MEETING THE NEEDS OF FISHERIES ENHANCEMENT ECOLOGY WITH NOVEL MARINE ENGINEERING - A NEW APPROACH TO ARTIFICIAL REEFS

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Abstract

A cyclic trend exists in artificial reef failures, with initial reef enthusiasm and construction often followed by anecdotal reef failure and antipathy. This cycle of enthusiasm, construction and ultimately failure as a result of poor evaluation of projected benefits (goals) leads to restrictions on their future development. Artificial reef development in Australia is an example where poorly planned artificial reef projects, with limited evaluation of pre-deployment objectives, resulted in a boom and bust cycle of artificial reef failure that resulted in a 20 year hiatus of reef development in the Australian context. In 2005 DPI deployed its first purpose built fishing reef structures using Reef Balls in coastal barrier lagoons and tide-dominated coastal bays Engineering requirements of these projects were limited to assessing the potential for the substrate to support reef modules, and the potential for scouring and deposition in the immediate vicinity of the reefs. The success of the program in estuarine systems supported the extension of trial deployments into coastal ocean waters. The most immediate challenge was developing reef designs that were suitable for offshore deployments. Following an extensive environmental assessment that placed as much emphasis on risks associated with structural stability and integrity as on potential ecological concerns, Australia's largest purpose-built artificial reef, constructed from 42 tonnes of steel deployed in 38m of water off Sydney's' south Head in October 2011. Although the overarching goal of the project was to create a new recreational fishing location, the primary design and engineering challenge was for the reef to survive the hostile NSW coastal shelf environment and to withstand a 1/100 year storm event (a wave height of approximately 18 m – H^{Max}) and maintain a minimum operational lifespan of 30 years. This presentation will detail the development of this unique project, the importance of the union between ecology and marine engineering and how the reef is performing 18 months after it first hit the ocean floor. A 7-step responsible approach to artificial reef development was produced to assess recent Australian artificial reef projects. A focus on pre-deployment planning, coupled with post deployment scientific evaluation has broken this cyclic trend in reef failures and established a sound base for future artificial reef research

and development. Ongoing development of Australian artificial reef projects is promising, with the results of reinvigorated estuarine artificial reef research being used to develop larger long-term projects in ocean waters of both Australia’s east and west coasts.

Introduction

The risk associated with artificial reef development with ambiguous construction objectives exists beyond the assessment of individual projects, arguably one of the greatest risks to the adoption of artificial reefs within a broader fisheries management strategy. Poorly conceived projects without adequate post-deployment evaluation underpin the cyclic nature of artificial reef failures. Badly planned and executed projects limit future developments of artificial reef use; not just as a fisheries enhancement initiative, but more broadly for applications such as habitat mitigation or coastal fortification. A review of worldwide artificial reef design, application, management and performance highlighted the general lack of planning and evaluation as primary reasons for poor artificial reef performance against construction goals (Baine, 2001). In particular, these include issues relating to the site selection of the reefs, their size, stability, cost, inadequate monitoring, unmanageable and unrestricted reef use and external climatic factors, all identified as major reasons for reef failure (Baine, 2001). A general lack of detailed evaluation of artificial reef performance has been highlighted (Seaman Jr and Jensen, 2000). Evaluation involves the assessment of pre-deployment objectives in a structured and scientifically valid framework to provide opportunity for projected benefits to be quantified. From 30 reviewed case studies, only 6% were identified to have met all their pre-deployment objectives with 20% displaying inconclusive results, while the majority (60%) only met portion of total pre-deployment objectives (Baine, 2001).

Planning involves setting project goals, detailed consideration of site constraints (e.g. existing site uses and restrictive zoning); materials appraisal (purpose-built versus materials of opportunity; concrete or steel) reef layout/design (e.g. multi-component patch arrangement versus large single unit reef structures). Failure to address one or more of these steps increases the probability of reef project failing (O'Leary et al., 2001). Ultimately each of these is influenced by a combination of intended purpose and social-economic factors including project budget, safe accessibility to the end user and safe navigation (e.g. depth) over the reef.

Guidelines surrounding the construction of artificial reefs have to date primarily been geographically centric in nature. For example, in Europe guidelines for the construction of artificial reefs in European waters were developed by the European Artificial Reef Research Network (EARRN) (Jensen, 1998). In the United States, the US National Artificial Reefs Plan guides artificial reef construction in the United States, first developed in 1985 (Stone, 1985) and revised significantly in 2007 (Relini et al., 2007, Murray, 1989, Murray, 1994). Both indicate that justification for reef deployment, at a minimum should include: i) environmental impact assessment, ii) the anticipated benefits of reef construction; iii) evaluation of alternative designs and placement methods, and; iv) provisions for baseline assessment studies (Baine, 2001), but fail to provide a planning and evaluation framework that could be generically adopted for a range of artificial reef projects.

