Journal of Coastal Research	SI 39	79 - 84	ICS 2004 (Proceedings)	Brazil	ISSN 0749-0208

Towards the Development of Regional Environmental Monitoring Systems to Ensure Sustainable Development of the Aquaculture Industry

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ABSTRACT

CHESHIRE, A.C. 2006. Towards the development of regional environmental monitoring systems to ensure sustainable development of the aquaculture industry. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), 79 - 84. Itajaí, SC, Brazil, ISSN 0749-0208.

Aquaculture is a rapidly growing industry that has the potential to provide significant economic benefit but also to cause substantial environmental harm. In general, monitoring programs have focused at the scale of individual farms and do not address issues associated with off-site or regional scale effects of aquaculture. The establishment of Regional Environmental Sustainability Assessments (RESA's) as a core component of environmental monitoring systems will ensure the ecological sustainability of aquaculture industries. RESA's are underpinned by risk assessments, which aim to identify the major environmental risks, associated with any given farming venture. Environmental risks may include on-site or off-site impacts caused directly by the farming venture but also indirect or flow-on effects to ecosystems. Risk assessments depend upon an assessment of both the likelihood and consequence of given risk events. In particular, assessments of the consequences of environmental impacts need to consider the spatial scale, temporal scale and conservation status of impacted habitats or species. IUCN redlist criteria can be useful in assessing consequences of impacts. Appropriate use of this system will increase confidence for industry, government and the community through the establishment of appropriate sets of operating guidelines for the industry.

ADDITIONAL INDEX WORDS: *Environmental sustainability, risk assessment, IUCN redlist.*

INTRODUCTION

Aquaculture now accounts for around 32% of global fish production with a GVP of around US$41 billion annually. Over the last decade farmed tonnages have grown at a compounding rate of close to 12% per annum (FAO, 2003). In large part this production has addressed the increasing demand for fisheries products that cannot be met from wild fisheries production (KEARNEY *et al.*, 2003) which has been relatively stable since the late 1980's (although if figures from China, Chile and Peru are excluded then wild fisheries production in the rest of the world has been declining) (KEARNEY *et al.*, 2003). Arguably, capture fisheries in many parts of the world are either fully or over exploited and this represents a major risk to the environmental health of coastal and ocean systems (FAO, 2003). Aquaculture is seen therefore, as a means of increasing the production of fisheries products and, given current rates of increase, it is expected that aquaculture production will equal the wild catch production by 2025.

There are however, growing concerns about the environmental effects of aquaculture (e.g. GOWEN and BRADBURY, 1987, FRID and MERCER, 1989, GOWEN *et al.*, 1994) and it needs to be understood that these effects have the capacity to impact on both the economic viability and the environmental sustainability of the industry.

This paper aims to discuss strategies to improve the environmental management of aquaculture through better targeting of monitoring and assessment programs. The paper illustrates many of the issues through examples taken from the farming of southern bluefin tuna (SBT, Thunnus maccoyii) in South Australia. However, the strategies discussed are generic and can be applied very broadly in support of the sustainable development of the aquaculture industry worldwide. In particular, the aim is to outline an approach to environmental monitoring and assessment that will help to ensure that aquaculture is developed in an ecologically sustainable manner.

CASE STUDY ON THE AQUACULTURE OF SOUTHERN BLUEFIN TUNA

The farming of southern bluefin tuna (Thunnus maccoyii) in Port Lincoln (South Australia) provides a good case study for the consideration of both the environmental consequences of farming and the use of a risk assessment framework in the development of monitoring and management programs. Southern bluefin tuna (SBT) were first farmed at Pt Lincoln in the early 1990's using sea-cage technologies similar to those developed for salmonid species. Since that time, the industry has expanded rapidly to be worth around Aud$300 million in 2001/2002 (Figure 1). It is now the largest aquaculture industry (by value) in Australia. Concomitant with this growth in the industry there have been substantial developments in farming systems including, since 1996/1997, the move to off-shore farming.

