sediment retention	1	1	1

Table A3 Deck of a displacement vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Cracks in deck/between plates: Water retention	6	37	21
Cracks in deck/between plates: Sediment retention	6	37	21
Cracks in deck/between plates: Refuge	6	37	21
Hawser pipe: Sediment retention	4	27	16
Hawser pipe: Refuge	4	27	16
Gunwale (toe rail): Sediment retention	4	23	13
Hatches: Water retention	1	19	10
Hatches: Sediment retention	1	19	10
Cockpit bins/open storage: Water retention	2	18	10
Cockpit bins/open storage: Sediment retention	2	18	10
Winch box: Water retention	2	18	10
Winch box: Sediment retention	2	18	10
Winch box: Refuge	2	18	10
Surface: Water retention	1	6	4
Surface: Sediment retention	1	6	4
Surface: Refuge	1	6	4
Surface: Catch parasites	1	6	4
Canvas screens: Water retention	1	4	3
Bulwarks: Sediment retention	1	3	2
Net chute: Sediment retention	1	2	2
Cutting boards: Bait parasites	1	1	1
Cutting boards: Internal fouling	1	1	1

Table A4 Propeller, rudder and anchor of a displacement vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Outboard sail drive legs: Internal fouling	196	485	340
Outboard sail drive legs: Water retention	196	485	340
Outboard sail drive legs: External fouling	86	208	147
Stern tubes cover/stern gland: Internal fouling	119	138	129
Stern tubes cover/stern gland: External fouling	43	112	77
Keel extension: External fouling	64	81	73
Keel extension: Internal fouling	64	81	73
Rope: External fouling	36	95	65
Rope: Sediment retention	36	95	65
Rope: Water retention	36	95	65
Tiller flat: External fouling	20	48	34
Tiller flat: Internal fouling	20	48	34
Propeller Surface: External fouling	8	33	21
Propeller Shaft: External fouling	8	33	21
Rudder surface: External fouling	9	18	14
Anchor chain: External fouling	3	24	14
Anchor chain: Sediment retention	3	24	14
Anchor surface: External fouling	2	20	11
Anchor surface: Sediment retention	2	20	11
Propeller nozzle: External fouling	2	16	9
Sea anchors/parachutes: External fouling	1	2	2
Sea anchors/parachutes: Water retention	1	2	2
Anchor buoys: External fouling	1	2	2
Anchor buoys: Internal fouling	1	2	2
Anchor buoys: Water retention	1	2	2