Historically, artificial reefs have been constructed out of cheap and convenient material (Pollard 1989, Kerr 1992); collectively known as ‘materials of opportunity’. These include discarded car tyres, decommissioned ships, obsolete oil rig platforms, car bodies, railway cars, pulverised ash blocks, fibreglass, bamboo, general waste material and a variety of surplus military equipment (Krohling et al., 2006, Einbinder et al., 2006, Reggio, 1987, Pickering, 1996, Svane and Petersen, 2001, Brickhill et al., 2005, Chapman and Clynick, 2006). Over the past two decades there has been extensive investment in the development of purpose-built artificial reefs (Kim, 2001, Kim et al., 1994), altering the way in which artificial reefs are constructed. This has resulted in a global shift away from the use of materials of opportunity, towards the use of dedicated reef designs (Sherman et al., 1999, Sutton and Bushnell, 2007, Pickering and Whitmarsh, 1997Purpose-built reefs are now considered a more suitable alternative for achieving specific fisheries management objectives (Sherman et al., 2002) and in many countries the use of these artificial reefs has become an important component of integrated fisheries management plans (Santos and Monteiro, 2007).

Previous reviews have investigated the world-wide use and performance of artificial reefs, both design-specific and those constructed from materials of opportunity, (Baine, 2001, McGurrin, 1989, Relini et al., 2007). This review is in the context of design-specific artificial reefs, integrating planning, scientific evaluation and management of design-specific artificial reefs for fisheries enhancement into a responsible approach to their development. Using this approach, an assessment of three recent east Australian artificial reef projects that utilised pur[pos0-built reef materials near the cities of Brisbane, Sydney and Melbourne was conducted to evaluate if pre-deployment planning, coupled with post deployment scientific evaluation can break the cyclic trend in reef failures and establish a sound base for future artificial reef research and development in Australia.

Principles of artificial reef construction

Successful artificial reef projects are able to demonstrate that the project has met its pre-deployment goal by implementing a multidisciplinary approach that encompasses ecological, physical and socio-economic variables of planning, evaluation and long-term operation (Fig. 1). The 7-steps of responsible artificial reef construction proposed by this review (Table1) are primarily focused around identifying the need for reef construction, considerations for site and substrate (material) selection, legislative approvals, pre-deployment environmental/impact assessment and setting of monitoring objectives (based on the projects need/goal).

Identifying the need

Artificial reef construction is rarely a proactive management response; rather a reactive response to a specific human need such as increased fishing harvest, coastal protection and/or fortification, tourism, or ecological need such as protection of sensitive marine systems, habitat restoration/rehabilitation and dedicated scientific research. The first question that should be considered is whether the reef is necessary and is its construction the most appropriate solution to the given problem (Meier, 1989) and will its placement be the most effective long-term management option (Baine, 2001). Being able to not only identify, but also justify, the need is essential. This is an integral part of the post-deployment evaluation process; the setting of broad goals (the need) will allow focused objectives to be articulated, ultimately driving monitoring plans and the evaluation process.

Select appropriate locations

Reef site selection is considered one of the most critical decisions in the reef planning process, and the most frequent cause of artificial reef failures (O'Leary et al., 2001). Optimum site selection needs to consider multiple aspects of ecological, physical and socio-economic factors. For example, ecological drivers need to be weighed against social need and physical restrictions (e.g. sediment type, depth and distance from access). In addition, site selection is required to consider and potentially make allowances for material type and reef layout. Constraint mapping techniques are commonly used in site selection studies to bring together social, economic and environmental considerations in an overall context (Gordon and William, 1994, Kennish et al., 2002). Constraint mapping involves the building up of layers of information concerning areas where some form of constraint exists, for example, existing users or user groups (stakeholders), potential for conflict, and environmental or engineering constraints (O'Leary et al., 2001).

Critique reef material and reef layout and design

Reef material

European guidelines developed to manage responsible artificial reef construction in the north Atlantic advocate the use of inert materials that are non-polluting (Baine, 2001). Guidelines such as these and increasingly stringent environmental legislation has lead to the increasing use of purpose built reef structures. These structures are considered a better alternative to the use of opportunistic materials as they are more effective in achieving specific fisheries management objectives. They are also desirable as removal of any potential pollutants can be pre-planned into the design to meet related sea-dumping legislation (Sherman et al., 2002). While the use of opportunistic materials may be cheaper initially, mainly due to the lack of design and manufacture