Farming is based on a wild-catch industry where fish are captured in waters from the Great Australian Bight and then transferred to grow out cages off Port Lincoln in South Australia. Fish are typically caught at a size of 20 kg and fed on a range of bait fish (including pilchards and herring) or in some cases manufactured pellets. Fish are then harvested from the cages at a weight of around 40 kg.

Rapid growth in farming volumes (Figure 1) has presented substantial management challenges to both government and industry in the development of an appropriate regulatory and legislative framework. The lack of knowledge about the

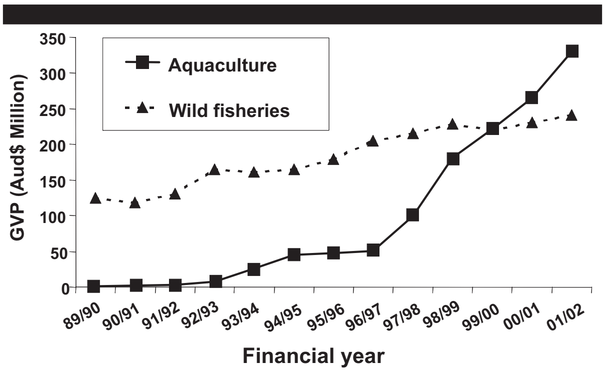

Figure 1. Changes in the value of production of the aquaculture industry in South Australia compared with the value of the wild fishery sector over the same period. Rapid increases in the size of the aquaculture industry have created major challenges for both farmers and regulators over the last 10 years.

environmental consequences of farming has also exposed industry to substantial risks both to their ongoing growth and profitability. Indeed, the move to offshore farming in 1996/1997 was largely driven by a major mortality event in 1996 with losses of around Aud$60 million (over a 3 day period). This mortality was attributed to the stirring up of bottom sediments during a severe storm and resulted in substantial debate about the extent to which farms were self-polluting.

In the year 2000 two major initiatives in support of the industry came to fruition these being the passing of the Aquaculture Act in South Australia and the establishment of the Cooperative Research Centre for Sustainable Finfish Aquaculture that was approved by the Australian Federal Government. Aquafin has provided a framework for industry and government researchers to undertake a comprehensive series of research programs including a number that have been designed to address the lack of knowledge about the environmental effects of tuna aquaculture.

ENVIRONMENTAL EFFECTS OF AQUACULTURE

Aquaculture systems vary substantially both in terms of volumes of production and the nature of the farming systems and the environmental impacts vary accordingly. This paper focuses on at sea, industrial scale production systems (as distinct from land based or subsistence based systems). In terms of at sea farming, two forms of aquaculture can be defined:

1. Additive farming depends upon the provision of feeds to animals in order to support growth (e.g. tuna farming where fish are fed either pelleted feeds or bait fish)
2. Extractive farming is dependant upon the extraction of materials from the environment. This includes most bivalve farming in which production is dependant upon organic material in the water flowing through the lease area (e.g. oyster farming which depends upon the natural growth of phytoplankton and other forms of particulate organic material to provide food).

By and large, a greater number of environmental problems have been attributed to additive aquaculture systems, where substantial inputs of food are made that contribute to the overall organic loading to the ecosystem. Environmental monitoring systems need to address the fundamental differences in the sorts of impacts that may arise from these different approaches to farming.

Aquaculture has the potential to impact on the environment in a variety of ways. In broad terms these impacts can be defined as on-site and off-site effects. On-site effects relate to impacts within the area designated for farming activities. Off-site effects relate to impacts on surrounding areas, which have not been designated for farming activities.

On-site Effects

These effects are generally considered to be the known or accepted effects of aquaculture that need to be managed as a part of the production process. On-site effects are typically of concern to the aquaculturalist in that they are likely to impact on fish health and production levels thereby impacting directly on the risk profile and potentially on the profitability of the industry. In general terms however, these direct effects are of little concern to the general community in that they are restricted to the physical location where the industry operates and by definition do not extend to surrounding waters.

