Threat Identification, Hazard Pathway Analysis and Assessment of the Key Biosecurity Risks presented by the establishment of the Mid West Aquaculture Development Zone in Western Australia

Prepared by

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Executive Summary

A threat identification, hazard pathway analysis and assessment of the key biosecurity risks posed by the development of the Mid West Aquaculture Development Zone in Western Australia was undertaken to assist in determining whether current proposed management controls are adequate to bring associated risks to the wider ecosystem to an acceptable level.

The assessment identified and assessed individual hazard pathways associated with each of three primary biosecurity risks that were identified associated with the proposal. Individual hazard pathways which might cumulatively lead to each of these risks were identified and evaluated with respect to their inherent risk (assuming no management controls) and their residual risk (following implementation of identified management controls). Analysis of these hazard pathways facilitated assessment of overall risk for each of the major overarching three risks identified below in a similar manner. In this way the adequacy of current management measures in place was assessed with respect to their ability to bring identified biosecurity risks to ecosystem sustainability associated with the aquaculture zone proposal to an acceptable level.

Risk	**Inherent Risk** (no management measures)	**Residual Risk** (based on implementation of identified management measures)
1. Significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild targeted fisheries based around the same or alternate species.	Moderate	Low
2. Escaped fish lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.	Moderate	Low
3. The introduction and/or spread of marine pests associated with aquaculture activity has a significant impact on the sustainability of local and/or regional ecosystems	High	Moderate

Residual risks were assessed as **Low** in the cases of disease and escaped fish (Risks 1 & 2). Such low residual risk levels are deemed acceptable given the implementation of the current management controls identified. Residual risk was assessed as **Moderate** in the case of marine pest risk (Risk 3). While residual likelihood was assessed as unlikely in this case, the moderate risk rating reflects the potentially significant consequence of marine pests to ecosystem structure as a whole. Moderate risk is not desirable and indicates a need for continuation of strong management actions and/or consideration of further risk control measures to be introduced in the near future.

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1. Context and Scope

The threat identification, hazard pathway analysis and risk assessment presented in this report has been undertaken to assist in identifying and assessing the potential biosecurity-related risks of finfish aquaculture associated with a Department of Fisheries (Department) proposal to establish an aquaculture development zone in the Mid West of Western Australia (referred to hereafter as the MWADZ (Mid West Aquaculture Development Zone) to the sustainability of ecosystems and their dependent extractive fisheries. The Environmental Protection Authority (EPA) received the proposal for the MWADZ development on the 16 April 2013; accepted that it was a strategic proposal; set the level of assessment at a Public Environmental Review (PER); and approved an Environmental Scoping Document (ESD) on 24 July 2013. To fulfill the ESD the PER is required to provide a detailed assessment of the preliminary key environmental factors identified for the strategic proposal, and achieve environmental quality objectives (EQO) of the ANZECC 2000 guidelines[1]. Ecosystem Health is an important EQO, which required the Department to achieve the EPA's objective to maintain the structure, function, diversity, distribution and viability of the benthic communities and habitats at a local and regional scale. The current assessment forms part of an overall ESD submission and specifically addresses biosecurity related risks.

This assessment does not seek to replicate previously conducted generic aquaculture risk assessments which are broader in scope, remain relevant to the MWADZ proposal and which include the following:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The "How to" Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
- Finfish Aquaculture in Western Australia: Final ESD Management Report for Marine Finfish Aquaculture (Vom Berg 2009; 2008; Fisheries Management Paper No 233, Department of Fisheries, Western Australia)

Instead, the current assessment has used these previous reports as a basis to identify the main broad areas of biosecurity threat that are most relevant to the MWADZ proposal. These threats were further broken down through the consideration of detailed hazard pathways that may lead to the realisation of these threats.

[1] ANZECC & ARMCANZ. 2000. Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy No 4, Australia and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand, Canberra, ACT.

Consideration of the threats facilitated the identification of key overarching risks to the identified objective of the assessment which was to ensure the establishment and operation of the MWADZ without biosecurity-related threats having significant impact on the sustainability of ecosystems and their dependent fisheries. These risks were then assessed.

Using this methodology, the current assessment sought to clearly identify the current risk management measures in place and assess their adequacy in bringing identified biosecurity risks to ecosystem sustainability associated with the MWADZ proposal to an acceptable level.

An aquaculture development zone (ADZ) is a designated area of water selected for its suitability for a specific aquaculture sector (in this case marine finfish). Designating areas as ADZs is a result of Departmental policy aimed at stimulating aquaculture investment through providing an 'investment ready' platform for organisations that wish to set up commercial aquaculture operations. More streamlined approvals processes are in place for organisations wanting to establish aquaculture operations within these zones. Extensive studies and modeling underpins the approval of a zone to ensure its potential effects are identified, well understood and managed. Establishing new aquaculture operations, or expanding existing ones, will provide significant economic benefits to the local community through the creation of job opportunities and regional economic diversification.

A Kimberley Aquaculture Development Zone (KADZ) has previously been officially declared by the Minister for Fisheries in Western Australia's northern waters. Covering a total area of almost 2,000 hectares, the zone is located within Cone Bay approximately 215 kilometres northeast of Broome. Extensive environmental studies completed for the zone indicate its capacity to support 20,000 tonnes of finfish without any significant environmental impact. An existing barramundi farm operates within the boundaries of the KADZ. The establishment of the zone has enabled the operator, MPA Fish Farms Pty Ltd, to secure environmental approval to increase its production capability from 2,000 to nearly 7,000 tonnes per annum.

This assessment relates to a second planned aquaculture development in the Mid West of Western Australia. The Mid West Aquaculture Development Zone (MWADZ) will be located within the State waters of the Abrolhos Islands Fish Habitat Protection Area (FHPA), north of the Pelsaert Group, about 60 kilometres west of Geraldton. The exact site will be determined after evaluating the results of environmental and technical studies.

The zone is being established through a process that primarily involves environmental assessment of the zone as a strategic proposal under Part IV of the *Environmental Protection Act 1986*. Approval of this strategic proposal will create opportunities for existing and future aquaculture operators to refer their proposals to the Environmental Protection Authority (EPA) as 'derived proposals'. The objective is a more streamlined assessment and regulation process due to early consideration of potential environmental impacts and cumulative impacts identified during the assessment process for the zone.

The Department surveyed and sampled a study area of 4,740 hectares in two locations within the FHPA. This identified 2,200 hectares in the Northern Area and 800 hectares in the Southern Area (see Figure 1) as the most suitable areas for finfish aquaculture. Technical environmental studies of these locations helped determine the exact delineation of the zone. The proposed zone is situated away from areas of highest conservation value and is subject to considerable water flushing driven by prevailing winds, waves and currents. Good water flow through the sea-cages in which the fish are grown is essential for high productivity and to minimise environmental impact.

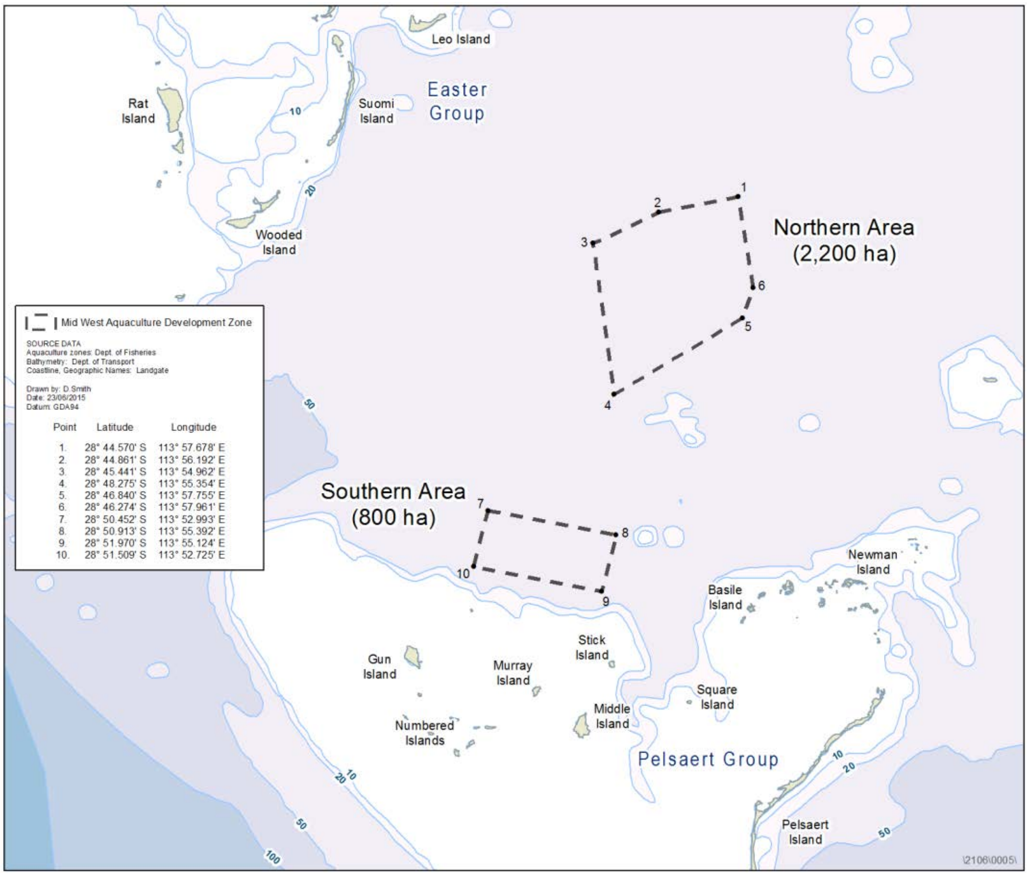

Figure 1: Proposed Mid West Aquaculture Development Zone

The Department will manage the proposed MWADZ within an integrated management framework that governs the workings of the zone. This will be similar to the framework developed for the Kimberley Aquaculture Development Zone. Its purpose is to:

- establish an overarching, integrated structure for managing the aquaculture activities within the zone;
- provide clear, efficient and effective processes for monitoring, evaluating and reporting;
- guide the development of marine finfish aquaculture;
- implement the monitoring and reporting processes; and
- ensure adaptive management occurs as part of a process of continuous improvement.

The zone management framework will incorporate:

- a zone Management Policy;
- an Environmental Monitoring and Management Plan (EMMP);
- a Ministerial Statement/Notice;
- Aquaculture Licences;
- Management and Environmental Monitoring Plans (MEMPs); and
- Aquaculture Leases.

The selection of suitable species for aquaculture in Western Australia is managed through the requirement for commercial aquaculture operators to obtain an aquaculture licence which is assessed with regard to the Department's Translocation Policy. The translocation of live fish into or within Western Australia, including those associated with aquaculture, can result in introduction and establishment of significant pest fish and pathogens. The introduction of these pest fish or pathogens into an area with a different disease status, or containing distinct native fish populations, can create significant economic, social, environmental and biological costs to Western Australia. The primary potential biosecurity risks associated with translocating fish into the state for marine aquaculture purposes include; disease transfer (to wild populations or cultured stocks), escapes and potential impacts on genetic diversity of native species, and the introduction of marine pests.