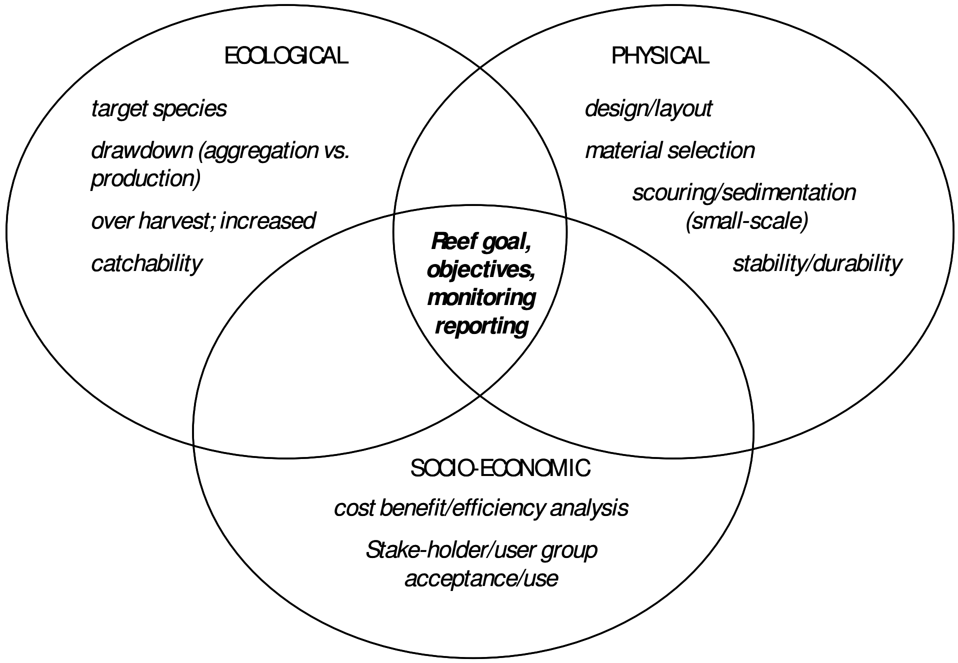

Figure1: Three critical criteria (ecological, physical, socio-economic) required for consideration when establishing goals, objectives, monitoring priorities and reporting structure for estuarine artificial reef projects.

cost, purpose-built artificial reef designs are preferable over opportunistic materials as they are:

- engineered to suit specific objectives such as target specific species, user groups and fishing gear;
- manufactured to suit a chosen location in terms of depth, oceanographic conditions and substratum type;
- designed to maximise the duration, durability and compatibility of the structure to avoid problems associated with material toxicity;
- considered to yield comparatively greater cost-benefits than the use of materials of opportunity;
- improved ability to assess reef performance as standardisation of design removes a major source of variability.

There are now a large variety of materials that have been extensively tested and widely used to manufacture artificial reefs (Kim et al., 1994).Materials include concrete, iron and steel reinforced concrete, ceramic, plastic, plastic concrete (concrete mixed with polyethylene, polypropylene sand and iron) and fibre reinforced plastic amongst others (O'Leary et al., 2001). These materials are used to create designs that incorporate a variety of shapes (e.g. blocks, cylinders and domes), configurations and varying dimensions, as well as high relief, complex steel structures that can stand over 30 m (100 ft) high (Kim et al., 1994).

Reef layout

Reef layout should incorporate a variety of biological, economic, physical sciences and engineering (Seaman Jr, 1996). Size, relief, complexity, location and biological factors can all influence assemblages of fishes on artificial reefs (Bohnsack et al., 1994) and physical parameters of design. Biological principles that should be considered include habitat limitation (Lindberg et al., 2006), habitat complexity (Anderson et al., 1989, Charbonnel et al., 2002) and refuge from predators (Belmaker et al., 2005). Physical principles deal with the size of the reef structure (Borntrager and Farrell, 1992) and the strength and stability of the reef materials. Reef size and its influence on species abundance is an ongoing debate. Where biomass has been reported in association with large artificial reefs, it may be composed of large but few individuals (Pickering and Whitmarsh, 1997). While greater densities of fish on smaller artificial reefs have also been reported (Bohnsack et al., 1994). The vertical relief, relative to water depth of an artificial reef can also influence abundance and diversity. In temperate waters, diversity has been shown to be greater on low-relief artificial structures than on natural structures (Ambrose and Swarbrick, 1989). Conversely, a study of high relief reefs found greater diversity on natural reefs than on artificial reefs (Burchmore et al., 1985). Psychological, social and economic aspects of human behaviour also are important when considering reef design, taking into account the requirements of possible end user groups (Ramos et al., 2007, O'Leary et al., 2001, Sutton and Bushnell, 2007).

Identify legislative procedures and obtain statutory approvals

Legislation surrounding the placement of material on the ocean floor is often complex and varies considerably between geo-political regions. This legislation is often detailed, and restrictive in terms of what, where and how much material may be deployed in the construction of artificial reefs. The evolution of artificial reefs, particularly the movement away from materials of opportunity to the adaptation of purpose-built materials has

Table 1: Proposed 7-step responsible approach to planning, constructing and evaluating artificial reefs; incorporating ecological, physical and socio-economic factors into scientific evaluation and management.

Principles
1. Identify the need fulfilled by artificial reef construction *i) who wants the reef?* *ii) why is the reef required?* *iii) what will the reef benefit - social vs. biological/ecological vs. physical?*
2. Select appropriate locations *i) prioritise locations based upon the need* *ii) conduct constraints mapping* *iii) stakeholder consultation*
3. Critique reef material *i) opt for design specific over materials of opportunity where possible* *ii) assess the most appropriate reef design (layout - stand alone structures vs. multi-component [modular], reef foot-print and volume) within budgetary constraints*
4. Identify legislative procedures *i) what is the local and regional statutory framework?* *ii) what are the permitting procedures?* *iii) undertake consultation with private stakeholders and user groups, statutory Government consenting and regulatory authorities and other non-statutory organisations (e.g. Port Corporations, relevant maritime safety authorities etc).*
5. Conduct a preliminary environmental/risk assessment *i) Pre-deployment impact/risk assessment to focus monitoring/research objectives: identify large-scale generic and small-scale site specific risks and potential consequences of reef construction*
6. Post deployment evaluation - set defined project goals and monitoring objectives to form 'objectives driven' monitoring plans *i) monitoring should include ecological, physical and socio-economic aspects of reef constrction where appropriate* *iv) define research objectives based upon risk assessment and permitting conditions (ecological/physical/socio-economic)* *v) develop a defined, measurable and attainable monitoring plan based on research objectives, relevant research expertise and capabilities*
7. Use adaptive management *i) define reef ownership and management responsibilities* *ii) develop management plans that include a concise description of management responses to environmental triggers and potential cumulative impacts; these should include provision to allow for adaptive responses to unforseen issues.* *iii) commitments should include decommissioning plans and procedures if required.*