Table A5 Fishing gear

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Trap ropes: Water retention	90	224	157
Trap ropes: External fouling	90	224	157
Traps - octupus: Water retention	24	224	124
Traps - octupus: External fouling	24	224	124
Traps - octupus: Refuge	24	224	124
Traps - octupus: Catch parasites	24	224	124
Floats - pots: Water retention	15	168	92
Floats - pots: External fouling	15	168	92
Floats - pots: Borers	15	168	92
Net - beach seine: Water retention	24	126	75
Net - beach seine: Sediment retention	24	126	75
Net - beach seine: External fouling	24	126	75
Net - beach seine: Refuge	24	126	75
Net - purse: Water retention	17	92	54
Net - purse: Sediment retention	17	92	54
Net - purse: External fouling	17	92	54
Net - purse: Refuge	17	92	54
Net - gill: Water retention	8	84	46
Net - gill: Sediment retention	8	84	46
Net - gill: External fouling	8	84	46
Net - gill: Refuge	8	84	46
Net reels: Water retention	28	60	44
Net reels: External fouling	28	60	44
Net reels: Refuge	28	60	44
Net reels: Catch parasites	28	60	44
Traps - cray/king crab: Water retention	25	60	43
Traps - cray/king crab: External fouling	25	60	43
Traps - cray/king crab: Refuge	25	60	43
Traps - cray/king crab: Catch parasites	25	60	43
Net - trawl: Water retention	17	66	41
Net - trawl: Sediment retention	17	66	41
Net - trawl: External fouling	17	66	41
Net - trawl: Refuge	17	66	41
Dingy/seine tender boat: Water retention	3	49	26
Dingy/seine tender boat: Sediment retention	3	49	26
Dingy/seine tender boat: External fouling	3	49	26
Dingy/seine tender boat: Internal fouling	3	49	26
Marker buoys: Water retention	2	45	24
Marker buoys: External fouling	2	45	24
Marker buoys: Borers	2	45	24
Traps - crab: Water retention	4	30	17
Traps - crab: External fouling	4	30	17
Traps - crab: Refuge	4	30	17
Traps - crab: Catch parasites	4	30	17
Floats - nets: Water retention	2	31	17
Floats - nets: External fouling	2	31	17
Net - dip: Water retention	2	12	7
Net - dip: Sediment retention	2	12	7
Net - dip: External fouling	2	12	7
Net - dip: Refuge	2	12	7
Trawl boards: Sediment retention	2	5	3
Scallop harvesters: Water retention	1	4	3
Scallop harvesters: External fouling	1	4	3
Scallop harvesters: Refuge	1	4	3
Scallop harvesters: Sediment retention	1	4	3
Scallop harvesters: Catch parasites	1	4	3
Waders/wet weather gear: Water retention	1	4	3
Waders/wet weather gear: Sediment retention	1	4	3
Weights - nets and pots: Sediment retention	1	3	2
Long lines: Water retention	1	2	2
Long lines: External fouling	1	2	2
Long lines: Refuge	1	2	2
Jigging machines (squid): External fouling	1	2	2
Diving gear: Water retention	1	2	2
Diving gear: Sediment retention	1	2	2
Winches/pulleys: Sediment retention	1	2	1
Hooker hoses: External fouling	1	1	1

Hooks: Bait parasites	1	1	1

Table A6 Hull of a trailerable vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Berley bucket: Parasites	225	420	323
Berley bucket: Internal fouling	45	112	79
Transducer: Internal fouling	40	90	65
Berley bucket: Bait	25	84	55
Skin fittings: External fouling	15	63	39
Paddle wheel and booth: Internal fouling	15	49	32
Exhaust outlet: Internal fouling	18	40	29
Exhaust outlet: Refuge	18	40	29
Berley bucket: External fouling	10	42	26
Zinc blocks: Internal fouling	11	36	23
Surface - timber: Internal fouling	8	30	19
Surface - timber: Borer	8	30	19
Plate case: Internal fouling	2	32	17
Water inlet/outlet cover plates: Internal fouling	2	32	17
Transducer: External fouling	6	24	15
Surface – fibreglass: Internal fouling	6	24	15
Surface – fibreglass: Borer	6	24	15
Paddle wheel and booth: External fouling	4	21	13
Surface - steel / alloy: External fouling	5	18	11
Zinc blocks: External fouling	4	17	10
Surface - timber: External fouling	4	15	9
Surface – fibreglass: External fouling	4	15	9
Keel – retractable: External fouling	2	16	9
Keel – retractable: Internal fouling	2	16	9
Keel – retractable: Borer	2	16	9
Echo sounder booth: External fouling	2	16	9
Echo sounder booth: Internal fouling	2	16	9
Plate case: External fouling	2	16	9
Garboard plank: External fouling	2	16	9
Marlin board: External fouling	2	16	9
Marlin board: Sediment retention	2	16	9
Exhaust outlet: External fouling	2	16	9
Keel – fixed: External fouling	3	13	8
Keel – fixed: Internal fouling	3	13	8
Keel – fixed: Borer	3	13	8
False keel: External fouling	4	6	5
False keel: Internal fouling	4	6	5
False keel: Borer	4	6	5