Likely suitable fish species to be cultured in the zone, based on existing commercial aquaculture interest, their suitability for aquaculture in Western Australia and/or ability to meet Departmental licensing and biosecurity requirements (e.g. being native species and suited to feeding with a formulated pathogen-free diet). They include the following species:

- Yellow tail kingfish (*Serioloa lalandi*)
- Mulloway (*Argyrosomus japonicus*)
- Dolphin fish (*Coryphaena hippurus*)
- Pink Snapper (*Pagrus auratus*)
- Cobia (*Rachycentron canadus*)

Based on this context, the current threat identification, hazard pathway analysis and risk assessment was conducted to identify and assess the potential biosecurity impacts of finfish aquaculture of these species associated with establishment and operation of the MWADZ on the sustainability of ecosystems, and their dependent fisheries. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) was assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

The assessment is generic in nature but has focused on yellow tail kingfish as a case study for aquaculture based on the following rationale:

- Yellow tail kingfish (YTK) is a likely candidate for consideration for culture in the Mid West of Western Australia, given the development of previous and current R&D projects based on this species.
- Disease risks of YTK are relatively well understood, given the development of a significant YTK industry and technical capacity elsewhere in Australia.
- Previous research projects have focused on disease risks associated with YTK [FRDC 2003/216 Detection and management of health issues in yellowtail kingfish (YTK, *Seriola lalandi*) - the foundation for a health program for Australian finfish aquaculture].
- An assessment of biosecurity risk based around this species is likely to be directly applicable to other species proposed for culture in the MWADZ.
- The current assessment is high level and generic in nature given the level of uncertainty around any future proposed aquaculture project and its extent.

2. Threat Identification, Hazard Pathway Analysis and Risk Identification and Assessment Methodology

The identification of threats, analysis of hazard pathways and assessment of risks that may be generated by the proposal to develop an aquaculture zone in the Mid-West of Western Australia was completed using methods that are consistent with the international standards for risk management and assessment (ISO 31000, 2009; IEC/ISO; 2009; SA-HB89; 2012). The process for assessment included three components – threat identification, hazard pathway analysis, identification of overarching risks and their assessment, and overarching risk assessment (see Figure 2).

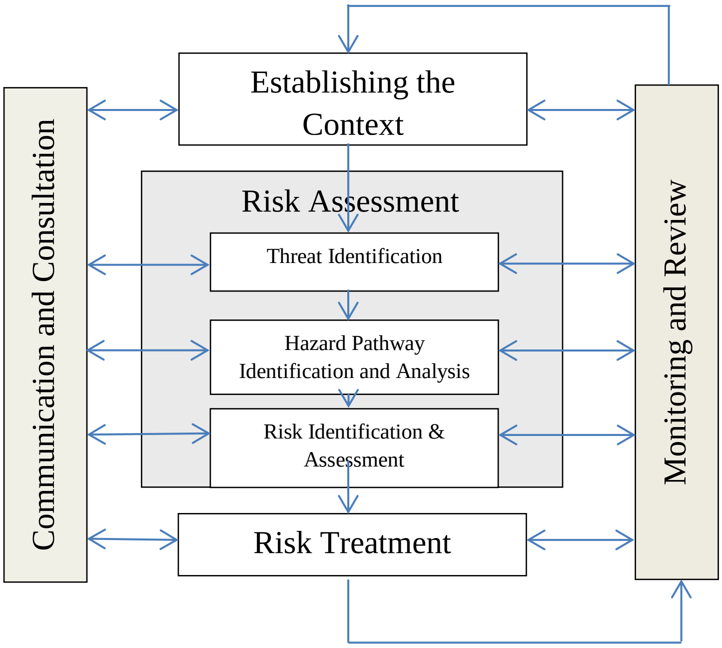

Figure 2: Description of risk assessment within the risk management process (modified from SA, 2012)

The specific protocols to complete each of these steps have been specifically tailored and extensively applied across a number of different aquatic management situations in Australia (Fletcher 2005, Fletcher et al. 2002, Jones and Fletcher 2012). Moreover this methodology has now been widely applied in many other locations in the world (Cochrane et al. 2008, FAO 2012, Fletcher 2008, Fletcher and Bianchi 2014) and is considered one of the 'must be read' methods supporting the implementation of the ecosystem approach (Cochrane 2013).

1.1 Threat Identification

Threat identification was based on review of the following previously conducted assessments and consideration of specific information associated with the MWADZ proposal:

- Marine Finfish Environmental Risk Assessment (de Jong & Tanner, FRDC Project 2003/223)
- National ESD Reporting Framework: The "How to" Guide for Aquaculture. Version 1.1 FRDC, Canberra, Australia (Fletcher et al., 2004)
- Finfish Aquaculture in Western Australia: Final ESD Risk Assessment Report for Sea-Cage and Land-Based Finfish Aquaculture (Vom Berg, 2008; Fisheries Management Paper No 229, Department of Fisheries, Western Australia)
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1.2 Hazard Pathway Identification

The identification of hazard pathways associated with the key threats identified within the scope of the current assessment was accomplished using ‘Failure Mode Analysis’. Failure Mode Analysis is an engineering technique used to identify critical steps or hazard pathways that can lead to systems failure or the realisation of threats. This process was conducted in order to assist with the orderly identification of issues relevant to assessment. The generated hazard pathways were used to assist with the identification of critical and often consecutive steps that may result in these threats that need to be considered as a result of undertaking aquaculture activity in the MWADZ.

1.3 Hazard Pathway Analysis

Individual hazards in each pathway were individually assessed with respect to their risk with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or a number of proposed management controls have been effected). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This, in turn, assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

The Consequence–Likelihood method was used to assess the level of the identified hazard pathway components associated with the key identified threats. The broad approach applied is a widely used method (SA, 2012) that is applied by many Western Australian Government agencies through WA RiskCover.

Undertaking hazard or risk analysis using the Consequence-Likelihood (C x L) methodology involves selecting the most appropriate combination of consequence (levels of impact; Table 1a) and the likelihood (levels of probability; Table 1b) of this consequence actually occurring (See Figure 3). The combination of these scores is then used to determine the risk rating (Table 1c; IEC/ISO, 2009, SA, 2012).

The International standards definition of risk is “*the effect of uncertainty on objectives*” (ISO, 2009). This definition of risk makes it clear that examining risk will inherently include the level of uncertainty generated from having incomplete information (SA, 2012). In the context of assessing the threats and risk associated with this proposal, the objectives to be achieved are the maintenance of sustainable ecosystems and their dependent fisheries, such that they are not significantly impacted by biosecurity impacts that may result from establishment of aquaculture operations in the MWADZ. Consequently, a “significant impact” that would result in a high risk would be one for which there was a reasonable likelihood that the number of individuals of an affected species would materially alter the longer-term sustainability of the ecosystem or its dependent commercial fisheries.

Table 1a: Levels of consequence for each of the objectives relevant to the assessment (modified from Fletcher, 2014)

Objective	Minor (1)	Moderate (2)	Major (3)	Severe (4)
Target Species	Measureable but minor levels of depletion but no impact on dynamics. Abundance range 100–70% unfished levels (B_0).	Target species Stock has been reduced to levels approaching that associated with B_{msy}. Abundance range <70% B_0 to >B_{msy}.	Stock has been reduced to levels below B_{msy} and close to where future recruitment may be affected. Abundance range B_{msy} to B_{rec}.	Significant stock size or range contraction has occurred with average recruitment levels clearly reduced (i.e. recruitment limited). Abundance range B_{rec}.
Ecosystem structure	Measurable minor changes to ecosystem structure, but no measurable change to function.	Maximum acceptable level of change in the ecosystem structure with no material change in function.	Ecosystem function now altered with some function or major components now missing and/or new species are prevalent.	Extreme change to structure and function. Complete species shifts in capture or prevalence in system.
Habitat	Measurable impacts very localised. Area directly affected well below maximum accepted.	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.	Above acceptable level of loss/ impact with region-wide dynamics or related systems may begin to be impacted.	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Table 1b: Levels of likelihood for each of the main risks analysed in this assessment (modified from Fletcher, 2015)

Level	Descriptor
Remote (1)	The consequence not heard of in these circumstances, but still plausible within the time frame (indicative probability 1-2%)
Unlikely (2)	The consequence is not expected to occur in the time frame but some evidence that it could occur under special circumstances (indicative probability of 3-9%)
Possible (3)	Evidence to suggest this consequence level may occur in some circumstances within the time frame (indicative probability of 10 to 39%)
Likely (4)	A particular consequence is expected to occur in the timeframe (indicative probability of 40 to 100%)

Table 1c: Hazard/Risk Analysis Matrix. The numbers in each cell indicate the Hazard/Risk Score, the colour indicates the Hazard/Risk Rankings (see Table 2)

		Likelihood Level			
Consequence level		Remote	Unlikely	Possible	Likely
		1	2	3	4
Minor	1	1	2	3	4
Moderate	2	2	4	6	8
Major	3	3	6	9	12
Severe	4	4	8	12	16

The residual consequences, likelihoods and resultant levels of hazard or risk are all dependent upon the effectiveness of the risk mitigation controls that are in place (SA, 2012). Determining the most appropriate combinations of consequence and likelihood scores therefore involves the collation and analysis of all information available on an issue. The best-practice technique for applying this method now makes use of all available lines of evidence for an issue and is effectively a risk-based variation of the 'weight of evidence' approach that has been adopted for many assessments (Linkov et al. 2009, Wise et al. 2007, Fletcher, 2014).

The hazard evaluation step uses the outcomes of the risk analysis to help make decisions about which hazards need treatment, the level of treatment and the priority for action. The different levels of management action can be determined by having the hazard or risk scores separated into different categories of hazard (Table 2).

Table 2: Risk Evaluation, Rankings and Outcomes [modified from Fletcher et al. (2002, 2005, 2015)]

Risk Level	**Hazard/Risk Score (C x L)**	**Description**	**Likely Management Response**
Negligible	0-2	Acceptable with no management actions or regular monitoring.	Brief justification
Low	3-4	Acceptable with no direct management actions and monitoring at specific intervals.	Full justification and periodic reports
Moderate	6-8	Acceptable with specific, direct management and regular monitoring.	Full regular performance report
High	9-16	Unacceptable unless additional management actions are undertaken. This may involve a recovery strategy with increased monitoring or even complete cessation of the activity.	Frequent and detailed performance reporting

Information Utilised

The key information used to generate the hazard and risk scores included:

- Broad knowledge of the proposal as provided in its application;
- A previous high level generic risk assessment conducted for marine finfish aquaculture in Australia (FRDC project 2003/223);
- An identified list of species likely to be under consideration for aquaculture in the MWADZ;
- A literature review of significant disease, genetic and marine pest issues associated with worldwide aquaculture with a focus on relevance to proposed culture species (with a focus on yellow tail kingfish); and
- Other relevant scientific studies and publications (see references).