been strongly influenced by the continued tightening policy which seeks to increase control over developments associated within the marine environment. Conditions placed upon approvals can often be used to focus monitoring priorities. For example, assessment of potential incidental capture of threatened or protected species (fish or other) may be a consenting condition relating to conservation legislation. This may prompt scientists to incorporate an assessment of reef community development into their monitoring plans to evaluate their presence or absence on the reef, while creel surveys may be used to assess catch composition and occurrence. Fisheries Managers may be prompted to include species identification guides and safe release strategies for these species into their management plans, with trigger points and contingency/mitigation options if a negative impact is detected. Legislative approvals may also be used to justify monitoring requirements to ensure evaluation of the reef is included in any reef project proposal.

Conduct a preliminary environmental/risk assessment

Most artificial reef projects will, at a minimum, require a preliminary environmental assessment, based on existing literature or related studies. However, it is often overlooked in the artificial reef planning process. Assessment of risk entails the identification of a potential hazard, a judgment of the likelihood that the hazard has of occurring and its subsequent consequence (Cardno, 2010). Risk assessment helps identify areas that may need further investigation post reef deployment and can inform the development of post-deployment monitoring plans. Physical impacts such as reef stability, sedimentation and scouring will be very site specific, as will the socio-economic impacts of reef deployment, often based on the local and/or regional political environment.

Post deployment performance evaluation - set defined project goals and monitoring objectives to form an 'objectives driven monitoring plan'

Fishers, managers, reef investors, conservation groups, related user groups (not directly benefiting from reef construction) and the general public (as combined 'owners' of the ocean resource) have an interest and right to know the outcome of reef evaluations (Seaman Jr and Jensen, 2000). However, artificial reef evaluation has traditionally not attracted the same attention or level of resources as reef design and deployment. As a result conclusions of reef effectiveness based on predetermined goals have been poorly articulated (Seaman Jr and Jensen, 2000), resulting in a cyclic failure of reef projects, where initial reef deployments and enthusiasm were followed by antipathy and reef failure, which restricted future development and use, by not evaluating the projected benefits (goals).

Although the physical and ecological results from artificial reef deployments have been comparatively well documented in the scientific literature, the benefits of reef development to humans is more often neglected. The lack of evaluation data is in part due to the focus of research on basic ecological questions rather than objectives based on broader construction goals (Seaman Jr and Jensen, 2000). Therefore, reef evaluation should, where possible, include a multidisciplinary approach. Physical and socio-economic objectives must be addressed with the same rigour applied to ecological studies of reef associated species (Fig. 2).

