STAGE 1: Additional information on multi-criteria decision analysis

Multi-criteria analysis (MCA) or multi-criteria decision analysis (MCDA) is a widely used approach to support decision-making. Examples of applications include environmental management, renewable energy, land use and infrastructure planning, manufacturing, and industrial practices. Geospatial applications of MCA/MCDA specifically address spatial problems, such as site suitability and network planning, by combining spatial data layers.

MCDA aims to solve a problem – or support decision-making – by building a decision model with a defined set of criteria, each of these criteria being given a relative weight. A null model of relative weights (simplest approach) is to equally weigh all criteria. If one or more variables are thought to be more influential on the outcome of interest, they can be given more weight relative to others. Criteria and associated weights can be elicited from an expert understanding of the system under study, often together with the primary scientific literature.

In this study, the biophysical suitability of the surrounding environment to host finfish aquaculture (hereby referred to as 'biophysical suitability') was determined using a multi-criteria analysis (suitability analysis). It is important to stress this generates a baseline understanding of the potential placement for finfish aquaculture to primarily rule out areas where activities are unlikely to occur based on biophysical characteristics alone.

Two research questions underpinning this analysis are:

What environmental variables can be used to determine biophysical suitability?

If one or more variables are more influential in determining biophysical suitability, what relative weights can be given to these variables?

The set of criteria to determine biophysical suitability was based on the primary scientific literature and an expert understanding of finfish aquaculture operations elicited with industry consultation (practitioners) (**Table 1**). Constraints on criteria indicated good (and best/optimal) environmental conditions, such as physiological tolerance of the cultivated species, resilience of infrastructure to be potentially deployed in dynamic marine environments and identified constraints to operations based on the potential for detrimental environmental impacts, for example situated directly over rocky reefs under Tasmanian regulations.

Typically, each criterion is expressed with specific units and scale, for example temperature in degrees Celsius and water depth in meters. To harmonize the scale among criteria, each criterion is translated to a categorial scale ranging from of 1 to 9, with each class being associated with a subset of conditions and 0 being unsuitable conditions (if defined).

In this study, varying relative weights were given to each criterion. Both the scale and associated weights were primarily based on expert (industry) consultation identifying the (relatively) more important factors impacting the feasibility of operations for finfish aquaculture in the future.

Both the set of criteria and associated weights were based on the *Pilot Marine Spatial Assessment Tool* (Ross et al., 2020). The weights were adjusted in this exercise because full coverage of substrate type over the study area was not available. The research team met with representatives from Tassal, Huon Aquaculture and Petuna in November 2020 to discuss the variables and weights used in Ross et al., (2020). From this consultation, weights were slightly modified to better represent statewide operational biophysical suitability for finfish aquaculture.

Example of calculation of biophysical suitability:
0.30 x [class of 5 for water temperature] +
0.15 x [class of 3 for water depth] +
0.25 x [class of 7 for current velocity] +
0.30 x [class of 7 for significant wave height] =
biophysical suitability score of 5.8

In addition to this score, if an area met any of the conditions to be unsuitable, then the overall biophysical suitability was set to '0' (unsuitable), regardless of the scores of other variables.

Relevant data was collated on all criteria. The spatiotemporal resolution of data differed among criteria based on data availability to ensure full coverage of the study area. However, in the case of substrate type (presence of reefs), only mapped areas were available, generally restricted to 1.5 kilometres from shore, or the 40-metres depth contour, whichever is closest to shore.

STAGE 1: Additional information on multi-criteria decision analysis

Table 1. Biophysical suitability classification for future finfish aquaculture operations. (Table 2 in report)

		Biophysical suitability classification					
		Unsuitable	*Less suitable*				*More suitable*
		0	**1**	**3**	**5**	**7**	**9**
Biophysical suitability variables	Water temperature (°C) *Average summer temperature at 5m below the surface in January and February 2015-16*	>22	21-22	20-21	19-20	18-19	<18
	Water depth (m)	--	--	10-15	15-25	25-40	>40
	Current speed (m/s) *Average summer current speed at 5m below the surface in January and February 2015-16*	<0.01	0.01-0.02	0.02-0.04	0.04-0.08	0.08-0.2	>0.2
	Substrate type	Presence of reef	--	--	--	--	--
	Significant wave height (m) *Maximum monthly significant wave height between 2010 and 2020*	>11	9-11	7-9	5-7	3-5	<3