On-site effects include changes in the nature of the environment within lease sites associated with:

- Physical processes where structures such as cages, nets or rope lines may affect the seabed by physically sweeping the area, interrupting water flow or changing the light environment.
- Accumulation of wastes from uneaten food, faecal material and fouling organisms that will cause changes in both the physico-chemistry of the seabed and the nature of biological processes.
- Changes in water quality including oxygen depletion, elevated levels of inorganic nutrients, introduction of chemicals or discharge of blood and oils associated with the feeding or killing process all of which contribute to declines in water quality.

Off-site Impacts

Off-site (or far-field) impacts are defined as those effects that extend beyond the boundaries of the area allocated for aquaculture and thereby impact across a broader extent of the marine environment. These impacts may include all of those identified above as on-site effects, where the spatial extent of the impact extends into surrounding areas, but also a series of additional impacts including:

- Chemical pollution where pharmaceutical agents or similar compounds are released into the water and may impact on non-target species,
- Algal blooms resulting from elevated nutrient levels including both phytoplankton and benthic algae,
- Marine animal interactions where animals with large spatial ranges (seals, dolphins, sharks, whales, birds, etc) are entangled or otherwise impacted as a consequence of the farming operation,
- Disease transmission where diseases of the farmed stock are transmitted to wild stocks,
- Wild escapes where selectively bred, genetically modified or introduced exotic species escape from farms and thereby act to interbreed with, or displace, native animals

ENVIRONMENTAL MONITORING PROGRAMS

Environmental monitoring programs aim to understand the extent to which these various effects cause impacts to the environment. To date the principle focus of environmental monitoring in most countries has been on the direct effects of aquaculture. In South Australia, for example, this comprises an assessment of the impacts from individual farming ventures. Compliance with regulatory arrangements, mangaged through licensing, is generally inferred from measurements of water quality or assessed directly using macrobenthic infauna as the key index of environmental health. The focus on individual leaseholders is to enable the identification and if necessary prosecution of non-compliant operators. At one level, this may not be unreasonable in that it is these effects (which may ultimately impact on production and fish health) that are clearly of concern to industry who, more often than not, fund the monitoring programs. As a consequence, however, there have been few attempts to assess the broader scale impacts and this has resulted in significant criticism of government. Community groups have argued effectively that environmental monitoring is only directed to ensuring production and economic development, and as such fails to address the community concerns in relation to the sustainable use of our marine environmental assets.

In part this criticism is unfair as it fails to recognize that the development of our understanding needs to progress from an assessment of direct effects through to the consideration of the much more complex issue of indirect effects. Not withstanding, the assessment of indirect impacts is essential if we are to ensure equitable use of the marine environment and its resources.

Other than the need to broaden the base of environmental monitoring (and management) the other major challenge is to recognize that there are many uncertainties in relation to both our knowledge about the system and its likely response to management interventions. Management of uncertainty is therefore one of the greatest challenges facing regulators, but this is often complicated because regulators tend to believe that they need to portray an image of being in control (of both the relevant knowledge and its application in a management context). The reality for most environmental managers is that environments change (through time and space). Ecosystems evolve and absolutes become increasingly less relevant; there is a need therefore, to adopt an adaptive approach to management that simultaneously addresses the inadequacies of our knowledge and the changes in the systems that we are working with. Sources of uncertainty include:

- Lack of knowledge about the assimilative capacity of the marine environment and therefore its ability to cope with impacts from various sorts of aquaculture.
- Lack of knowledge about the way impacts will manifest themselves. For example, the introduction of exotic species of micro-algae (such as Physteria) may profoundly change the risk of algal blooms associated with any given level of nutrients. Such a change would result in subsequent changes in the risk profile for industry and may require a fundamental reassessment of management approaches and environmental standards.
- Our lack of knowledge about the biology and ecology of higher level predators (such as marine mammals and large sharks) makes it difficult to predict how aquaculture may affect either the behaviour of these animals (eg frequency of approach to humans) or the conservation status of populations.