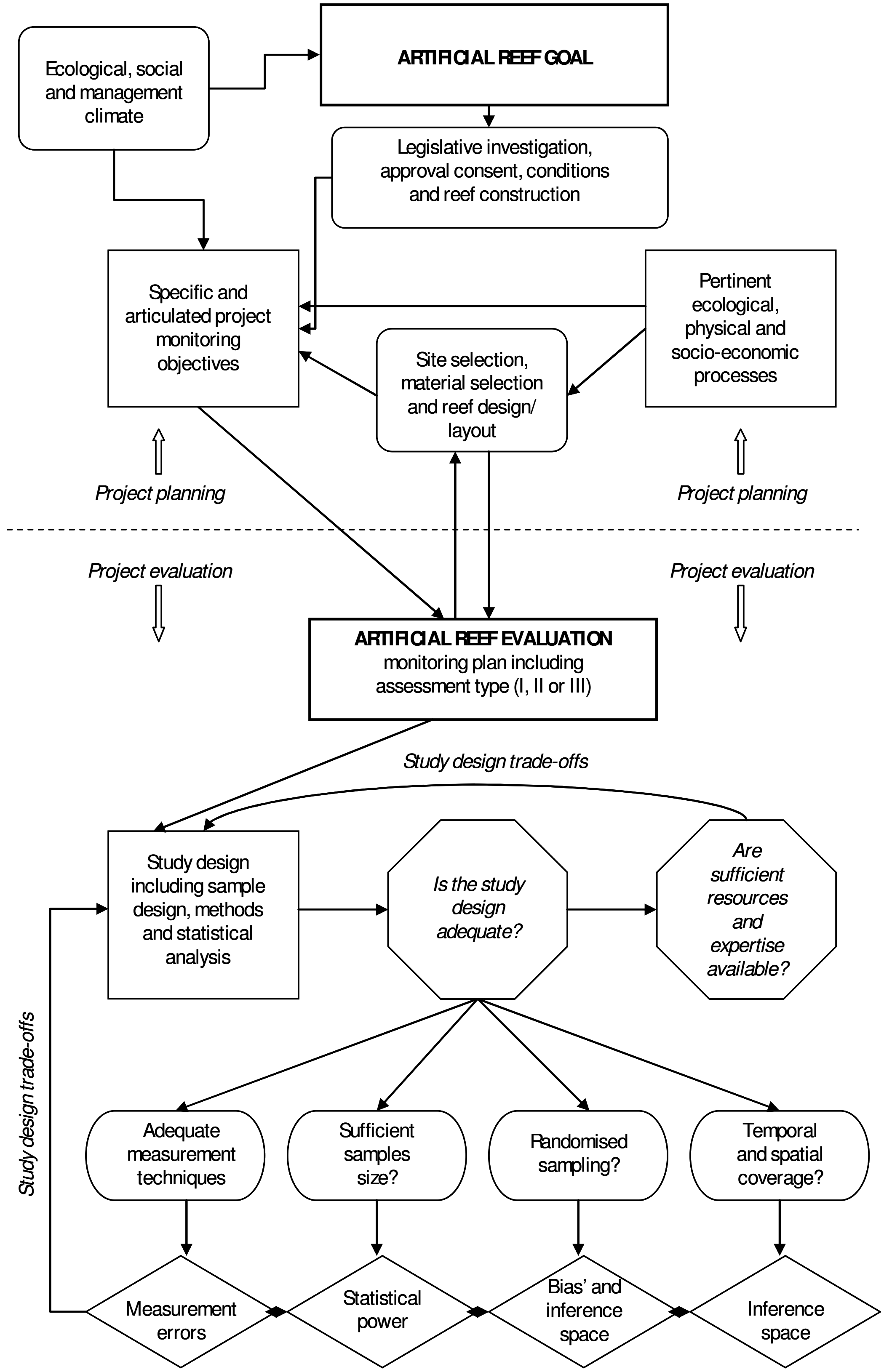

Figure 2: Flow-diagram graphically illustrating the integration of evaluation requirements into the planning and implementation of artificial reefs (modified from Lindberg and Relini, 2000).

Development of monitoring plans based on project goals and objectives

Monitoring plans need to be well structured and focused on primary goals and objectives to ensure the right level and amount of data is collected to allow projected benefits to be clearly addressed in conclusions (Seaman Jr, 2000). Experimental assessment of artificial reef systems is improving, incorporating techniques such as otolith microchemistry, acoustic telemetry, stable isotope analysis (Brickhill et al., 2005) and baited remote underwater video (BRUV). BRUVs in particular allow large amounts of data to be collected at a relatively low cost and effort (Lowry et al., 2011a, Lowry et al., 2011b).

Monitoring plans should be developed that outline appropriate procedures to detect a range of components. These include, but are not limited to, changes in significant components of the marine environment, assessment of impacts on threatened species, reef structural integrity and socio-economic measures such as success of the reef in terms of catch rates, catch composition and popularity among the user groups for which the reef was initially constructed. Additionally, evaluation of a project may not necessarily be as simple as demonstrating that the projected benefits (goal) of the reef's construction were met (e.g. increased fisheries harvest, increased recreational fishing opportunities, resources allocation/protection, tourism and research); but may also provide data to demonstrate that potential impacts (often highlighted in statutory approval conditions, or as part of the pre-deployment environmental/risk assessment) are being investigated and addressed as part of the evaluation monitoring plan.

Seaman Jr (2000) proposed a broad, conceptual approach to reef assessment based on three evaluation types (Table 2). This approach was developed to provide a conceptual view of reef assessment that may be adopted depending on two competing factors: i) the level of assessment required, balanced against; ii) the amount and expertise of resources available. Type I is ‘descriptive’, involving a brief and descriptive assessment (often with limited replication) of the reefs deployment, early colonisation (fish, invertebrates and fouling) and a basic socio-economic appraisal (is the reef being used and by whom – was the reef construction a sound investment?). Type II is ‘analytical and comparative’, where the physical and ecological structure of the reef is described, with replication over a pre-determined time. This provides for an ecological comparison of the reef with itself, providing more qualitative data than the ‘snap-shot’ of the Type I descriptive study. Obviously, this may also include physical and/or socio-economic aspects of the reef’s development through time where required by the pre-deployment goals and objectives (more often associated with Government reef proponents). Type III is ‘interaction and prediction’, incorporating both Type I and II and is the most fiscal and resource intensive, addressing how the reef interacts with neighbouring natural habitats and how it compares with other artificial reefs and/or management activities, allowing a level of prediction to be established. Ultimately, the reality of highly capital intensive projects such as artificial reefs may mean that even though a Type III approach may provide the most useful data in furthering research associated with artificial reefs (more often aligned with university based assessment), the extensive expertise and potentially prohibitive cost of such evaluations may ultimately mean that only a Type I or II approach is adopted. The evaluation approach taken will also depend on the known confidence of interactions. If the deployment is routine, in the same type of location using a similar reef design, the monitoring approach may not require the same level of evaluation as newer, untested projects.

Table 2: Broad approaches to reef evaluation based upon information requirements and monitoring resources proposed by Seaman and Jensen (2000).