Geospatial biophysical suitability was computed on a pre-defined grid of horizontal units, either at a horizontal resolution of 1 kilometre (Stage 1 statewide and Stage 2 north coast of Tasmania only) or 500 metres (Stage 2 southeast of Tasmania only). The resolution varied due to the extent of the study area and the resolution of the available data. The higher resolution in the southeast was made possible by the CSIRO Storm Bay hydrodynamic model in this region (model run tasseH1p2; Wild-Allen et al., 2021). Spatial data layers were then collated and for each grid cell, a score of biophysical suitability was computed. The full coverage (surface) of the resulting biophysical suitability was the outcome of this analysis.

Outputs of the MCDA (biophysical suitability analysis) were used in this study to:

1. Identify regions where more detailed investigations were undertaken in Stage 2 by ruling out areas where finfish aquaculture is unlikely to occur, for example, where water is too warm, or where the ocean may be too dynamic (inserted as wave height) even with current and upcoming marine engineering innovations.;

2. Form the basis of some of the zones derived in the software Marxan with Zones when implementing hypothetical scenarios. More details on Marxan with Zones are provided in the next section.

STAGE 2: Additional information on methods used in the software Marxan with Zones

Objectives and software zones

The overall goals, related spatial data sets, and final scenario targets were set under the advice and review of the Advisory Committee iteratively through a series of meetings. The objective of the project was to carry out a sector-based spatial planning exercise to investigate potential sustainable growth opportunities for finfish aquaculture in Tasmania. As such it was determined that two spatial zones implemented in the software Marxan with Zones were appropriate for this exercise: finfish aquaculture and other uses. Other uses were not further broken down into specific activities in this exercise. Through exploration of the data and scoping analyses it was determined that more informative outputs could be derived by further dividing biophysical suitability in separate classes (as ranges of scores). This was meant to account for the underlying spatial variability of the datasets representing other uses included in the analysis. Thus, the final Marxan zones used were: finfish aquaculture ('very high', 'high' and 'medium' biophysical suitability), and all other uses.

Software horizontal unit definition

Marxan with Zones requires the definition of spatial units within which to summarize all features. For this exercise we term these 'horizontal units'. A uniform grid for each study region was created for our horizontal units. The resolution of horizontal units was based on the resolution of data inputs, including the output of the biophysical suitability analysis (conducted in Stage 1). A 500-m grid was used in the southeast of Tasmania and a 1-km grid was used in the north coast of Tasmania.

Datasets used to represent other marine uses

In line with the overall objective of the project – to carry out a sector-based spatial planning exercise to investigate potential sustainable growth opportunities for finfish aquaculture in Tasmania – we compiled available datasets to represent other marine uses in Tasmania that could interact with finfish aquaculture (**Table 2, Table 3**). This broadly represented economic activities, surrogates for social values such as boat ramps (as recreational use), residential dwellings, mapped high human use value areas, and areas of high ecological value (e.g., geoconservation sites and mapped high biological value areas). The suite of datasets was similar between study areas (southeast and north coast of Tasmania), but did differ depending on identified values, data availability and geographic context and extent of each study area. A full description of these values and associated sources of data are detailed in the report.

Software zone costs

We explored possible cost metrics to include as part the analysis. In the software Marxan with Zones, cost metrics are used to explicitly integrate opportunity costs to other sectors when choosing a given sector. For example, in the case of assigning a finfish aquaculture Marxan zone in this study, including a cost metric based upon commercial fisheries catch per unit effort would align with standard practice formulations within the software as the choice to have an aquaculture site may result in opportunity costs for other commercial sectors. While ideally the costs for each Marxan zone would be set relevant to the actual costs of that activity, the resolution of available datasets in this study is generally coarse and not with sufficient details warranting their inclusion as a cost layer in the software Marxan with Zones. For example, catch for (non-reef) commercial fisheries is reported at sub-blocks level, which inherently does not match the resolution of other datasets which were more broadly aligned with the grid of horizontal units. As a result, we chose to use horizontal unit area as the cost measure with the underlying assumption that such costs are spatially homogenous. If relevant fine scale detailed data becomes available, we would recommend consideration of further definition of cost layers for inclusion.