Table A7 Internal spaces of a trailerable vessel

Sub-component: Infection mode	MinRPN	MaxRPN	Average
Anchor well: Water retention	162	280	221
Anchor well: Sediment retention	162	280	221
Bilge pump: Water retention	100	180	140
Bilge pump: Sediment retention	100	180	140
Bilge pump: Internal fouling	100	180	140
Bilge - open: Water retention	54	140	97
Bilge - open: Sediment retention	54	140	97
Bilge - open: Refuge	54	140	97
Floatation pods: Water retention	60	120	90
Floatation pods: Sediment retention	60	120	90
Floatation pods: Internal fouling	60	120	90
Heat exchanger: Internal fouling	29	140	84
Heat exchanger: Sediment retention	29	140	84
Seawater/grey-water inlet/outlets: Water retention	30	111	71
Seawater/grey-water inlet/outlets: Internal fouling	30	111	71
Live bait tank pick-up: Internal fouling	20	54	37
Live bait tank pick-up: Water retention	20	54	37
Outboard sail drive legs: Internal fouling	9	60	35
Outboard sail drive legs: Water retention	9	60	35
Engine cooling water filter: Water retention	2	50	26
Engine cooling water filter: Sediment retention	2	50	26
Engine cooling water filter: Refuge	2	50	26
Dead catch tank: Water retention	9	32	21
Dead catch tank: Sediment retention	9	32	21
Dead catch tank: Parasites	9	32	21
Live bait tank: Water retention	6	24	15
Live bait tank: Sediment retention	6	24	15
Live bait tank: Parasites	6	24	15
Engine cooling water filter: Internal fouling	2	20	11
Storage - boxes: Water retention	1	8	5
Storage - boxes: Sediment retention	1	8	5
Storage - boxes: Refuge	1	8	5
Outboard sail drive legs: External fouling	1	6	4

Appendix B Sub-components ranked by average RPN

Sub-component: Infection mode	Average RPN	Rank by Av RPN	Maximum RPN	Rank by Max RPN	Area chart priority
Sea/grey-water inlet/outlets: Water retention	519	1	685	4	High
Sea/grey-water inlet/outlets: Internal fouling	495	2	642	5	High
Sonar tubes: Internal fouling	468	3	504	6	High
Sewage holding tank: Water retention	455	4	900	1	High
Sewage holding tank: Sediment retention	455	5	900	2	High
Sewage holding tank: Refuge	455	6	900	3	High
Outboard sail drive legs: Internal fouling	340	7	485	7	High
Outboard sail drive legs: Water retention	340	8	485	8	High
Berley bucket*: Parasites	323	9	420	9	High
Skin fittings: External fouling	307	10	395	11	High
Plate case: Internal fouling	241	11	400	10	High
Echo sounder booth: Internal fouling	227	12	265	18	High
Keel cooling pipes: Internal fouling	222	13	291	15	High
Anchor well*: Water retention	221	14	280	16	High
Anchor well*: Sediment retention	221	15	280	17	High
Water inlet/outlet cover plates: Internal fouling	196	16	291	14	High