		EVALUATION TYPE	
Characteristic of Investigation	One: descriptive	Two: Analytical and Comparative	Three: Interactive and Predictive
Intensity of data collection	low-moderate	moderate-high	high-very high
Rigor of training required	high	high	high-very high
Study Duration	short	short-long	short-long
Nature of information	initial condition of reef or at some point in time	development of reef system; processes changes	comparison with other systems; efficiency prediction
Scope of inferences	instantaneous snap-shot; presence-absence	pattern; comparing over time and space	cause and effect; explain pattern
Complexity of data analysis	basic statistics	high	very high

Use of adaptive management

Previous reviews of the application, management and performance of artificial reef programs have concluded that many of the problems have arisen from general planning and management issues, without a standard approach to reef management (Baine, 2001). A broad framework to adaptive reef management should be incorporated into the primary planning process. Adaptive management means that although the management of the reef in a broader ecological and/or statutory framework may provide direction for pre- and post- reef evaluation, this management is required to react and respond to the findings of post-deployment reef evaluation (Fig. 3).

Historical, socio-economic and political factors associated with artificial reefs vary (Baine, 2001), often between states or provinces of the same country. Being able to describe measures that can be implemented to avoid or offset potential impacts identified by reef evaluation should be addressed in the form of dedicated management plans for individual reefs.

Artificial reefs in the Australian Context

Artificial reef development in Australia illustrates the boom and bust cycle of failure of poorly evaluated reef programs. The first reported artificial reef in Australia was created in 1965 from concrete pipes deployed in Port Phillip Bay, a large heavily urbanised tide dominated coastal bay on the south-east Australian coast (Kerr, 1992, NLWRA, 2012). Within a few years reefs were constructed primarily for recreational fishing and diving in the three eastern and one southern Australian states in estuarine and offshore locations (Branden et al., 1994, Kerr, 1992). Despite early enthusiasm, artificial reef research in Australia stalled in the mid 1980’s. By failing to evaluate projected benefits these initial reef deployments, construction was followed by antipathy and anecdotal reef failure. In addition, car tyres were used intensively in the south-west Pacific for reef construction (Collins et al., 1995) and were the first choice of many early Australian reef developments (Kerr, 1992). An increasing awareness of the potential for tyres to leach zinc when immersed in sea water (totalling 10mg/tyre after 3 months) (Collins et al., 1995, Collins et al., 2002) lead to environmental legislation around the disposal of waste ‘materials of opportunity’ at sea such as car tyres to becoming increasingly stringent. Further, the inability of early projects to demonstrate structured evaluation of deployment goals lead to negative reviews of their potential development (Coutin, 2001, Kerr, 1992, Pears and Williams, 2005) and the beginning of the boom and bust cyclic failure of artificial reefs in the Australia context.

Renewed interest in artificial reefs first surfaced in the State of New South Wales (NSW), where recreational fishing is an important leisure activity for approximately 1 million people (17 % of the state's population) (Henry and Lyle, 2003). The introduction of a general recreational fishing fee in 2001 resulted in funding being directed towards the use of artificial structures as a recreational fisheries enhancement tool, part of an integrated management approach to recreational fisheries enhancement that also included offshore fish aggregation devices (FADs). In 2005, NSW deployed the first trial purpose-built artificial reefs in Australia as part of the Estuarine Artificial Reef pilot research project in three coastal estuaries (Lake Macquarie, Botany Bay and St Georges Basin) (Folpp et al., 2013, Lowry et al., 2010). This was followed by the Moreton Bay Artificial Reefs Project (QLD), which began in 2008 and was situated adjacent to the city of Brisbane. The Port Phillip Bay Recreational Fishing Reefs Project (VIC) followed in 2009 with construction of a series of design-specific reefs adjacent to Melbourne along the eastern shore of Port Phillip Bay. The latest was the

Goegraph Bay artificial reef project in Western Australia, which saw two large purpose0-built reef constructed in early 2013.