1.4 Risk Identification and Assessment

Based on consideration of the identified broad areas of biosecurity threat and their constituent hazard pathways, overarching risks were identified associated with the MWADZ proposal. Assessment of these overarching risks was conducted as described for the hazard pathway assessment described above. Once again the inherent hazard or risk was first assessed in the absence of any management control measures, followed by assessment of residual risk following application of the identified management controls.

The assessment of economic impact on the aquaculture industry itself resulting from such risks was not considered within the scope of this assessment.

This set of assessments is focused upon biosecurity risks and as such does not specifically examine any wider ecological, social, economic or political risks surrounding the development of the MWADZ.

3. Threat Identification, Hazard Pathway Identification and Hazard Pathway Analysis

3.1 Threat Identification

Using a component-tree based approach (Fletcher et al., 2004) three broad areas of biosecurity-related threat were identified that were considered both most relevant to the MWADZ proposal and within the scope of the current assessment. These key threats were as follows:

- Potential impacts of disease on wild targeted fish species.
- Potential impact of escaped fish on wild targeted fish stocks (genetic and competitive).

- Potential impact of introduced marine pests associated with aquaculture on ecosystem sustainability.

3.2 Hazard Pathway Identification

Three separate hazard identification pathways were generated associated with the key threats identified (Figures 3a, b & c) to reflect identification of the pathways leading to:

- introduction of a significant pathogen or disease into an aquaculture facility that would first be required to result in subsequent impact to target fisheries sustainability (e.g. through spread of disease);
- aquaculture escapes and resultant potential significant detrimental genetic or competitive effects on wild fish populations, impacting targeted species sustainability; and
- potential introduction/spread and establishment of marine pest species, impacting ecosystem sustainability.

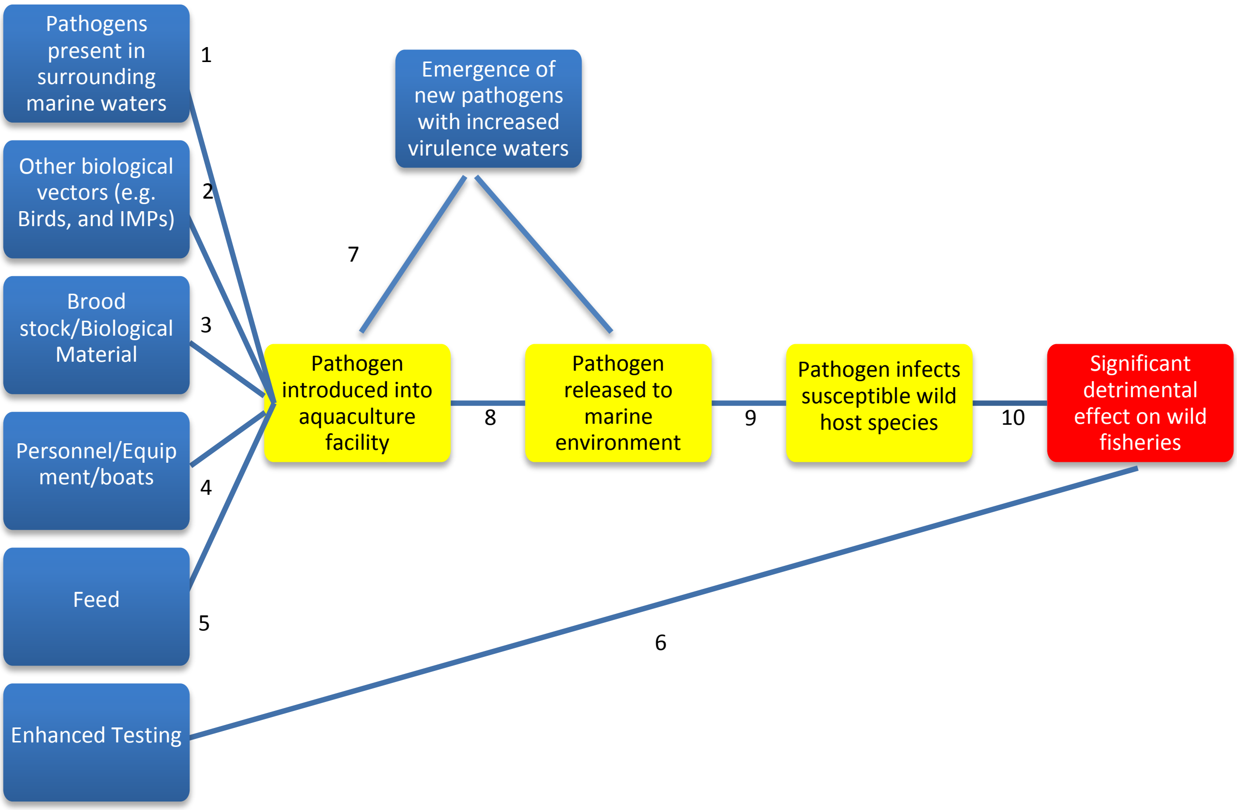

Figure 3a: Compendium map of potential pathways leading to a pathogen introduction and potential disease outbreak in an MWADZ aquaculture facility that may lead to potential spread of disease to wild fisheries and subsequent significant impact. *Numbers refer to hazard pathways reviewed in Table 3.*

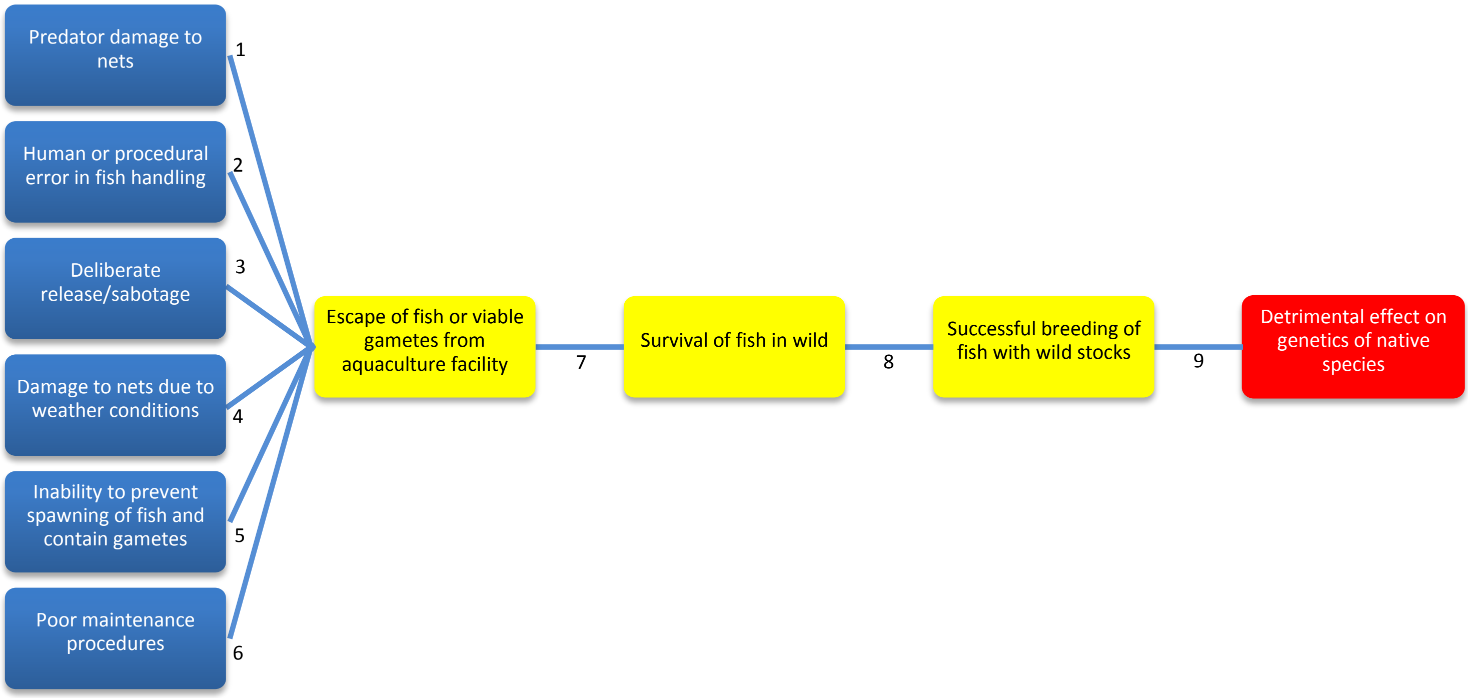

Figure 3b: Compendium map of potential pathways leading to potential negative genetic effects on wild fisheries arising from a potential MWADZ aquaculture facility that may lead to subsequent significant impact. *Numbers refer to hazard pathways reviewed in Table 3*

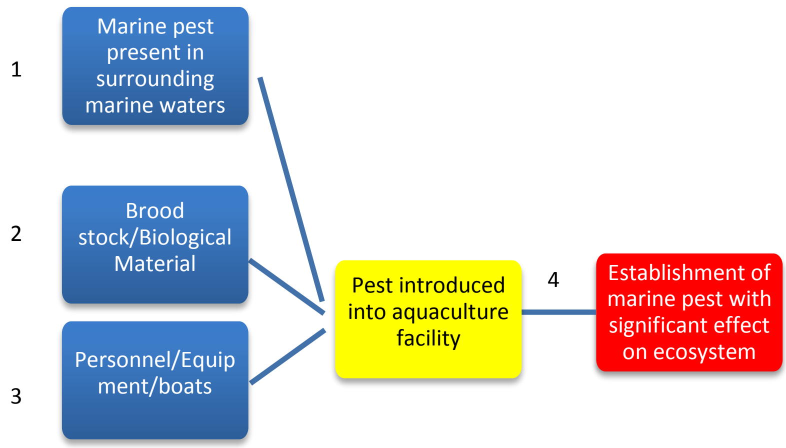

Figure 3c: Compendium map of potential pathways leading to marine-pest associated impacts arising from a potential MWADZ aquaculture facility that may lead to subsequent significant loss. *Numbers refer to hazard pathways reviewed in Table 3*

3.3 Hazard Pathway Analysis

For the purpose of hazard pathway analysis, hazards were considered based on biological consequence to target species, ecosystem and/or habitat as detailed in Table 1a. While significant biological consequence is generally a prerequisite that may lead to subsequent economic and social consequence (e.g. economic and reputational loss via loss of market access resulting from detection of pathogen which leads to trade issues and social amenity impact) these aspects are not evaluated in the current assessment.

2.3.1 Hazard Pathway 1: Pathogen introduction and disease development

2.3.1.1 Overview of potential impacts of disease originating from aquaculture on wild fish

The potential effect of disease on marine fisheries worldwide was recently assessed by Lafferty et al (2015), who identified 67 examples of disease that can impact commercial species of which 49% affect marine finfish. Many documented examples exist where marine sea-cage cultured fish, that may be produced under controlled hatchery conditions, are affected by disease likely introduced from the surrounding marine environment (e.g. Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). This is perhaps not surprising, given the nature of open sea-cage based aquaculture and the level of potential pathogens demonstrated to be naturally present in coastal sea water (Suttle, 2005). The majority of potential pathogens of fish may be relatively benign in wild fish where co-evolution and a naturally low abundance of potential hosts has favoured development of a life cycle that does not cause death of a host that might otherwise ultimately result in extinction of that pathogen.