Echo sounder booth: External fouling	194	17	249	20	High
Bob-stay fitting: Internal fouling	170	18	300	12	High
Bob-stay fitting: Refuge	170	19	300	13	High
Paddle wheel and booth: Internal fouling	170	20	261	19	High
Trap ropes: Water retention	157	21	224	26	High
Trap ropes: External fouling	157	22	224	27	High
Outboard sail drive legs: External fouling	147	23	208	28	High
Block space: External fouling	145	24	235	21	High
Transducer: External fouling	141	25	200	29	High
Bilge pump*: Water retention	140	26	180	33	High
Bilge pump*: Sediment retention	140	27	180	34	High
Bilge pump*: Internal fouling	140	28	180	35	High
Stern tubes cover/stern gland: Internal fouling	129	29	138	53	Medium
Paddle wheel and booth: External fouling	126	30	174	36	High
Traps - octupus: Water retention	124	31	224	22	Medium
Traps - octupus: External fouling	124	32	224	23	Medium
Traps - octupus: Refuge	124	33	224	24	Medium
Traps - octupus: Catch parasites	124	34	224	25	Medium
Keel – retractable: External fouling	122	35	180	30	High
Keel – retractable: Internal fouling	122	36	180	31	High
Keel – retractable: Borer	122	37	180	32	High
Bilge – closed: Water retention	109	38	159	40	Medium
Bilge – closed: Sediment retention	109	39	159	41	Medium
Bilge – closed: Refuge	109	40	159	42	Medium
Keel cooling pipes: External fouling	101	41	141	47	High
Bilge – open*: Water retention	97	42	140	50	High
Bilge – open*: Sediment retention	97	43	140	51	High
Bilge – open*: Refuge	97	44	140	52	High
Engine cooling water filter: Water retention	92	45	146	43	High
Engine cooling water filter: Sediment retention	92	46	146	44	High
Engine cooling water filter: Refuge	92	47	146	45	High
Engine cooling water filter: Internal fouling	92	48	146	46	High
Floats - pots: Water retention	92	49	168	37	Medium
Floats - pots: External fouling	92	50	168	38	Medium
Floats - pots: Borers	92	51	168	39	Medium
Floatation pods*: Water retention	90	52	120	68	Medium
Floatation pods*: Sediment retention	90	53	120	69	Medium
Floatation pods*: Internal fouling	90	54	120	70	Medium
Keel – fixed: External fouling	89	55	125	65	High
Surface - fibreglass: Internal fouling	87	56	126	63	High
Surface - fibreglass: Borer	87	57	126	64	High
Surface - timber: External fouling	86	58	118	71	High
Heat exchanger*: Internal fouling	84	59	140	48	Medium
Heat exchanger*: Sediment retention	84	60	140	49	Medium
Anchor well: Water retention	84	61	128	54	Medium
Anchor well: Sediment retention	84	62	128	55	Medium
False keel: External fouling	84	63	126	60	High
False keel: Internal fouling	84	64	126	61	High
False keel: Borer	84	65	126	62	High