Any environmental monitoring program therefore needs to be able to report on the extent to which an activity (in this context a farm or collection of farms) is having an impact on the broader environment. In so doing, environmental monitoring programs should have a substantial focus on the off-site effects, because it is these "unintended" consequences of the activity, which are most likely to impact adversely on other uses of the marine environment (i.e. need to be managed in a planning context) or on the biodiversity and conservation of marine life in general.

These assessments need to be conducted at both local (on-site) and regional (off-site) scales in order to provide the information necessary to effectively manage the risks. Such assessments also need to be able to provide information which can be used to modify management practices at either the site level or at the regional level (e.g. feed types, rates of use of drugs, timing of stocking and de-stocking, total stocking densities, distances between cages, species mix, approved feeds and chemical agents).

Use of an ESD framework for monitoring and management of Aquaculture

The development of regional scale environmental monitoring programs can be controversial in that they have the capacity to substantially change the cost structure for industry and require government to manage a much more complex set of regulatory arrangements. There is a need therefore, to adopt a strategy that allows stakeholders (industry, government and the community) to assess and prioritize environmental risks from aquaculture. In turn, this will focus research and management efforts around real threats to the environment and ensure both the relevance and cost-effectiveness of monitoring programs.

Throughout the last 6 years, there has been a major focus in Australia on ensuring the sustainability of fishing and aquaculture industries. This work has culminated in the development of a risk assessment framework that aims to direct monitoring and management effort to processes which are perceived as presenting the highest risks to sustainability of the industry (FLETCHER *et al.*, 2003).

The framework operates through a program involving all stakeholders and aims to:

1. Develop a list of the key environmental issues associated with any given aquaculture sector.
2. Prioritize these issues using a formal risk assessment process.
3. For the high priority issues, identify quantitative indices that provide a basis for performance assessment.
4. Develop methods for the measurement of these indices.
5. Agree a reporting timeframe against which assessments will be undertaken.

Component trees

The process begins by developing a series of "component trees" that collectively identify the range of issues that need to be considered through the risk assessment process (FLETCHER *et al.*, 2003). Eight broad sub-headings are considered under the three main headings included in Figure 2. Under each of these sub-headings a detailed component tree can be developed that aims to document stakeholder concerns (e.g. Figure 3). At this stage of the process, there is no attempt to screen or limit the issues that are put up for consideration.

The example given in Figure 3 is very much abbreviated. Not withstanding, it illustrates the way in which issues can be identified and detailed through the development of the component trees. In this example, the consideration of issues in relation to the ecological well-being of non-farmed species aims to identify threats, from the farming process, on other species in the environment. The first sub-division identifies threats to species that directly interact with farming systems as distinct from those that are impacted via flow on effects of farming.

Direct effects: Early in the history of farming southern bluefin tuna, a number of great white sharks (Carcharadon charcharias) were trapped in predator nets that were draped around the cages. These large-mesh nets were intended to keep sharks away from the inner cage-nets and although they achieved this aim, there was a high mortality rate, not only for sharks but also for dolphins, which became entangled in the predator net. The industry subsequently stopped using the predator nets, which has substantially reduced incidental mortalities, but there are now instances where sharks become trapped inside the cages by biting through the cage-nets. Generally, these sharks have been destroyed to prevent them killing the farmed fish and to allow divers to enter the water and repair the net. This destruction of the sharks is seen as problematical because the great white shark is a protected species (ENVIRONMENT AUSTRALIA, 2002) in Australia.