Aquaculture, however, presents a different opportunity and set of selective pressures that favour more rapid evolution of pathogens and development of a life cycle that is not constrained by host abundance (Einer-Jensen et al, 2004). Indeed, many examples exist of the emergence of new pathogenic strains of viruses that are naturally present in wild fish but have been responsible for significant mortality in aquaculture (e.g. Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). The potential re-export of large quantities of potentially modified pathogens into the environment remains a key concern associated with marine cage-based aquaculture, though the impact of disease export on wild fisheries remains controversial since there are few quantitative data demonstrating that wild species near farms suffer more from infectious diseases than those in other areas (Lafferty et al, 2015).

This problem is exacerbated in part due to the difficulties in identifying and studying disease epizootics in wild fish where sick fish may be hard to identify and a decreased fitness likely renders them at increased risk of predation.

In addition to the risk of new emerging pathogens associated with aquaculture practices, significant disease risks are also associated with translocation of fish for aquaculture which may expose previously naive fish to an exotic range of new pathogens against which they may have limited natural immunity. The introduction of VHSV in the Great Lakes region of North America appears to be an example of the apparent translocation of a previously exotic virus to a new environment. This appears to have resulted in widespread and non-specific fish kill events in wild fish, though the exact source of origin of the virus remains unclear (Kim & Faisal, 2011).

2.3.1.2 Hazard analysis: Pathogen introduction and disease development

The hazard pathway components identified in the compendium map detailed in Figure 3a were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3a. Prior to conducting this exercise, a review of relevant literature documenting pathogens that are known to affect the range of species identified for the potential development of aquaculture in the MWADZ was conducted, with a focus on yellow tail kingfish (YTK) as a case study. Consequence to target species was specifically considered as the primary likely consequence in developing this assessment based on a worst-case scenario model using relevant examples applicable to the culture of the proposed species (i.e. YTK).

Table 3a: Assessment of hazards identified in Figure 3a *Hazards were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or a number of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Pathogens present in surrounding marine waters	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk Level: Moderate**	**Likelihood** While every effort can be made to develop juvenile fish of a high health status in hatcheries, open sea-cage aquaculture (as proposed for the MWADZ) exposes cultured species during their grow-out phase to a range of potential pathogens that are present in the marine environment and are horizontally transmitted via water (reviewed by Lafferty et al 2015). Interestingly, studies have shown that in the order of 10^7 viral particles may be present in every millilitre of coastal seawater (Suttle et al, 2005). An additional risk factor is the interaction of cultured fish species with wild fish. This interaction may include both their wild conspecific counterparts, which would be expected to share a similar profile of potential susceptibility to pathogens and other local species. Numerous studies, worldwide, have documented examples of the likely introduction of significant disease-causing pathogens into marine aquaculture sea-cages from surrounding waters based on presumed horizontal transmission (e.g.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to inability to control the presence of and introduction of pathogens into sea-based aquaculture facilities. **Consequence** Consequence may be reduced to **Minor (1)** with respect to wild fish stocks based on the implementation of management controls including the following: • Management and industry measures to promote high levels of fish welfare and husbandry conditions in aquaculture; Management policy only permitting locally-sourced and present species for aquaculture in the zone. This ensures suitability for culture under proposed conditions (local adaptation and welfare) in addition to reducing consequence of introduction of exotic diseases;

		infectious salmon anaemia virus, viral haemorrhagic septicemia virus, salmonid alpha virus; Nylund et al, 2003, Snow et al, 2004, Snow et al, 2010). Such introductions have resulted from pathogens shown to be naturally present in local waters that, prior to their emergence in marine aquaculture, were considered to be exotic. In the case of seriolids, which are a species under consideration for culture in the MWADZ, wild fish are believed to be the primary reservoir of parasitic infection for fish cultured in sea-cages (Diggles & Hutson 2005). Significant knowledge of the range of pathogens affecting kingfish aquaculture in Australia has developed alongside an emerging industry (for review see Diggles & Hutson 2005). A total of 41 plausible disease hazards to YTK health were compiled by Shepherd et al (2003) who further evaluated the risk of these hazards associated with YTK aquaculture. The likelihood of introduction of these pathogens into sea-based aquaculture facilities is assessed as **Likely (4)** based on the documented presence and association of many of them with YTK aquaculture to date in Australia and the general difficulty in preventing introduction of pathogens known to be abundant in the environment into open sea-cage aquaculture systems. **Consequence** Overall, Red Sea bream-like iridovirus (RSIV) has been previously identified as one of the highest risk hazards to YTK aquaculture (Shepherd 2003). This pathogen is also considered of particular potential consequence to wild fisheries based on its non-specific host range and pathogenicity.		• Siting of proposed aquaculture farms away from the habitat of susceptible hosts; • Establishment of zones based on effective disease control principles; and • Development of emergency response plans and capability (government and industry) to contain disease outbreaks and limit spread of pathogens to wild fish.

		At the facility level, the consequence of introduction of pathogen such as RSIV would be dependent on a range of husbandry factors and may not necessarily result in a disease outbreak and significant transmission to wild fisheries. The interactions between the susceptible host, the virulent pathogen, and the favorable environmental conditions required for a disease to develop are complex and difficult to predict for both cultured and wild fish. However, numerous examples of significant losses to the aquaculture industry are known, with potentially stressful conditions associated with aquaculture known to be a contributing factor. While consequence to the aquaculture sector may be severe [the focus of the previous risk assessments e.g. Shepherd (2003)], consequence to the overarching objective of this assessment (that disease would impact the longer-term sustainability of wild fisheries target species) is considered to be **Moderate (2)**. This is based on the fact that, while there have been no documented cases of the direct transfer of native or exotic diseases from sea-cage cultured fish to wild stock in Australia (de Jong & Tanner 2004), examples do exist worldwide as recently reviewed by Lafferty et al (2015). Lafferty considered that of 57 evaluated infectious agents found in aquaculture, 45 might be exported to wild species. Whether pathogens potentially amplified in aquaculture impact wild fisheries depends on the quantity, location, and nature of the exported infectious agent combined with host susceptibility, resistance and tolerance (Lafferty et al, 2005). Fortunately, wild stocks are often adapted to their infectious agents as a result of co-evolution and		

		the population-level consequences of increased exposure should be mild (Jackson et al 2013). Consequence is considered moderate based on a precautionary principle and takes into account potential of exotic disease introduction where such inherent disease resilience in wild stocks is less likely.		
2. Other biological vectors (e.g. birds)	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Interaction with native fish is considered above due to the fact that horizontal transfer from fish generally occurs via the water column. Birds have been implicated in the spread of some pathogens (e.g. infectious pancreatic necrosis virus of Atlantic salmon; McAllister and Owens, 1992) and their involvement in introduction of pathogens into a sea-cage facility is thus assessed as **Possible (3)** in the absence of appropriate management controls. **Consequence** Consequence (as per section 1 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on implementation of a range of management measures specifically designed to exclude predators including birds. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

3. Brood stock/ biological material	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Brood stock or hatchery-reared juveniles are a source of potential introduction of pathogen into a sea-cage aquaculture facility. Pathogen transfer can occur via vertical transmission from parental brood stock (which may be wild-sourced) or via horizontal transmission from within a hatchery. In the absence of management controls and basic biosecurity measures, the transfer of potentially significant pathogen is considered **Likely (4)** in association with the translocation of biological material. **Consequence** Consequence (as per sections 1 & 2 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on consideration of the following management measures: • The use of specific pathogen-free brood stock and exclusion of known significant pathogens through a program of sensitive brood stock screening conducted by an appropriate laboratory; • A brood stock development program aimed at “closing” the genetic pool as soon as practical to reduce the threat of introduction of new pathogens; • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice; and • Health testing of stock prior to translocation to a sea-cage environment. **Consequence** Potential consequence may be reduced to **Minor (1)** based on the management controls described in section 1 of this table.

4.Personnel/ equipment/boats	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** For this scenario, the pathogen must first be present in the local environment or on imported equipment. This is considered **Possible (3)** if equipment or infrastructure is shared between facilities and/or imported for re-use. Comprehensive epidemiological studies based on other significant pathogens of aquaculture (e.g. infectious salmon anaemia virus; Jarp & Karlsen, 1997) have documented the role of personnel and equipment in spreading infection between marine aquaculture sites (e.g. divers, boats, equipment, etc.). Likelihood in the absence of management control or industry best-practice guidelines is assessed as **Possible (3)**. **Consequence** Consequence (as per sections 1, 2 & 3 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the implementation of management controls including: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Adequate site and individual operator separation. Dedicated infrastructure not shared with other high-risk users (e.g. processing plants, other aquaculture enterprises, wild-capture fisheries enterprises). • Adequate exclusion zones around aquaculture facilities • Development of an industry code-of-practice focused on biosecurity. • Consolidation of industry and avoidance of existence of multiple independent operators in close proximity to one another. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

5. Feed	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Imported feed has been identified as one of the more likely sources for potential introduction of exotic viruses (Baldock 1999). Marine finfish aquaculture may be dependent on high-quality, brood stock-conditioning feeds, especially in the development stages of new species aquaculture. In the absence of any control on feed sourcing, likelihood of disease introduction is considered **Likely (4)**. Feed has been previously implicated in the introduction of disease to aquaculture (VHS in turbot; Munro, 1996) and also in the introduction of a virus that caused a disease epidemic in wild pilchards in Australia (Jones et al 1997). **Consequence** Consequence (as per sections 1, 2, 3 & 4 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the implementation of management controls including the following: • Feed must be AQIS-approved or produce by a manufacturer that complies with ISO 9001:2008. • Commercial pelleted-feed only allowed at sea-cage facilities. • Feed other than commercial pellets must be frozen to kill macro-parasites. • Fish-based feed must only be used within bio-secure hatchery facilities. • Fish for grow-out required to be monitored for mortality and health screened prior to translocation to sea-based grow-out sites. • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.