Surface - steel / alloy: External fouling	84	66	115	72	High

Appendix B cont…

Sub – component: Infection mode	Average RPN	Index by Av RPN	Maximum RPN	Index by Max RPN	Area chart priority
Surface - fibreglass: External fouling	84	67	115	73	High
Stabilisers/trim tabs - folding: External fouling	83	68	120	66	High
Stabilisers/trim tabs - folding: Internal fouling	83	69	120	67	High
Rolling chock - fixed: External fouling	79	70	106	79	High
Rolling chock - fixed: Internal fouling	79	71	106	80	High
Berley bucket*: Internal fouling	79	72	112	75	High
Head fitting: External fouling	78	73	100	84	High
Head fitting: Internal fouling	78	74	100	85	High
Head fitting: Sediment retention	78	75	100	86	High
Stern tubes cover/stern gland: External fouling	77	76	112	74	High
Garboard plank: External fouling	77	77	108	78	High
Net – beach seine: Water retention	75	78	126	56	Medium
Net – beach seine: Sediment retention	75	79	126	57	Medium
Net – beach seine: External fouling	75	80	126	58	Medium
Net – beach seine: Refuge	75	81	126	59	Medium
Keel - fixed: Internal fouling	74	82	101	81	High
Keel - fixed: Borer	74	83	101	82	High
Keel extension: External fouling	73	84	81	105	High
Keel extension: Internal fouling	73	85	81	106	High
Surface - timber: Internal fouling	71	86	94	93	High
Surface - timber: Borer	71	87	94	94	High
Sea/grey-water inlet/outlets*: Water retention	71	88	111	76	Medium
Sea/grey-water inlet/outlets*: Internal fouling	71	89	111	77	Medium
Bob-stay fitting: External fouling	70	90	100	83	High
Ballast tanks/brine storage tanks: Water retention	66	91	96	87	High
Ballast tanks/brine storage tanks: Sediment retention	66	92	96	88	High
Ballast tanks/brine storage tanks: Internal fouling	66	93	96	89	High
Anchor rope: External fouling	65	94	94	90	Medium
Anchor rope: Sediment retention	65	95	94	91	Medium
Anchor rope: Water retention	65	96	94	92	Medium
Transducer*: Internal fouling	65	97	90	99	Medium
Berley bucket*: Bait	55	98	84	104	High
Net – purse: Water retention	54	99	92	95	Medium
Net – purse: Sediment retention	54	100	92	96	Medium
Net – purse: External fouling	54	101	92	97	Medium
Net – purse: Refuge	54	102	92	98	Medium
Heat exchanger: Internal fouling	54	103	69	110	Medium
Marlin board: External fouling	52	104	75	107	High
Marlin board: Sediment retention	52	105	75	108	High
Live catch storage - wet well: External fouling	49	106	56	127	High
Live catch storage - wet well: Catch parasites	49	107	56	128	High
Live catch storage - circulation tank: External fouling	49	108	56	129	High
Live catch storage - circulation tank: Catch parasites	49	109	56	130	High
Net – gill: Water retention	46	110	84	100	Medium
Net – gill: Sediment retention	46	111	84	101	Medium
Net – gill: External fouling	46	112	84	102	Medium
Net – gill: Refuge	46	113	84	103	Medium
Zinc blocks: Internal fouling	46	114	72	109	Medium
Net reels: Water retention	44	115	60	117	Medium
Net reels: External fouling	44	116	60	118	Medium
Net reels: Refuge	44	117	60	119	Medium
Net reels: Catch parasites	44	118	60	120	Medium
Traps - cray/king crab: Water retention	43	119	60	123	High
Traps - cray/king crab: External fouling	43	120	60	124	High
Traps - cray/king crab: Refuge	43	121	60	125	High
Traps - cray/king crab: Catch parasites	43	122	60	126	High
Heat exchanger: Sediment retention	42	123	63	116	Medium
Net – trawl: Water retention	41	124	66	111	Medium
Net – trawl: Sediment retention	41	125	66	112	Medium
Net – trawl: External fouling	41	126	66	113	Medium
Net – trawl: Refuge	41	127	66	114	Medium
Skin fittings*: External fouling	39	128	63	115	Medium
Live bait tank pick-up*: Internal fouling	37	129	54	131	Medium
Live bait tank pick-up*: Water retention	37	130	54	132	Medium
Outboard sail drive legs*: Internal fouling	35	131	60	121	Low
Outboard sail drive legs*: Water retention	35	132	60	122	Low