Indirect effects: A different form of interaction is seen in the case of the predation by silver gulls on the chicks of other native species that nest on islands close to the tuna-farming zone. Gulls are known to scavenge on pilchards and other foods that are fed to the tuna and this results in a substantial increase in food availability to gulls. In turn, this increase in food is believed to have resulted in a substantial increase in gull numbers. However, this food is only available during the farming season (early summer through to late winter). During

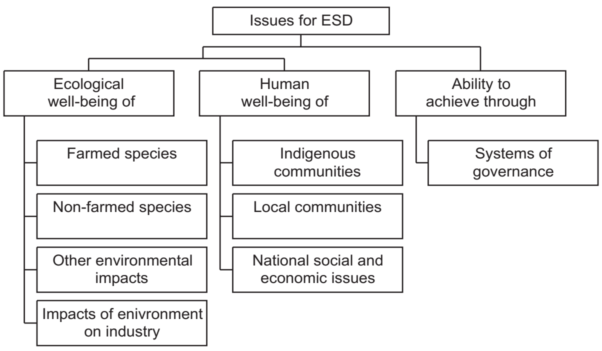

Figure 2. Major areas to be addressed in the identification of potential risks from aquaculture (after FLETCHER *et al.*, 2003).

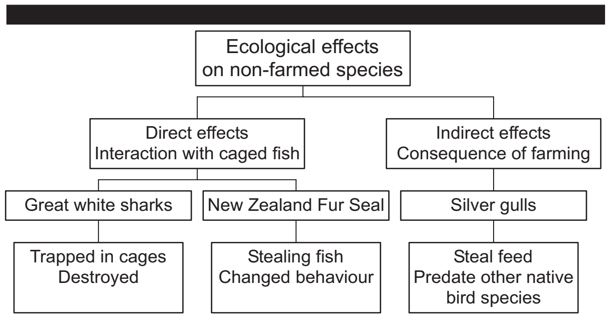

Figure 3. An example of an assessment of the potential risks to ecological well-being of non-farmed species.

Table 1. *Matrix of risk scores given assessments of likelihood of an event by the consequences (assuming the event occurs). Four risk categories are defined high (dark shading), moderate (medium shading), low (light shading), negligible (no shading) (modified from* FLETCHER *et al., 2003).*

Likelihood		Consequences					
		Neg-ligible	Minor	Mod-erate	Severe	Major	Catas-trophic
		0	1	2	4	6	8
Likely	6	0	6	12	24	36	48
Occasional	5	0	5	10	20	30	40
Possible	4	0	4	8	16	24	32
Unlikely	3	0	3	6	12	18	24
Rare	2	0	2	4	8	12	16
Remote	1	0	1	2	4	6	8

spring, when other bird species nest on adjacent islands, the gulls are unable to obtain food by scavenging from aquaculture farms. It is believed that the gulls then transfer their attention to these nesting birds and that the elevated gull numbers results in a greater level of predation on eggs and chicks of other species (the extent of this problem is currently being evaluated through an honours program by Ms Shelly Harrison at Flinders University in South Australia).

Risk Assessment

Once the issues have been identified (through the preparation of the component tree) there is a need to undertake an analysis of the risk presented by each of the components (FLETCHER *et al*., 2003). This risk assessment is performed using a generic algorithm for risk, which is defined as the product of the probability of the risk event occurring (on a scale of 0-6) and the consequence if the event does occur (on a scale of 0-8).

RISK = [PROBABILITY OF EVENT] x [CONSEQUENCE]

This process leads to the production of a risk score (Table 1), which can then be used to define the priorities for monitoring and management programs. In general, the risks of an event are broken into four categories:

1. High risk (score 20-48) where the risk is seen as requiring immediate attention,
2. Moderate risk (score 8-18) - risks are considered to be acceptable as long as a plan is in place to reduce risks into the future, Low risk (score 1-6) - where the risks are considered to be broadly acceptable given the current management practices,
3. Negligible risk (score 0)- where no action is required.

Once this process of risk assessment has been completed, then monitoring programs can be developed. These programs should be focussed on addressing the issues identified as presenting a high or medium risk with resources allocated proportionately.