6. Enhanced testing	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** It is **Likely (4)** that an expanding aquaculture industry associated with an enhanced testing regime results in an increased knowledge with respect to the range of potential diseases affecting a species or present in a geographic range. This has proven the case for seriolids in Australia, where there has been a considerable increase in knowledge with respect to their potential health issues (Diggles and Hutson 2005). **Consequence** Increased testing leads to an improved understanding of health conditions potentially affecting wild fish and wider ecosystems. This may be of benefit in understanding impacts on wild stocks in relation to changing environmental pressures. Increased testing is also likely to reduce potential consequence to wild fisheries by reducing risks of significant disease occurrence and subsequent spread to wild fish. If significant pathogen was detected through extensive brood stock screening, animals would be destroyed while in quarantine and not enter the production cycle. Thus, potentially limiting consequence. Australia enjoys a high biosecurity status and reputation, being free from a range of significant pathogens affecting finfish worldwide. Consequence is assessed as **Minor (1)**.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** based on the possibility that previously unrecognised health issues may be identified based on increased levels of health surveillance. **Consequence** Consequence of enhanced testing having a detrimental effect can be further reduced [though remains **Minor (1)**] through implementation of management controls aimed at rapid communication and containment of disease outbreaks based on results of increased diagnostic surveillance. Examples of management controls include: • Development of a controlled communication plan to limit negative effect. • Research to back up understanding consequence of the finding (e.g. is it likely that the pathogen was already present in Western Australian waters?). • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Regular compliance visits and

		However, while out of scope of the current hazard evaluation focused on sustainability impacts to target species, the highlighting of a detrimental health issue (or disease previously considered to be exotic) associated with a species could have significant negative consequence to trade and to the wild fisheries sector.		record auditing. • Potential to routinely test selected animals from the farm (targeted surveillance). • Potential to improve passive surveillance via introduction of a compulsory real-time mechanism for reporting of mortalities to the regulating body.
7. Emergence of significant new pathogens with increased virulence with an aquaculture facility	**Likelihood: Possible (3)** **Consequence: Moderate (2)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Introduction and maintenance of pathogens in intensive aquaculture could lead to the **Possible (3)** emergence of previously unknown or emerging disease. Examples of where this is thought to have occurred include Viral Haemorrhagic Septicaemia Virus (VHSV) (Einer-Jensen et al., 2004) and Infectious Salmon Anaemia Virus (ISAV) (Godoy et al., 2013). The potential stressors associated with commercial aquaculture that exert selection pressures on pathogens that drives their evolution (especially in the case of rapidly evolving organisms such as RNA viruses) are also well understood and include factors such as high stocking densities, stress, temperature and availability of susceptible hosts. **Consequence** Consequence (as per sections 1, 2, 3, 4 & 5 of this table) is assessed as **Moderate (2)**.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on the following management controls: • Development and compliance with approved biosecurity management arrangements and best-husbandry practice. • Potential to implement measures to ensure fallowing as part of the production cycle to ensure pathogens are not maintained continuously within a facility or within an area. • Potential to insist on management controls to limit the pressure from pathogens (e.g. regular cleaning and exchange of nets as required in the South Australian YTK industry).

		The adaptation of pathogens within aquaculture and their subsequent release poses a relatively unknown consequence to wild fish stocks which may be less adapted to be able to overcome new variants of pathogen.		• Establishment of zones based on effective pathogen control principles. **Consequence** Consequence may be reduced to **Minor (1)** based on the rationale described above.
8-9. Pathogen is released to the marine environment and infects susceptible species	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Pathogens will **Likely (4)** be released to the wider environment if they are present in a sea-cage aquaculture site due to the lack of ability to contain it. Some documented examples exist that suggest evidence of infection of wild fish with pathogens thought to have originated from aquaculture operations (Krkosek et al., 2006). Often these are associated with wild fish that enter and live in sea-cages alongside the cultured target species. **Consequence** Consequence (as per sections 1, 2, 3, 4, 5 & 7 of this table) is assessed as **Moderate (2)**. Consequence of infection alone is considered moderate in the potential case of a disease previously considered exotic to Australia or in the case of a modified variant of pathogen that might evolve in association with aquaculture for reasons outlined in section 1. This is especially the case where significant infection levels or emerging disease issues are	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to lack of ability to completely contain potential spread of infection. The level of spread can, however, be reduced - leading to potentially lower consequence. **Consequence** Consequence (level of transfer of pathogen) can be reduced to **Minor (1)** through implementation of management measures aimed at early detection and subsequent fallowing of farms. Examples of management measures include: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • All measures taken to ensure early detection of significant pathogen (e.g. passive and targeted surveillance).

		left unchecked without treatment or containment measures.		• Regulator to ensure clear process for timely implementation of containment measures in the event of detection of significant pathogen. • Implementation of appropriate and timely disease treatments regime for endemic diseases. • Consideration of vaccination as a strategy to reduce effects of opportunistic or ubiquitous pathogens.
10. Pathogen results in significant impact to wild fish/ecosystems	**Likelihood: Possible (3)** **Consequence: Severe (4)** **Hazard score: (12)** **Risk level: High**	**Likelihood** In the absence of management controls, likelihood is assessed as **Possible (3)**. Susceptibility of a species (e.g. YTK) to a disease in aquaculture that results in disease suggests it likely that wild stocks of the same species in the region might also be susceptible to the pathogen in question. Likelihood will depend on a range of factors including the pathogen shedding rate and survival outside the host, requirement for intermediate hosts, water currents and dilution effects, and proximity to and density of susceptible species. There have been few examples worldwide of pathogens leading to measurable losses in wild stocks despite their abundance in significant finfish aquaculture industries.	**Likelihood: Unlikely (2)** **Consequence Severe (4)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Likelihood may be reduced to **Unlikely (2)** based on the introduction of management measures aimed at reducing risk of disease emergence and ensuring rapid containment of emerging disease as described above. **Consequence** Consequence remains unchanged at **Severe (4)**.

		However, it should be noted that impacts of disease on wild stocks may be difficult to detect since compromised animals are often predated upon and obvious large fish kills due to disease are rare events. An exception is a mass mortality event that occurred in pilchards in South and Western Australia. The exact origins of this virus were never fully determined, but were considered likely to have been associated with practices connected to the tuna aquaculture industry (Jones et al., 1997). **Consequence** Consequence of this hazard is assessed as **Severe (4)** based on a scenario where significant impacts to the sustainability of targeted wild species occur.		

2.3.2 Hazard Pathway 2: Potential negative effects of aquaculture escapees on wild fisheries

2.3.2.1 Overview of potential impacts of aquaculture escapees on wild fish

Escapes are an almost inevitable occurrence in association with marine sea-cage aquaculture and occur largely as a result of technical and operational failures of fish farming equipment (Jensen et al 2010). They may be ongoing at a low level or episodic and significant based on, for example, extreme weather events. The size and extent of escapes can be difficult to measure and can not only occur as a result of juvenile or adult fish escaping nets but can also result from the release of viable larvae following spawning of aquacultured fish. Common causes of escapes in Norwegian aquaculture (reviewed by Jensen et al., 2010) include progressive mooring failure, breakdown and sinking of steel cages and abrasion and tearing of nets with the latter category accounting for two thirds of reported escape incidents. In terms of volumes, large-scale escape events constituted only 19% of incidents but accounted for 91% of escaped fish, indicating that a management focus on this category of escapes might have the greatest effect in diminishing consequence of escapes (Jensen et al., 2010). The impact of escapes can include negative genetic effects on wild populations through interbreeding and a potentially high relative contribution of aquaculture fish to the wild breeding stock in local areas following significant levels of escapes. Other impacts can include competition between aquaculture fish with wild fish for resources (e.g. food/habitat). Worldwide, this issue has been the subject of significant study for Atlantic salmon, based on the significant worldwide culture of this species, coupled to conservation concerns surrounding declining populations in the wild. In addition, Atlantic salmon are at a relative advanced level of domestication (often associated with reduced or altered genetic diversity) and wild stocks are composed of distinct populations that are often genetically identifiable at the local catchment level.

2.3.2.2 Hazard Analysis: Potential negative effects of aquaculture escapees on wild fisheries

The hazard pathway components identified in the compendium map detailed in Figure 3b were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3b. Prior to conducting this exercise a review of potential negative genetic and competitive effects of aquaculture escapees on wild fisheries from the potential development of aquaculture in the MWADZ was conducted, with a focus on yellowtail kingfish (YTK) as a case study. Consequence to target species was specifically considered in developing this assessment based on a worst-case scenario model using relevant examples applicable to the culture of the proposed species, with a focus on YTK.

Table 3b: Assessment of hazards identified in Figure 3b *Hazards were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or a number of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1. Escape of fish associated with sea cage operations	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** The issue of escapes has undoubtedly been most widely studied in the North Atlantic where in Norway alone, 3.93 million Atlantic salmon, 0.98 million rainbow trout and 1.05 million cod escaped between 2001 and 2009 (Jensen et al 2010). A review of the Department of Primary Industry Finfish escape register (http://www.pir.sa.gov.au/aquaculture/monitoring_and_assessment/register_-_finfish_escape) illustrates the fact that escapes are an ongoing and anticipated hazard also associated with YTK finfish aquaculture in Australia. On this basis escapes from sea-cages within the MWADZ are considered **Likely (4)**. Escapes are largely caused by technical and operational failures of fish farming equipment and may result from low level "leakage" and through significant episodic events such as storms (Naylor et al 2005). In general, causes of escapes can include predator damage (e.g. caused by birds or sharks), human error, deliberate sabotage, poor selection of or maintenance of equipment, and damage caused by weather.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Remains unchanged at **Likely (4)** due to the fact that a certain level of escapes associated with marine aquaculture probably cannot be avoided (Waples et al., 2012). **Consequence** May be reduced to **Minor (1)** based on the implementation of policy controls aimed at limiting the frequency and extent of escape events as advocated in a review by Jensen et al. (2010) which include the following: • Mandatory reporting of all escape events. • Establishment of a mechanism to analyse and learn from mandatory reporting. • Conduct mandatory, rapid technical assessments to determine causes of serious

		Consequence Consequence of escapes is ultimately dependent on the volume of escaped fish coupled to the ability of those fish to survive in the wild, compete for resources, spread disease and/or contribute their genes to future generations. This hazard considers consequence from a perspective of volume of fish released, since other aspects are dealt with separately elsewhere. In the absence of adequate management controls the consequence of escapes will undoubtedly be increased through the enhanced opportunity of increased volumes of fish to be released to the wider environment. The present level of escapees worldwide is regarded as a problem for the future sustainability of sea-cage aquaculture (Naylor et al., 2005). The ecological and genetic impacts of escapees are dependent on a wide range of poorly understood and species-specific factors but may be exacerbated by the numerical imbalances between caged compared to wild populations (e.g. in Norway 0.5-1 million fish return to rivers each year versus 325 million fish held in sea-cages at any one time (Jensen et al 2010). The only practical way to limit the potential impact of escaped aquaculture fish is to implement measures to reduce the likelihood of escape events occurring. In the absence of such measures, the likelihood of escapes is high and the consequence (in terms of volume of escapes) is deemed **Moderate (2)**.		escapes. • Introduce a technical standard for sea-cage aquaculture equipment coupled to an independent mechanism to enforce the standard. • Ensure mandatory training of fish farm staff in escape-critical operations and techniques. Correlative evidence has indicated that after implementation of a technical standard for sea-cage farms in Norway (NS9415) took effect in 2004, the total number of escaped salmon declined from >600,000 fish per year (2001-2006) to <200,000 fish per year (2007-2009) despite the total number of fish held in sea-cages increasing by 44% during this period (Jensen et al 2010). Such an approach did not lead to reduced escapes of cod however, suggesting that other measures such as improved netting materials may be warranted. Other methods to reduce frequency of escape events include siting of sea-cages in areas with appropriate shelter from inclement weather, the maintenance of good husbandry procedures, adequate staff training, installation of anti-predator devices and ensuring security of sites.