Tiller flat: External fouling	34	133	48	143	Medium
Tiller flat: Internal fouling	34	134	48	144	Medium

Appendix B cont…

Sub-component: Infection mode	Average RPN	Index by Av RPN	Maximum RPN	Index by Max RPN	Area chart priority
Paddle wheel and booth*: Internal fouling	32	135	49	142	Medium
Rudder control room: Water retention	32	136	49	136	Medium
Rudder control room: Internal fouling	32	137	49	137	Medium
Live catch storage - wet well: Water retention	30	138	42	148	High
Live catch storage - circulation tank: Water retention	30	139	42	149	High
Exhaust outlet*: Internal fouling	29	140	40	151	Low
Exhaust outlet*: Refuge	29	141	40	152	Low
Dingy/seine tender boat: Water retention	26	142	49	138	Medium
Dingy/seine tender boat: Sediment retention	26	143	49	139	Medium
Dingy/seine tender boat: External fouling	26	144	49	140	Medium
Dingy/seine tender boat: Internal fouling	26	145	49	141	Medium
Engine cooling water filter*: Water retention	26	146	50	133	Medium
Engine cooling water filter*: Sediment retention	26	147	50	134	Medium
Engine cooling water filter*: Refuge	26	148	50	135	Medium
Berley bucket*: External fouling	26	149	42	150	Medium
Marker bouys: Water retention	24	150	45	145	Medium
Marker bouys: External fouling	24	151	45	146	Medium
Marker bouys: Borers	24	152	45	147	Medium
Zinc blocks*: Internal fouling	23	153	36	156	Medium
Cracks in deck/between plates: Water retention	21	154	37	153	Medium
Cracks in deck/between plates: Sediment retention	21	155	37	154	Medium
Cracks in deck/between plates: Refuge	21	156	37	155	Medium
Propeller surface: External fouling	21	157	33	157	Medium
Properller shaft: External fouling	21	158	33	158	Medium
Dead catch tank*: Water retention	21	159	32	161	Medium
Dead catch tank*: Sediment retention	21	160	32	162	Medium
Dead catch tank*: Parasites	21	161	32	163	Medium
Exhaust outlet: External fouling	21	162	32	164	Medium
Surface - timber*: Internal fouling	19	163	30	171	Medium
Surface - timber*: Borer	19	164	30	172	Medium
Plate case*: Internal fouling	17	165	32	159	Low
Water inlet/outlet cover plates*: Internal fouling	17	166	32	160	Low
Traps - crab: Water retention	17	167	30	167	Medium
Traps - crab: External fouling	17	168	30	168	Medium
Traps - crab: Refuge	17	169	30	169	Medium
Traps - crab: Catch parasites	17	170	30	170	Medium
Floats - nets: Water retention	17	171	31	165	Low
Floats - nets: External fouling	17	172	31	166	Low
Hawser pipe: Sediment retention	16	173	27	173	Medium
Hawser pipe: Refuge	16	174	27	174	Medium
Live bait tank*: Water retention	15	175	24	177	Medium
Live bait tank*: Sediment retention	15	176	24	178	Medium
Live bait tank*: Parasites	15	177	24	179	Medium
Transducer*: External fouling	15	178	24	180	Medium
Surface - fibreglass*: Internal fouling	15	179	24	181	Low
Surface - fibreglass*: Borer	15	180	24	182	Low
Rudder surface: External fouling	14	181	18	192	Medium
Anchor chain: External fouling	14	182	24	175	Low
Anchor chain: Sediment retention	14	183	24	176	Low
Gunwale (toe rail): Sediment retention	13	184	23	183	Low
Zinc blocks: External fouling	13	185	22	184	Medium
Paddle wheel and booth*: External fouling	13	186	21	185	Medium
Surface - steel / alloy*: External fouling	11	187	18	191	Medium
Engine cooling water filter*: Internal fouling	11	188	20	186	Medium
Anchor surface: External fouling	11	189	20	187	Low
Anchor surface: Sediment retention	11	190	20	188	Low
Zinc blocks*: External fouling	10	191	17	198	Low
Hatches: Water retention	10	192	19	189	Low
Hatches: Sediment retention	10	193	19	190	Low
Cockpit bins/open storage: Water retention	10	194	18	193	Low
Cockpit bins/open storage: Sediment retention	10	195	18	194	Low
Winch box: Water retention	10	196	18	195	Low
Winch box: Sediment retention	10	197	18	196	Low
Winch box: Refuge	10	198	18	197	Low
Exhaust outlet: Internal fouling	10	199	10	226	Low

Exhaust outlet: Refuge	10	200	10	227	Low
Surface - timber*: External fouling	9	201	15	210	Low
Surface - fibreglass*: External fouling	9	202	15	211	Low