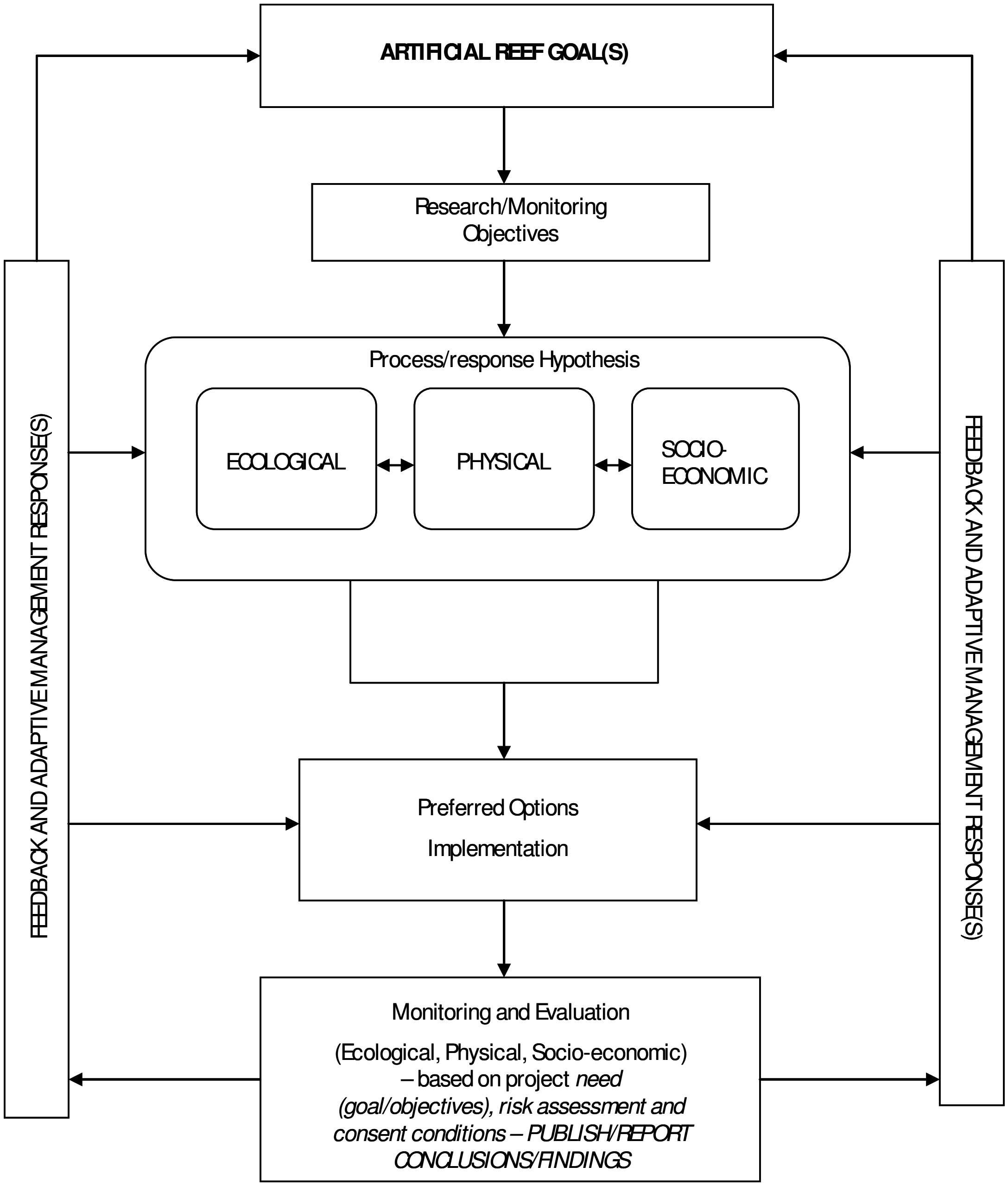

Figure 3: Flow-diagram graphically illustrating an adaptive management framework for artificial reefs (modified from Milon et al., 2000).

NSW Estuarine Artificial Reefs Project

This project was developed in response to a need for better understanding of artificial reefs as a recreational fisheries enhancement tool. The construction of pilot design-specific estuarine artificial reefs was done to gain experience in artificial reef design and construction while providing ecological data to further reef understanding and allow assessment of suitable reef evaluation techniques (Lowry et al., 2010). The objectives of the project were to investigate fish assemblages associated with artificial reefs (recruitment and colonisation) and compare these to neighbouring natural reef structures and investigate epibenthic community development. In addition, baited remote underwater video (BRUV) and diver underwater visual census (UVC) techniques were assessed to evaluate their effectiveness in describing fish populations (Lowry et al., 2011b, Lowry et al., 2012). This information was to be used to allow transfer of knowledge regarding construction, deployment and monitoring of artificial reefs into other suitable locations.

Between 2005 and 2007 following a detailed statutory approval process (ERM, 2005b, ERM, 2005a, ERM, 2006), 540 concrete design-specific modules (Reef Balls®) were used to construct 18 replicate artificial reefs (6 replicated reef patches in each estuary at approximately 6 monthly intervals). The three estuaries were Lake Macquarie (a large extensively urbanised wave-dominated coastal barrier lagoon); Botany Bay (a large extensively urbanised tide-dominated coastal bay); and St Georges Basin (a semi-urbanised wave-dominated coastal barrier lagoon). The study used approximately 850 h of BRUV footage from 1,500 individual deployments over two and a half years between the three estuaries. The evaluation of the reefs documented fish and epibenthic assemblages on the constructed reefs. Results demonstrated that structures specifically designed as artificial reefs can be effective at extending the habitats and increasing the abundance of a variety of fish species, including a number of recreationally important Sparids in temperate estuarine systems (Folpp et al., 2011, Lowry et al., 2010, McKenzie et al., 2011, Folpp et al., 2013). In addition, analysis of approximately 1,700 images documenting the epibenthic development on the concrete modules taken over 2 years following deployment identified rapid development, however unlike the fish community, the community was characterised by low diversity with only three species groups recorded (filamentous turfing algae, polychaetes and echinoderms).

Building on this trial project, existing pilot reefs were augmented by 150% between 2008-2011 and further fisheries enhancement initiatives were undertaken with construction of two new large estuarine artificial reefs on the NSW far south coast each consisting of 400 concrete modules. The reefs constructed as both part of the trial and subsequent reef expansion projects have in part succeeded in meeting their pre-determined objectives (Baine performance of 2 – Table 4). Both ecological and socio-economic benefits were realised by their construction, however appraisal of reef performance in terms of their perceived success by anglers was limited.

Table 4: Reef performance scale proposed by Baine (2001) based on evaluation of artificial reef performance against project goals/objectives.