2. Escape through spawning	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Escape through spawning has been documented to occur for pelagic spawning species such as Atlantic cod (Jorstad et al 2008). Species such as YTK have been shown to mature and spawn at 13 months of age under favourable conditions (Kolkovski et al., 2004). Since a single female may produce 0.5-2 million eggs per spawning event, the capacity for escape of fertilised eggs from open sea-cages is high. This hazard is thus deemed **Likely (4)** in the absence of measures to limit potential release of viable gametes and larvae. **Consequence** Consequence is again influenced by a wide variety of factors that influence the subsequent development and fate of fertilised eggs and larvae. Consequence is rated as **Moderate (2)** based on the expectation that rearing of fish over a general 2-year production cycle is likely to lead to some maturation of fish (though this issue requires species-specific consideration) and thus potentially significant release of viable eggs. The fact that this occurs within the known range of native fish of the same species suggests that opportunity for future development of those eggs may be on a par with those of native fish. This may be especially so given the expected lack of domestication of stock that may be associated with emerging industries marine finfish industries in the MWADZ.	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Likelihood remains unchanged at **Likely (4)**. Although mechanisms to inhibit escape by this method are being explored for some sectors, a practical and cost-effective method has yet to be developed and remains a research priority (Jensen 2010). **Consequence** Consequence remains unchanged at **Moderate (2)** given the level of uncertainty surrounding levels of spawning, survival and subsequent recruitment linked to cultured fish. In the proximity of an experimental cod farming sea-cage, 20-25% of cod larvae in plankton samples were determined by genetic analyses to have originated from 1000 farmed cod (Jorstad et al 2008). Previous recommendations have suggested that in the case of Atlantic salmon, intrusion rates should be kept below 5% to avoid substantial and definite genetic changes to wild populations (Hindar & Diserud., 2007).

3. Survival of fish in wild and competition for resources.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** In the example cited above, 4-6% of juvenile cod caught in the area in the following year were offspring of experimentally-farmed cod (Jorstad et al 2008) suggesting the contribution of escaped larvae to wild stocks could be substantial (Jorstad et al 2008). This is obviously highly species and locational specific. Within a fish's native range, survival of larval fish from aquaculture (especially based on F1 generation) may be expected to be on a par with those of wild fish, given a suitable receiving environment. Escaping older fish may, however, fare less well due to conditioning associated with aquaculture. This hazard is thus deemed **Likely (4)**. **Consequence** The degree of competition for resources is likely to depend on numbers of escaped fish relative to numbers of fish of the same species and of other wild fish species. Again, in the case of Atlantic salmon, escapees have been shown to consume much the same diet as wild salmon in coastal oceanic waters (Hislop and Webb 1992, Jacobsen and Hansen 2001). In the case of YTK, tagging work has suggested the possibility of interaction between farmed and wild fish in the Spencer Gulf, South Australia. YTK are carnivorous (Henry and Gillanders 1999) and therefore escaped fish have potential to compete for food resources with other carnivorous species.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Remains unchanged at **Likely (4)** due to the inability to influence survival of fish in the wild. **Consequence** Remains unchanged at **Minor (1)** due to the relative inability to influence survival once escaped from aquaculture. That said, experience suggests that escaped YTK often reside near cages for days, which can facilitate their recapture (Zaluski 2003). While this is not a recommended strategy upon which to rely, appropriate emergency response protocols could reduce the consequence in the case of adult fish.

		However, there is no evidence that levels of non-fishing mortality in species such as YTK are currently density dependent; suggesting the consequence to stocks resulting from the competition for resources may be **Minor (1)**.		
4.Breeding of cultured fish with wild stocks	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** Successful spawning of escaped farmed salmon in rivers both within and outside their native range has been demonstrated (reviewed by Weir and Grant 2005). Given domestication, however, spawning success may be just 20-40% of that of wild salmon and even lower for males (1-24%; Fleming et al., 1996, 2000). Given the lack of domestication associated with other new aquaculture species considered for culture in Western Australia and the nature of their reproductive biology it seems likely that this potential spawning contribution to wild fish populations could be higher. Likelihood is thus assessed as **Likely (4)**. **Consequence** Again, consequence is largely dependent on the volume of escapes and thus potential of escapees to interfere with the breeding of wild stocks either directly or indirectly. It is assessed as **Moderate (2)** based on the potential for pelagic batch spawning to spawn in cages and escape as either juveniles or adults in areas known to be within the native range of the cultured species.	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** due to the very likely possibility of some aquaculture escapees interbreeding with wild fish. **Consequence** Maybe reduced to **Minor (1)** based on implementation of a range of measures described above aimed at reducing numbers of escapes, preventing their interaction with wild fish and/or promoting their recapture.

5.Detrimental genetic effects on wild populations	**Likelihood: Likely (4)** **Consequence: Moderate (2)** **Hazard score: (8)** **Risk level: Moderate**	**Likelihood** In 2007, a large EU-funded project sought to assess the genetic impact of aquaculture activities on native populations on a species by species basis (Svasand et al 2007). In the case of Atlantic salmon, the study concluded that escapes can have significant direct impacts on wild populations by reducing mean fitness. Modeling suggested the impact will depend on the magnitude and frequency of escapes. In the case of Atlantic cod, a pelagic batch-spawner (similar to species under consideration for culture in the MWADZ), less is known though studies are ongoing on possible gene interactions between wild and farmed cod. In the case of YTK, recent studies aimed at assessing the genetic population structure of this species across temperate Australia and New Zealand indicated that Western Australian *Seriola lalandi* was genetically distinct from those sampled from other localities (Miller et al., 2011). Based on a precautionary approach, the likelihood of escapes having a detrimental effect (especially those of a different origin to those naturally found in Western Australia) on wild stocks of the same species is deemed **Likely (4)**, especially in the case with pelagic spawners where maturation and spawning may be very difficult to control. **Consequence** In the case of Atlantic salmon, modelling suggesting the impact will depend on the magnitude and frequency of escapes (Svasand et	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Likelihood remains unchanged at **Likely (4)** based on some degree of likely future interaction of cultured and wild fish stocks. **Consequence** The consequence of a detrimental effect can be reduced to **Minor (1)** through measures aimed at reducing the volume of escapees and/or their ability to contribute to future generations. Such measures applicable to the MWADZ include the general management and technical measures detailed above to prevent escapes. In the case of cod aquaculture, research efforts are focusing on the possibility of using sterile fish for aquaculture and to develop a line of fish that reaches harvest size prior to maturation (Jorstad et al., 2008). In the case of the MWADZ, likelihood of a negative genetic impact may be reduced through local sourcing of brood stock and through strategies aimed at ensuring harvest of fish prior to large scale spawning. Given that *Seriola lalandi* have been reported to generally spawn at 5-7 years this may reduce likelihood with respect to this species.

		al., 2007). It seems reasonable to assume that the same applies to other species, coupled to the local abundance of wild fish and genetic population structuring of the same species. In the case of YTK, the existence of a discrete genetic and potentially locally-adapted stock of Western Australian *Seriola lalandi* may enhance the potential consequence of interbreeding between escapees of a different origin. Given a lack of management controls aimed at controlling translocation of fish into the MWADZ (e.g. sourcing of fish from South Australia) enhanced consequence may result from a lack of control over aquaculture-associated translocation. Based on the general lack of knowledge surrounding the genetic implications of marine finfish escapees, the consequence of escaped fish and larva on the genetics of wild populations is assessed as **Moderate (2)** in the absence of management controls.		

2.3.3 Hazard Pathway 3: Potential negative effects of marine pests introduced or spread as a result of aquaculture activity

2.3.3.1 Overview of potential impacts of marine pests introduced or spread as a result of aquaculture activity (habitat and ecosystem)

Invasive marine pests are plants or animals that may be introduced into marine ecosystems outside their natural range and that have significant economic, socio-cultural/human health and/or ecological impacts. Damages and costs associated with controlling invasive marine species in the USA are estimated to amount to US$14.2 billion annually (Pimentel *et al*., 2005).

Marine pests can have significant impacts on ecosystems and the commercial viability of their dependent fisheries and are often difficult or impossible to eradicate once established. For example, the North American comb jelly (*Mnemiopsis leidyi*) was introduced into the Black Sea in the early 1980s, with its population subsequently exploding to reach a billion tonnes in the region. The jellyfish was responsible for the collapse of pelagic commercial fisheries, resulting in severe economic hardship in the region. The introduction of the Pacific Sea Star (*Asterias amurensis*) into Tasmania and subsequently Port Philip Bay resulted in populations growing to approximately 30 million. This pest feeds on mussels, scallops and clams and hence poses a huge threat to shellfish fisheries as well as to the commercial viability of mariculture operations. Pests can also carry new diseases that can have significant impact on wild capture fisheries and aquaculture species (e.g. White Spot Syndrome Virus which poses a risk to the most valuable wild-capture crustacean fisheries in the State).

Aquaculture businesses could assist in the further spreading of marine pests already present in the State, through movements associated with commercial operations of through provision of infrastructure suited to their proliferation. Alternatively, the aquaculture industry itself could be directly responsible for introduction of marine pests, for example, through introduction via feed sources or brood stock or via the use of imported equipment that is not sufficiently cleaned.

This assessment focuses on the potential ecological impacts of marine pests to ecosystems and their dependent fisheries. However, it is clear that marine pests can also significantly impact the commercial viability of aquaculture operations themselves (Edwards & Leung, 2008; Fitridge et al., 2012).

2.3.3.2 Hazard Analysis: Potential negative effects of aquaculture on the environment

The hazard pathway components identified in the compendium map detailed in Figure 3c were individually analysed with respect to both the inherent hazard (baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (remaining hazard once one or more of the proposed management controls have been effected) as indicated in Table 3c. Prior to conducting this exercise, a literature review of potential negative effects resulting from the introduction of marine pests from the potential development of aquaculture in the MWADZ was conducted. Consequence was assessed based on impact to habitats and ecosystem which are most likely to be primarily affected by marine pests.