Appendix B cont…

Sub-component: Infection mode	Average RPN	Index by Av RPN	Maximum RPN	Index by Max RPN	Area chart priority
Keel - retractable*: External fouling	9	203	16	200	Low
Keel - retractable*: Internal fouling	9	204	16	201	Low
Keel - retractable*: Borer	9	205	16	202	Low
Echo sounder booth*: External fouling	9	206	16	203	Low
Echo sounder booth*: Internal fouling	9	207	16	204	Low
Plate case*: External fouling	9	208	16	205	Low
Garboard plank*: External fouling	9	209	16	206	Low
Marlin board*: External fouling	9	210	16	207	Low
Marlin board*: Sediment retention	9	211	16	208	Low
Exhaust outlet*: External fouling	9	212	16	209	Low
Propeller nozzle: External fouling	9	213	16	199	Medium
Shower holding tank: Water retention	8	214	12	215	Low
Keel - fixed*: External fouling	8	215	12	212	Low
Keel - fixed*: Internal fouling	8	216	12	213	Low
Keel - fixed*: Borer	8	217	12	214	Low
Net - dip: Water retention	7	218	12	216	Low
Net - dip: Sediment retention	7	219	12	217	Low
Net - dip: External fouling	7	220	12	218	Low
Net - dip: Refuge	7	221	12	219	Low
Storage rooms - gear: Water retention	7	222	10	220	Low
Storage rooms - gear: Sediment retention	7	223	10	221	Low
Storage rooms - gear: Refuge	7	224	10	222	Low
Storage - boxes: Water retention	7	225	10	223	Low
Storage - boxes*: Water retention	7	225	8	230	Low
Storage - boxes: Sediment retention	7	226	10	224	Low
Storage - boxes*: Sediment retention	5	226	8	231	Low
Storage - boxes: Refuge	5	227	10	225	Low
Storage - boxes*: Refuge	5	227	8	232	Low
False keel*: External fouling	5	228	6	238	Low
False keel*: Internal fouling	5	229	6	239	Low
False keel*: Borer	5	230	6	240	Low
Cockpits: Water retention	5	231	8	228	Low
Cockpits: Sediment retention	5	232	8	229	Low
Focastle/accommodation: Water retention	4	236	6	241	Low
Deck surface: Water retention	4	237	6	233	Low
Deck surface: Sediment retention	4	238	6	234	Low
Deck surface: Refuge	4	239	6	235	Low
Deck surface: Catch parasites	4	240	6	236	Low
Outboard sail drive legs*: External fouling	4	241	6	237	Low
Trawl boards: Sediment retention	3	242	5	242	Low
Dead catch storage - freezer: Catch parasites	3	243	4	243	Low
Dead catch storage - freezer: Bait	3	244	4	244	Low
Dead catch storage - ice room: Catch parasites	3	245	4	245	Low
Dead catch storage - ice room: Bait	3	246	4	246	Low
Dead catch storage - spray room: Water retention	3	247	4	247	Low
Dead catch storage - spray room: Catch parasites	3	248	4	248	Low
Dead catch storage - spray room: Bait	3	249	4	249	Low
Dead catch storage - insulated: Catch parasites	3	250	4	250	Low
Dead catch storage - insulated: Water retention	3	251	4	251	Low
Dead catch storage - insulated: Bait	3	252	4	252	Low
Scallop harvesters: Water retention	3	253	4	253	Low
Scallop harvesters: External fouling	3	254	4	254	Low
Scallop harvesters: Refuge	3	255	4	255	Low
Scallop harvesters: Sediment retention	3	256	4	256	Low
Scallop harvesters: Catch parasites	3	257	4	257	Low
Waders/wet weather gear: Water retention	3	258	4	258	Low
Waders/wet weather gear: Sediment retention	3	259	4	259	Low
Canvas screens: Water retention	3	260	4	260	Low
Bilge - open: Water retention	3	261	3	263	Low
Bilge - open: Sediment retention	3	262	3	264	Low
Bilge - open: Refuge	3	263	3	265	Low
Weights - nets and pots: Sediment retention	2	264	3	261	Low
Bulwarks: Sediment retention	2	265	3	262	Low
Long lines: Water retention	2	266	2	266	Low

Long lines: External fouling	2	267	2	267	Low
Long lines: Refuge	2	268	2	268	Low
Sea anchors/parachutes: External fouling	2	269	2	269	Low
Sea anchors/parachutes: Water retention	2	270	2	270	Low

Appendix B cont…

Sub-component: Infection mode	Average RPN	Index by Av RPN	Maximum RPN	Index by Max RPN	Area chart priority
Anchor bouys: External fouling	2	271	2	271	Low
Anchor bouys: Internal fouling	2	272	2	272	Low
Anchor bouys: Water retention	2	273	2	273	Low
Jigging machines (squid): External fouling	2	274	2	274	Low
Diving gear: Water retention	2	275	2	275	Low
Diving gear: Sediment retention	2	276	2	276	Low
Net chute: Sediment retention	2	277	2	277	Low
Winches/pulleys: Sediment retention	1	278	2	278	Low
Toilet/shower: Water retention	1	279	1	279	Low
Ice makers (sea water): Water retention	1	280	1	280	Low
Wheelhouse: Water retention	1	281	1	281	Low
Wheelhouse: Sediment retention	1	282	1	282	Low
Hooker hoses: External fouling	1	283	1	283	Low
Hooks: Bait parasites	1	284	1	284	Low
Cutting boards: Bait parasites	1	285	1	285	Low
Cutting boards: Internal fouling	1	286	1	286	Low

* indicates trailerable vessel