STAGE 2: Additional information on methods used in the software Marxan with Zones

Defining hypothetical scenarios in Marxan with Zones

Four hypothetical Marxan with Zones scenarios were set under the guidance an-review of the Advisory Committee in each study area of Stage 2: the southeast and north coast of Tasmania. Details on scenarios are provided in the report in Box 5 (southeast; page 31) and Box 6 (north coast; page 51). Scenarios were defined to vary those features that appeared to have greatest spatial variability as well as high value for multiple marine uses – namely buffered areas around rocky reefs, buffered areas around boat ramps, and non-reef commercial fisheries. Broadly, targets were set as high as possible while minimizing trade-offs across Marxan zones to reflect the goal of maximising values for all uses in the region. Initial targets were set with the Advisory Committee adhering to this principle and then further refined as Marxan with Zones was calibrated. Where targets varied, this is noted in the figure captions of each Marxan scenario outputs in the report.

To determine sensitivity of spatial solutions among hypothetical scenarios to changes in data and quantitative targets, and illustrate trade-offs, a synthesis of all four hypothetical scenarios was created for each study area. This synthesis indicates consistent assignment of any one horizontal unit to either the finfish aquaculture Marxan zones or other uses zone across the four hypothetical scenarios. Alternatively, areas where assignment varied among scenarios were included as 'uncertain areas' where specific choices made on targets and trade-offs influence outcomes.

STAGE 2: Additional information on methods used in the software Marxan with Zones

Table 2. Qualitative objectives and quantitative targets (%) used in the four scenarios implemented in the software Marxan with Zones (detailed in **Box 5** in the report) for the southeast of Tasmania (Table 4 in report).

Marxan Zones	Data	Qualitative objectives	Quantitative targets			
			Scenario 1 'Baseline'	Scenario 2 'Commercial fishing'	Scenario 3 'Recreation and conservation'	Scenario 4 'All other marine uses'
Finfish aquaculture ry high biophysical suitability)	Finfish aquaculture biophysical suitability (Stage 1)	Develop finfish aquaculture in biophysically suitable areas	Initial target: 60% of both very high biophysical suitability (score > 7) and high biophysical suitability (score between 6 and 7) Actual proportion of area assigned to finfish aquaculture varied during analyses between 50 and 85% depending on quantitative targets of other uses being met. Actual targets reached are inserted in captions of Figures 16-19.			
Finfish aquaculture high biophysical suitability)						
Other uses	Rocky reefs	Decrease the possibility of detrimental impacts to rocky reefs as habitat of significant commercial, recreational and conservation value	90%: 2-km buffered area around the Actaeon/Friars and 1-km buffered area around all other reefs	90%: 5-km buffered area around the Actaeon/Friars and 500-m buffered area around all other reefs	90%: 2-km buffered area around the Actaeon/Friars and 1-km buffered area around all other reefs	90%: 5-km buffered area around the Actaeon/Friars and 1-km buffered area around all other reefs
	Commercial (non-reef) scalefish – Derwent Estuary area	Maintain existing commercial fisheries	100% of area			
	Commercial (non-reef) scalefish – Tiger Flathead area	Maintain existing commercial fisheries	Not included	60% of area	Not included	60% of area
	Distance from coastal access points (boat ramps)	Maintain recreational marine areas (e.g., boating, fishing, diving)	90% of 1-km buffered area around boat ramps		90% :10-km (travel) buffered area around high-use boat ramps and 1-km buffered area around all other boat ramps	
	High navigation density	Maintain existing navigation channels for safe navigation by all marine users	100% of existing areas of high-density navigation			
	Registered moorings and popular anchorages	Maintain existing moorings and popular anchorage areas	90% of 1-km buffered area around registered moorings and popular anchorages			
	Distance to residential dwellings	Minimise noise and light pollution to residents	90% of 1-km buffered area around residential dwellings located within 1 km of the coast			
	Distance to high human use value area along the foreshore	Maintain identified high human use value areas	90%: 2-km buffered area around high human use foreshore areas			
	Existing (marine) geoconservation sites	Conserve environmentally significant areas	100% of (marine) geoconservation sites			
	Distance to high biological value areas along the foreshore	Decrease the possibility of detrimental impacts to environmentally significant areas	90% of 1-km buffered area around high biological value foreshore areas			