Table 3c: Assessment of hazards identified in Figure 3c *Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or more of the proposed management controls have been implemented).*

Hazard	Inherent Hazard Assuming No Management Controls	Justification	Residual Hazard Following Implementation of Management Controls	Justification and Identified Management Controls
1.Marine pest present in surrounding waters	**Likelihood: Likely (4)** **Consequence: Minor (1)** **Hazard score: (4)** **Risk level: Low**	**Likelihood** Examples exist of marine biofouling pest species thought to be introduced to the State that have been introduced into aquaculture facilities (i.e. *Didemnum perlucidum* at pearl farms in the Abrolhos Islands). The source of introduction remains unknown but is likely to have resulted from infested vessels visiting the area and/or via water-borne transmission from the surrounding environment. This indicates that marine pests are likely to be present in the surrounding waters of the MWADZ. A key vector for introduction of marine pests into Western Australia is international shipping, with major ports representing key sources of initial introduction. The main access port for the MWADZ is likely to be the port of Geraldton. Geraldton port is the largest and the primary vector node in the area that hosts international vessels; predominantly bulk carriers to support trade for the region's resources industry.	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Likelihood can be reduced to **Possible (3)** based on management actions targeted around reducing risk of introduction of marine pests into the State. Current measures in place include: 1. Management strategy aimed at preventing marine pests being introduced into Western Australia. The Department uses a risk-based approach to preventing introduction of marine pests into Western Australia. This approach includes a risk-based assessment of international vessels entering State waters based on maintenance and voyage history. High-risk vessels undergo specialist pest inspections prior to being granted entry into Western Australia. This program is supported by a compliance regime.

		A detailed assessment of its marine pest risk profile was recently conducted (Bridgwood and McDonald 2014) which identified its primary sources of international and domestic risk as China and Kwinana/Fremantle respectively. Other potential marine pests have been reported at the Port of Geraldton in previous Introduced Marine Pest (IMP) surveys. Based on the known presence of marine pests in the area and the regular visitation of international and domestic shipping from areas known to harbour potential marine pests, the likelihood of marine pests being present in local waters is assessed as **Likely (4)** in the absence of management controls. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ unless the marine pest in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.		Resource projects often operate under a suite of specific ministerial conditions which dictate specific additional biosecurity requirements. Management of other vessels is voluntary through the new Department of Fisheries Vessel Check (international/interstate movements). Current control is by regulation 176 of the *Fish Resources Management Regulations 1995*, movement of non-endemic fish (as all high-risk Invasive Marine Species (IMS) are listed as noxious except pacific oysters). 2. Statewide monitoring program for the early detection of marine pests at high risk ports in Western Australia. The Department maintains a state-wide monitoring regime to detect pest incursions at an early stage, which is necessary to support their potential control. This is based on a recognised and agreed national surveillance system and is supported by a research program aimed at continuous improvement to the monitoring network. 3. Development of pest control and management strategies. The Department maintains emergency response capacity to determine the spread of marine pests and to attempt their control using a risk-based

				assessment process. **Consequence** Consequence would remain unchanged at **Minor (1)**.
2.Brood stock /biological material	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** The MWADZ proposal is focused around finfish aquaculture of species native to Western Australia. It seems unlikely that brood stock likely to be locally sourced would be a significant source of introduction of marine pests (excluding disease agents and/or parasites which are considered under disease risks). Other biological material introduced could be associated with feed sources which, depending on their composition, could represent some risk if unmanaged. Overall likelihood is considered **Unlikely (2)**. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ, unless the marine pests in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.	**Likelihood: Remote (1)** **Consequence: Minor (1)** **Hazard score: (1)** **Risk level: Negligible**	**Likelihood** Likelihood may be further reduced to **Remote (1)** based on licensing requirements to restrict species to native locally-sourced species and to restrict sources of feed as outlined among the measures below: • Feed must be AQIS-approved or produced by a manufacturer that complies with ISO 9001:2008. • Only commercial pelleted feed permitted at sea-cage facilities. • Feed other than commercial pellet must be frozen to kill any marine pests. • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. **Consequence** Consequence would remain unchanged at **Minor (1)**.

3.Personnel/ Equipment/Boats	**Likelihood: Possible (3)** **Consequence: Minor (1)** **Hazard score: (3)** **Risk level: Low**	**Likelihood** Equipment and vessels can be a source of introduction of marine pests in the absence of effective management controls. Around the world aquaculture has been identified as a major vector for the introduction of marine pests (Grosholz et al., 2015). This has occurred through the intentional introduction of non-indigenous culture species (from foreign waters), as well as accidentally translocated species (Grosholz et al., 2015). Accidental introduction is likely, primarily through 'hitch hiking' on vessels associated with aquaculture activities. Limited data exists on introduced pests associated with aquaculture, but a recent study of introduced pests in Californian waters found 126 non-native species originating from aquaculture activities, of which 112 of these introductions are believed to be accidental introductions. 106 of these species have become established in at least one location (Grosholz et al., 2015). Likelihood is thus assessed as **Possible (3)**. **Consequence** Consequence is **Minor (1)** from the perspective of the MWADZ, unless the marine pest in question is introduced into the facility, becomes established and/or is spread to the wider ecosystem.	**Likelihood: Unlikely (2)** **Consequence: Minor (1)** **Hazard score: (2)** **Risk level: Negligible**	**Likelihood** Likelihood can be reduced to **Unlikely (2)** based on application of biosecurity management controls appropriate to the aquaculture operation. These would include the following: • Development of and compliance with approved biosecurity management arrangements and best-husbandry practice. • Development of an industry Code of Practice focused on biosecurity. • Development of protocols for farm management practices (e.g. regular vessel hull cleaning, regular monitoring for high-risk introduced species, etc.) **Consequence** Consequence would remain unchanged at **Minor (1)**.

4. Establishment of introduced marine pests and significant detrimental effect on habitat and ecosystem	**Likelihood: Likely (4)** **Consequence: Major (3)** **Hazard score: (12)** **Risk level: High**	**Likelihood** Marine pests are, by their nature, species shown to establish readily in appropriate receiving environments and have significant ecological and/or other impacts. If they are introduced, they are **Likely (4)** to become established and have an impact. The likelihood is species-dependent and (in part) based on the environmental requirements of the pest species (often broad in the case of marine pests) with that of the receiving environment. A comprehensive likelihood analysis was conducted by Bridgwood and McDonald (2014). This considers such requirements of specific pest species to identify those of most risk to the Mid West region where the proposed MWADZ is to be developed. **Consequence** Generally, the impact of invasive marine species (from aquaculture activities) is negative (Grosholz et al., 2015). The establishment of marine pests can (by definition) alter habitat dynamics and ecosystem function with the appearance of new species that may compete for resources with existing species. The impact of marine pests can be difficult to predict. In the case of *Didendum perlucidum*, impact has largely been restricted to artificial structures such as those associated with aquaculture and or port infrastructure. While mostly restricted in its distribution to disturbed or artificial habitat, it has been recorded in the Swan River, where negative impacts such as fouling	**Likelihood: Unlikely (2)** **Consequence Major (3)** **Hazard score: (6)** **Risk level: Moderate**	**Likelihood** Likelihood of establishment and spread may be reduced to **Unlikely (2)** by implementation of the controls outlined above. In addition, installation of a biosecurity monitoring program in association with the MWADZ would support early detection of marine pests and reduce chance of establishment. Enforcing compulsory reporting of marine pest incidents to regulators would also enhance the prospect of early detection and reduce likelihood of establishment through providing opportunity to implement controls. Likelihood can be reduced through eradication at the earliest possible stage in the invasion process. The Department maintains an incident response capacity and is developing tools and capacity to support effective eradication of marine pests associated with man-made infrastructure. **Consequence** Consequence would remain unchanged at **Major (3)** should pests establish to the point where the implementation of controls are unlikely to be effective.

		seagrass has been observed (Simpson pers comm.). Potential consequence clearly remains highly dependent on the marine pest in question and its biological characteristics. Consequence is conservatively assessed as **Major (3)**.		

4. Risk Identification and Assessment

4.1 Risk Identification

Following identification of key threats and detailed analysis of hazard pathways leading to potential realization of these threats, three overarching risks of most relevance to the activities proposed in association with the MWADZ were identified. These were as follows:

1. *That a significant pathogen or disease spread from an infected aquaculture facility could lead to a significant impact on wild targeted fisheries based around the same or alternate species.*

2. *That escaped fish could lead to a significant impact on the sustainability of wild stocks through either competitive interaction or genetic mixing.*

3. *That the introduction of marine pests could lead to a significant impact on habitat dynamics and alteration of ecosystem function at a regional scale.*

These risks were assessed with a consideration to their cumulative impact using the precautionary approach described in the methodology.

4.2 Risk Analysis Risk 1

4.2.1 Nature of Risk

> *That a significant pathogen or disease spread from an infected aquaculture facility could lead to a significant impact on wild targeted fisheries.*

In order to realise this risk, one or more of the hazard pathways identified in section 3 must result in the introduction of a potentially significant pathogen into the MWADZ. The pathogen present on the farm must then be exported from the facility at sufficient levels, and come into contact with susceptible wild stocks and successfully infect these susceptible stocks, resulting in disease occurrence. The resulting disease must have a significant impact on wild stocks of fisheries which they support. This risk assesses the material risk to stocks and does not cover potential consequent reputational loss.

4.2.2 Inherent Risk Analysis

4.2.2.1 Likelihood

There are a number of significant pathogens of the marine fish proposed for aquaculture in the MWADZ, including for YTK.

Diseases may potentially be introduced into sea-cage farms directly from the environment (e.g. as a result of transmission from wild fish), via sub-clinically infected stocked fish, via movement of personnel and infrastructure, via the use of untreated aquaculture feeds or via other vectors. Once introduced into an aquaculture facility, pathogens may persist, be transmitted between generations and potentially adapt to a state of virulence higher that that seen in the wild (where there may be no evolutionary advantage to kill a host) as a result of the selection pressures associated with intensive aquaculture. Spread of pathogens from aquaculture facilities could then occur via effluent, escapes, and/or predation. In the absence of biosecurity management controls, the inherent likelihood of a significant disease occurring at a marine aquaculture farm, being spread to wild stocks and having a significant impact on those stocks and associated fisheries is assessed as **Likely (4).**

4.2.2.2 Consequence

The consequence of this risk is assessed as **Moderate (2).** The severity of consequence is, in part, linked to the specific nature of the species and pathogen or disease under consideration. It is also linked to the relative abundance of farmed versus wild fish and opportunities for their interaction. This assessment reflects the fact that, while some major pathogens associated with marine finfish aquaculture may have a broad host range and be responsible for high levels of mortality in aquaculture, there is little evidence to suggest that they have had a significant impact on wild fish stocks. This is even the case for aquaculture in the northern hemisphere where, despite intensive studies on Atlantic salmon, the extent to which aquaculture exerts a negative influence on wild stocks remains contentious. While declines in wild fish stocks may be measurable, difficulties exist in determining the factors contributing to these declines which may be multifactorial. Marine finfish fisheries represent significant Western Australian fisheries in economic terms. They also have a high social value, supporting regional employment and communities as well as a strong recreational sector. Spread of a significant pathogen could ultimately impact a wide range of species and the fisheries and ecosystems which they support.

4.2.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 8 and therefore the **inherent risk level is Moderate**.

4.2.3 Residual Risk Analysis

4.2.3.1 Likelihood

There are a number of management measures in place that reduce the likelihood of one or more of the hazard pathways identified in section 3 leading to the introduction and spread of a significant pathogen or disease from an infected aquaculture facility and (in turn) leading to a demonstrated impact on wild fisheries.

It is in the interest of the State to support development of a sustainable aquaculture industry in the MWADZ through implementation of biosecurity control measures aimed at:

- preventing introduction and emergence of disease onto a farm;
- ensuring effective early detection and containment of significant pathogens; and
- preventing their release into the environment.