Quantitatively Defining Likelihood and Consequence Scores

As with most risk assessment processes the challenge in applying this system is in quantifying the likelihood and consequence scores. In broad terms a consistent system for quantifying likelihood can be developed based on past history. We know, for example, that across the entire industry sector white sharks are trapped in tuna cages once or twice per year so we would score this as "occasional" (likelihood = 5). Similarly, we know that gulls constantly scavenge waste feed from farms although at this stage we only have hearsay evidence that this leads to elevated levels of predation on eggs and chicks of other species. Until proven otherwise, the precautionary principle would lead us to assume that this predation is occurring and we would score this as "likely" (likelihood = 6). In so doing there needs to be some consideration as to whether or not there are reasonable preventative measures that can or are being utilised. In such cases, this may well change the likelihood score. In the case of gull scavenging, industry variously adopts a number of control measures including nets over cages and the use of blocks of frozen pilchards (which thaw in-situ releasing the pilchards underwater) both of which substantially inhibit the capacity for gulls to scavenge the food (Harrison, pers. comm.). In such cases, the likelihood should be estimated based on the assessment given the controls that are currently in place, rather than based on an assessment of the uncontrolled risks.

Estimates of consequence however, are much more problematical (technically) and consequently much more open to dispute. Given the fundamental dichotomy in views, between those with an interest in exploiting a resource and those with an interest in protecting a resource, there may be little ground for agreement about the severity of consequences associated with any given event.

There are opportunities to address this problem. In general, terms environmental impacts may be expressed in terms of either impacts on key taxa (e.g. impact on abundance of endangered species such as great white sharks) or in terms of the extent of a disturbance across an entire habitat (e.g. reductions in density or spatial extent of seagrass meadows). In either case the consequences of an event can be quantified in terms of:

1. The spatial scale of the impact relative to the scale of the receiving ecosystem or the numbers of individuals of a key species impacted relative to the size of the population.
2. The temporal scale of the impact in terms of the timeframe for recovery; this may include the timeframe for reestablishment of ecosystems or recovery of numbers of a key species.
3. The conservation significance of the impacted system or taxa

Examples of these issues are detailed in the following.

Impacts on key taxa: In most cases, species that are considered to be of conservation significance have already been identified as being in need of management and this would have included a consideration of the demographics of the population under consideration. The white shark example given above provides a good case study for impacts on key species. Currently we know relatively little about the demographics of white sharks and therefore estimates of the impact of any single mortality event may be considered contentious. Whereas farmers (and increasingly regulators) adopt the view that losses of a few individuals will not impact on the viability of the populations in southern Australia, many conservationists argue that any mortality associated with aquaculture is unacceptable and represents a substantial risk to the conservation of the species. There is a need therefore, to implement a systematic

Table 2. *Proposed system for applying the redlist categories to quantify the consequence scores for risk assessment purposes. Note that the IUCN system (IUCN, 1994) provides detailed quantitative demographic criteria for species falling into each category.*

IUCN category	General description	Consequence Score
Critically endangered	This category reflects an "extremely high" risk of extinction in the wild in the immediate future	Catastrophic 8
Endangered	Has a "very high" risk of extinction in the near future	Major 6
Vulnerable	Has a "high" risk of extinction in the medium-term future	Severe 4
Conservation dependent	Species rely on an existing conservation program to remain out of one of the "threatened" categories above.	Moderate 2
Near threatened	Close to being "vulnerable".	Minor 1
Least concern	The category into which taxa	Negligible 0

and consistent process for the assessment of consequences that can be agreed by all stakeholders.

One such system that lends itself to this purpose is the IUCN (International Union for the Conservation of Nature) Red Listing system (IUCN, 1994). This system is used for classifying the conservation status of a species and it is possible to utilize the IUCN categories to provide a quantitative score for assessing the consequence of mortalities (Table 2).

The Red List classifications are widely used and have been in place, with modifications, for over 30 years. They are internationally accepted as providing a consistent, reliable basis on which to determine the conservation status of species from many taxonomic groups (IUCN, 1994). Recently, the IUCN has published Red Lists of the plants (WALTER and GILLETT, 1998) and some groups of animals (BAILLIE and GROOMBRIDGE, 1996) of the world. These lists categorize the conservation status of vascular plants, birds and mammals on a global scale. Lists of threatened species of groups such as marine fish have also been compiled (HUDSON, 1996).