STAGE 2: Additional information on methods used in the software Marxan with Zones

Table 3. Qualitative objectives and quantitative targets (%) used in the four scenarios implemented in the software Marxan with Zones (detailed in **Box 6** in the report) for the north coast of Tasmania (Table 6 in report).

Marxan Zones	Data	Qualitative objectives	Quantitative targets			
			Scenario 1 'Baseline'	Scenario 2 'Recreation and commercial fishing (both high)'	Scenario 3 'Recreation and commercial fishing (both moderate)'	Scenario 4 'Moderate recreation and high commercial fishing'
Finfish aquaculture (high biophysical suitability) Finfish aquaculture (medium biophysical suitability)	Finfish aquaculture biophysical suitability (Stage 1)	Develop finfish aquaculture in biophysically suitable areas	Initial target: 65% of both high biophysical suitability (score between 6 and 7) and medium biophysical suitability (score between 5 and 6) Unlike the study area in the southeast of Tasmania, this target was reached in most scenarios (with some exceptions), which indicated a proper threshold for optimizing the potential for finfish aquaculture against other uses.			
Other uses	Rocky reefs	Decrease the possibility of detrimental impacts to rocky reefs as habitat of significant commercial, recreational and conservation value	90%: 1-km buffered area around identified reefs			
	Commercial fisheries (southern rock lobster and abalone)	Maintain existing commercial fisheries	80% of identified areas			
	Commercial fisheries: Other (non-reef scalefish and northwest area)	Maintain existing commercial fisheries	60% of identified areas	80% of identified areas	70% of identified areas	80% of identified areas
	Distance from boat ramps	Maintain recreational marine areas (boating, fishing, diving, etc)	90%: 1-km buffered area around all boat ramps	90%: 10-km buffered area around popular boat ramps and 1-km buffered area around other boat ramps	90%: 10-km buffered area around popular boat ramps and 1-km buffered area around other boat ramps (within 1 nautical mile from the shore)	
	Navigation: High navigation density corridor and marine infrastructure (cables/pipelines)	Maintain existing navigation channels for safe navigation by all marine users and protection of existing cables and pipelines	100% of identified areas			
	Moorings and anchorages buffer	Maintain moorings and anchorage areas	90%: 1-km buffered area			
	Distance to residential dwellings	Minimise noise and light pollution to residents	90%: 1-km buffered area			
	Distance to high human use value areas along the foreshore	Maintain high human use value areas	90%: 2-km buffered area			
	Distance to high natural value areas along the foreshore	Decrease the possibility of detrimental impacts to environmentally significant areas	90%: 1-km buffered area			

References

Ross J, Adams V, Villanueva C, Bush F (2020) Pilot Marine Spatial Assessment Tool - Evaluating options for assessing and balancing marine use change within Tasmanian coastal waters using a spatial assessment tool. Institute for Marine and Antarctic Studies, Hobart, Tasmania

Wild-Allen K, Andrewartha J, Baird M, Beardsley J, Bodrossy L, Eriksen R, Gregor R, Griffin D, Herzfeld M, Hughes D, Langlais C, Margvelashvili N, Martini A, Revill A, Rizwi F, Skerratt J, Schwanger C, Sherrin K, Frydman S, Wild D. (2021) Storm Bay Biogeochemical Modelling and Information System. FRDC 2017-215 Technical Milestone Report February 2021. CSIRO Oceans & Atmosphere, Hobart.

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