A summary of the proposed management measures associated with the MWADZ is detailed below:

Control Category	Management Control	DoF Control Mechanism
1. Preventing pathogen introduction and disease emergence	Sourcing of brood stock from within Australia.	• Translocation policy and translocation approvals.
	Effective quarantine and surveillance of brood stock for detection of known pathogen hazards.	• Protocols and Department-approved testing regimes. • Management and Environmental Monitoring Plan (MEMP) requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Regulation of permitted unpasteurised feeds for brood stock conditioning.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Controls over water intake to prevent introduction of pathogens into hatchery facilities.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
2. Early detection of disease issues	Timely recording and reporting of abnormal mortalities to the Department of Fisheries.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines). • Regulation 69 of the FRMR.
	Regular passive surveillance of stocks and investigation of cause of mortalities.	• MEMP requirements (under s.92A of the FRMA).

3. Preventing release of pathogen into the environment	Development of and adherence to technical standards governing sea-cage construction and operation (i.e. to reduce the likelihood of release of stock via escapes).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Facility and Departmental contingency plans to optimise containment in event of an incident.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Aquatic Biosecurity section Incident Management Protocol – at a broad generic level • Emergency powers to deal with biological threats (Part 16A of the FRMA)
	Development of emergency response and containment protocols.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Aquatic Biosecurity section Incident Management Protocol – at a broad generic level • Emergency powers to deal with biological threats (Part 16A of the FRMA)
	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).

Assuming both implementation of and compliance with these management measures, the residual likelihood associated with the proposal is assessed as **Unlikely (2)**. This is due to the establishment of controls over the major known pathways for introduction of pathogens onto farms and development of protocols to rapidly detect and control emerging disease issues.

4.2.3.2 Consequence

Residual Consequence remains unchanged at **Moderate (2)**.

4.2.3.3 Overall Residual Risk

The overall residual risk of a significant pathogen or disease spread from an infected aquaculture facility within proposed aquaculture zone leading to a significant impact on wild targeted fisheries is considered low and acceptable.

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 4 and therefore the **residual risk level is Low**.

4.3 Risk Analysis Risk 2

4.3.1 Nature of Risk

> *That escaped fish could lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing.*

In order to realise this risk, fish escaping either as larvae, juveniles or adults must survive in the wild and interact with wild fish of the same species causing significant impacts to wild fish populations either through competition for resources or by interbreeding.

4.3.2 Inherent Risk Analysis

4.3.2.1 Likelihood

While escapes associated with sea-cage based aquaculture are considered almost inevitable, significant advances have been made in understanding the cause of these escapes and thus developing improved management strategies aimed at limiting these occurrences. Given weather patterns in Western Australia, the relative exposure of offshore aquaculture operations in the MWADZ, and the biology of the species under consideration, the likelihood of escaped fish having an impact to sustainability of wild stocks is linked to the magnitude and frequency of escape events in addition to the size of fish escaping. Evidence exists to indicate that escaped yellowtail kingfish can survive in the wild (Fowler et al., 2003). Where such species are cultured within their natural range, the potential for interaction between wild and cultured fish may also be high as has been demonstrated in the Spencer Gulf of South Australia (Fowler et al., 2003). Fish escaping at larger sizes may have become adapted to aquaculture conditions and may hang around cages subsequent to release events or exhibit modified behaviours which may limit the likelihood of direct interaction with wild stocks. In support of this, Fowler et al. (2003) demonstrated that a population of fish in the northern Spencer Gulf region, identified as being of cultured origin, had apparently different opportunistic and reduced foraging behaviours compared to wild fish. While little direct evidence exists to suggest that escapes from the proposed MWADZ would have a significant genetic or competitive impact on sustainability of wild fish, likelihood is conservatively assessed as **Possible (3)**.

4.3.2.2 Consequence

Consequence is conservatively assessed as **Moderate (2)** with potential reductions to stocks that could approach levels estimated as approaching that associated with levels lower than 70% of unfished levels.

4.3.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 6 and therefore the **inherent risk level is Moderate**.

4.3.3 Residual Risk Analysis

4.3.3.1 Likelihood

Likelihood that escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing may be further reduced through introduction of measures aimed at reducing the frequency and magnitude of escape events.

The range of primary management measures aimed at further reducing this likelihood are detailed below:

Control Category	Management Control	DoF Control Mechanism
1. Preventing escapes	Development of and adherence to technical standards governing sea-cage construction and operation (i.e. to reduce the likelihood of release of stock via escapes).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Mandatory reporting of escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Mandatory technical investigations to determine cause of significant escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Mandatory training for staff in escape-critical operations.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Adherence to good-husbandry practice (e.g. removal of mortalities, predator controls).	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
	Reducing capacity for spawning of aquaculture stock.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
2. Promoting recapture	Development of and adherence to recapture protocols and emergency response procedures.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).

	Mandatory reporting of escapes.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
3. Reducing opportunity for interaction of stock escapees with wild fish	Siting of zone and farms in areas outside those of key habitats for cultured species.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
	Good-husbandry practice (e.g. limiting excess feed) to minimise attraction of wild fish to cages.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).
4. Reducing impact of potential interaction	Use of F1 generation brood stock sourced from a sufficient breeding nucleus of local stock.	• Translocation policy and translocation approvals. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA).

Likelihood of escapes leading to an impact on sustainability of wild stocks is also influenced by the degree of domestication of the aquaculture stock in question. Higher degrees of domestication and genetic selection in favour of properties considered conducive to aquaculture production (e.g. high growth rates) can lead to a stock which has significantly different genetic and phenotypic characteristics from its parent population. The likelihood of escapee fish impacting sustainability of local wild fish populations can be reduced by limiting the degree of genetic differentiation of the cultured stock from its wild fish siblings. This could be managed by maintaining a strategy of hatchery production of F1 generation stock based on locally-sourced brood stock. If marine finfish proposed for culture are all F1 generation, significant genetic selection is unlikely to have occurred and thus the potential for their escape and interaction with wild fish to lead to detrimental effects would be low.

Based on implementation of these measures, the residual likelihood of escaped fish leading to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing is considered to be **Unlikely (2)** under current proposed aquaculture scenarios.

4.3.3.2 Consequence

Consequence would remain unchanged as **Moderate (2)**.

4.3.3.3 Overall Residual Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 4 and therefore the **residual risk level is Low**.

4.4 Risk Analysis Risk 3

4.4.1 Nature of Risk

> *That the introduction of or spread of existing marine pests as a result of aquaculture activity associated with the MWADZ could lead to a significant impact on habitat dynamics and alteration of ecosystem function at a regional scale.*

In order to realise this risk, marine pests must either be present in the MWADZ region or be imported into the area as a direct result of aquaculture or other activities in the area. They must then become established on aquaculture infrastructure and/or in the wider environment which (in turn) leads to a significant and detrimental ecological impact.

4.4.2 Inherent Risk Analysis

4.4.2.1 Likelihood

Potential marine pests are known to be present in the region and thought to have been introduced into the State mostly as a result of anthropogenic activity involving international shipping. It is more likely that the MWADZ proposal might play a role in spreading pests already present in the State than be directly responsible for the import of new pest species.

In the absence of management controls governing biosecurity in the MWADZ, the likelihood of activities associated with the MWADZ contributing to the introduction or spread of marine pests that may lead to a significant impact to local ecosystems is assessed as **Possible (3)**. The infrastructure associated with marine farming will represent a new opportunity for the establishment of marine biofouling organisms. Associated vessel movements may present a vector for subsequent dispersal.

4.4.2.2 Consequence

The consequence of significant impact is assessed as **Major (3)** at the ecosystem level since habitat dynamics and ecosystem function are likely to be fundamentally altered by the presence of new species at potentially high levels of abundance.

4.4.2.3 Overall Inherent Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall inherent risk is 9 and therefore the **inherent risk level is High**.

4.4.3 Residual Risk Analysis

4.4.3.1 Likelihood

The likelihood of significant impact from marine pest species is dependent on the degree of biosecurity management associated with facilities within the MWADZ. Management controls that can mitigate potential effects include those detailed in table below:

Control Category	Management Control	DoF Control Mechanism
1. Measures to prevent introduction of marine pests from surrounding waters	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards. Regular cleaning of infrastructure (e.g. nets). Implementation of a supporting vessel-management regime.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
2. Measures to prevent introduction of marine pests in association with brood stock/ biological material	Sourcing of brood stock from within Western Australia. Regulation of permitted unpasteurized feeds for brood stock conditioning.	• Translocation policy and translocation approval. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
3. Measures to prevent introduction of marine pests with personnel/ equipment/ vessels	Adherence to good-husbandry practices to maintain high on-farm health and biosecurity standards. Development of specific industry cleaning protocols for any materials introduced from outside the region.	• Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines).
4. Measures to prevent establishment of marine pests resulting from aquaculture activity and consequential ecological impact	Development of and compliance with a regular biosecurity monitoring regime for the MWADZ. Compulsory reporting of suspect pests by MWADZ operators. Industry/Departmental biosecurity incident response processes and capacity. Translocation control of species cultured within the MWADZ.	• Translocation policy and translocation approval. • Aquaculture Licence conditions (under s.95 of the FRMA). • MEMP requirements (under s.92A of the FRMA). • Biosecurity management arrangements (under FRMA legislation and associated policy guidelines). • Monitoring for invasive marine species (e.g. Early-Warning System checks) • Zone-specific incident response plans • Emergency powers to deal with biological threats (Part 16A of the FRMA) • Protocols and Department-approved testing regimes.

Based on implementation of these control measures, the residual likelihood of aquaculture operations introducing and/or spreading marine pests resulting in a significant impact to regional habitats and ecosystems is considered **Unlikely (2)** under current aquaculture scenarios.

4.4.3.2 Consequence

Residual consequence remains unchanged at **Major (3)**.

4.4.3.3 Overall Residual Risk

Using Table 1c, the Hazard/Risk Score (C x L) for the overall residual risk is 6 and therefore the **residual risk level is Moderate**.

5. Summary

Key overall risks identified in association with the proposal to develop marine finfish aquaculture in the MWADZ were identified as follows:

1. *That a significant pathogen or disease is spread from an infected aquaculture facility leading to a significant impact on wild target fisheries based around the same or alternate species.*

2. *That escaped fish lead to a significant impact on the future sustainability of wild stocks through either competitive interaction or genetic mixing.*

3. *That the introduction and/or spread of marine pests in association with aquaculture activity have a significant impact on the sustainability of local ecosystems.*

Critical pathways that could collectively lead to realisation of these risks were identified (hazards) and reviewed systematically. Considering the biosecurity measures associated with development of the MWADZ to address these hazards, the residual risk of identified overarching risks for risks 1-3 was assessed as **Low**, **Low** and **Moderate**, respectively. Low-moderate risks suggest that current or planned risk control measures are adequate in reducing levels of identified risk to acceptable levels.

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