The widespread acceptance of the IUCN Red List Criteria is due, in part, to it providing an unambiguous set of guidelines and a clear quantitative basis for classifications. These criteria are used to identify whether a species is under threat and include assessments of population decline, locality restriction, and population size and extinction probability analysis. A taxon that appears threatened, according to any one or more of these categories, can be placed in a category ranging from "Least concern" to "Critically endangered (Table 2). Importantly, species which are recognized as under threat and therefore in need of protection are likely to have been independently classified using this system for conservation purposes, as is the case in Australia where the Federal Government maintains a list of threatened species. In this case the great white shark is already listed as "Vulnerable" (ENVIRONMENT AUSTRALIA, 2002) and therefore any impact on white shark numbers would be scored as a "4" ("Severe" consequence) under this system. Applying the risk formula the overall risk would then be defined as 20 indicating that this is a high risk issue that needs to be addressed through management. This outcome is also consistent with the findings of the white shark recovery plan (ENVIRONMENT AUSTRALIA, 2002), which identifies mortality from entrapment in tuna cages as the major source of mortality for this species.

Impacts on key habitats: Similar arguments can be made for impacts on habitats. A consideration of the spatial extent of an impact, the time-frame for recovery and the conservation significance of the area underpin the assessment of consequences.

Conservation significance can be defined based on a variety of criteria. In Australia for example there are already a range of formal criteria, endorsed by IUCN (KELLEHER and KENCHINGTON, 1991) and Environment Australia (ANZECC TFMPA, 1998), for use in the selection of Marine Protected Areas, buffer areas and general use areas. These criteria range from social, economic, international and national importance to scientific, ecological and biogeographical importance and naturalness (EDYVANE, 1999).

The values used in Table 3 are provided to illustrate the

Table 3. *Quantitative basis for assigning consequence scores based on impacts to habitats. Values for spatial and temporal scale are indicative and would need to be agreed within a regulatory framework.*

Conservation significance	% of area impacted	Time frame for recovery (years)	Consequences of impact	Score
General use	1	<1	Negligible	0
General use	5	2	Minor	1
General use	20	5	Moderate	2
Buffer areas	50	10	Severe	4
Buffer areas	70	50	Major	6
Protected areas	90	200	Catastrophic	8

concept that consequence scores need to consider 3 key factors these being the score for spatial scale of the impact (AREA), the score for temporal scale of the impact (TIME) and the score for conservation significance of the environment being impacted (CONS). The conservation significance of the environment should take precedence in defining consequences over the other criteria. An algorithm that lends itself to this purpose is:

$$\text{Consequence Score} = [\ (\text{AREA}+\text{TIME}) / 2\ ] + \text{CONS}$$

where any value greater than 8 is rounded down to 8 (in any case implying a catastrophic consequence).

CONCLUSIONS

The potential for environmental impacts and the nature of those impacts differs substantially for different aquaculture systems. There is a need therefore to customize environmental monitoring programs to address the key environmental risks presented by any given venture. Such risks can be identified using stakeholder based consultative forums and prioritized using formal risk assessment strategies. Once prioritized, risks can be managed through environmental monitoring programs.

Collectively the systems proposed in this paper would provide a quantitative and consistent process for identifying environmental issues, assessing risks and thereby prioritizing environmental monitoring and management actions.

ACKNOWLEDGEMENTS

This paper has benefited from discussions with many colleagues and collaborators including Steve Clarke, Maylene Loo, Milena Fernandes and Grant Westphalen (SARDI Aquatic Sciences); Brian Jeffries, Daryl Evans, David Ellis (SA tuna industry); Mark Parnell, Michelle Grady, Tony Flaherty (Conservation Council of South Australia).

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