Scale	Reef performance
- 3	The reef has failed in its objectives and has negatively impacted on the local environment or sea users. Research reefs that have failed through poor monitoring and management and yield no useful results.
- 2	The reef has failed in its objectives but has no discernible negative impact on the local environment or sea users. Research reefs that have produced no useful data, although this may be as a result of external factors.
- 1	The reef has failed in its objectives but exhibits other beneficial effects in terms of the local environment or sea users. Research reefs that have produced results that are questionable in their interpretation.
0	The reef's performance in terms of its objectives is inconclusive. Both negative and positive aspects of its creation are identifiable but the overall success of the reef is indeterminable. Management and/or design of the reef are flawed. Published material is unclear and/or confusing. Research reefs providing inconclusive data.
1	The reef has only succeeded in meeting its objectives with limited success. Other beneficial effects are recognisable. Design features or management measures are flawed and require review in order to increase reef success. Research reefs that have provided data of limited use for the assessment of reef performance and management.
2	The reef has succeeded in meeting its objectives in part. Benefits to the local environment or sea users are realised by the reef's creation. Minor changes to design or management may be warranted but are not critical. Research reefs that have provided useful data for the assessment of localised reef performance and management.
3	The reef has successfully met all of its objectives. The design features and management of the reef do not require change. Research reefs that have provided extensive and accurate data useful for the general assessment of reef performance and management.

Sydney offshore artificial reef (OAR) project

Reef design considerations

The goal of construction of this first trial steel skeletal offshore artificial reef (OAR) was to increased recreational fishing opportunities, and as with its estuarine predecessors, the success of the reef is to be determined by dedicated scientific evaluation. To gain the necessary approvals, concurrences and permits a comprehensive environmental assessment was undertaken (Cardno, 2010). Research on this reef is building upon the results of the estuarine artificial reef program and is investigating movement of key recreational species around the structure. It is also investigating the dynamics of artificial reef benthic and fish communities with particular reference to the cycling of nutrients and broader questions relating to the role of artificial structures in terms of production. The monitoring is also critically answering questions related to the long-term operation and structural integrity of the reef.

Design specifications for the OAR were based on Australian standards for similar offshore structures with a 30 year design life. The model for the stability assessment was based on the following parameters (WorleyParsons, 2010):

- water depth of 38 m;
- a 100 year average recurrence interval (ARI) design wave (H_s) in the primary wave SSE direction of 9.3 m (17.4 H_{max});
- a 100 year ARI design wave period (T_p) of 15.1 seconds;
- a minimum Factor of Safety (FOS) of 1.15 for overturning; and
- load increases associated with marine growth (20mm at base and 70mm at top of unit).

The final OAR unit design is 12 m x 15 m x 12 m (height x length x width) with the bulk of the internal structure in the lower 4 m of the structure, giving it a low centre of gravity for increased stability (Fig. 4). The OAR unit was designed by WorleyParson under contract from NSW DPI and was manufactured from square hollow sections (SHS) and rectangular hollow sections (RHS) and plates, weighing approximately 42 tonnes (dry weight). Four concrete anchor blocks are connected to each corner to ensure OAR stability. The unit was designed as three separate segments that could be prefabricated in location remote from coastal infrastructure which allowed each steel component to be prefabricated and test assembled in the steel workshop. Completed modules were then transported by road to Sydney where assembly is completed. Load-out and sea-fastening of the unit and associated mooring blocks to the deck of the deployment barge was completed onsite. The OAR was lowered into position in early October 2012 this was followed by the attachment of moorings and inspection by divers prior to commissioning on the 13 October 2011 (Lowry, 2013).

Preliminary results

Preliminary results from the post placement monitoring are primarily derived from video observations (baited and unbaited) around the OAR. Baited remote underwater video (BRUV) has identified a total of 23 species (Table 4) (Lowry, 2013). The number of species identified per month has followed a moderate increase in richness from 4 species pre-deployment to a peak of 16 species 8 months post deployment. Comparison of baited and unbaited video sampling identified depth related differences in assemblage associated with the OAR. Species commonly associated with the base of the structure include Port Jackson sharks (*Heterodontus portusjacksoni*) Wobbegongs (*Orectolobus maculatus*) and various species of rays while schooling species such as yellowtail scad (*Trachurus novaezelandiae*) and silver trevally (*Pseudocaranx dentex*) dominated the upper sections of the structure (Lowry, 2013).

Rapid recruitment of large numbers of mobile schooling species particularly mado (*Atypichthys strigatus*), yellowtail scad (*Trachurus novaezelandiae*) and Ocean leatherjackets (*Nelusetta ayraudi*) is reflected in the relative abundance data. Several species targeted by recreational anglers such as Snapper (*Pagrus auratus*), Silver trevally (Pseudocaranx dentex) Yellowtail kingfish (Seriola lalandi), and Blue morwong (Nemadactylus valenciennesi) and were also regularly identified on video samples (Fig. 5) (Lowry, 2013).

Comparison of video observations over the three month period following deployment showed that the majority of the structure had changed from being bare to completely covered in encrusting organisms including serpulid polychaetes, barnacles, filamentous algae, bryozoans and hydroids. No introduced marine pests or species that are protected under conservation legislation were observed.

Visual inspection and video surveys of the OAR identified no structural flaws in any of the OAR components even following a number of large storm events in its first two years following deployment that produced waves in excess of 14 m (HMax) in April 2012 in the vicinity of the OAR (per comms). At the depth of 38m at the OAR site, there is unlikely to be sediment movement such that there would be significant regional burial or scour of the structure, or capture of sediment that would be worked onshore (WorleyParsons, 2010). Inspection of areas around the base of the structure (footings and mooring blocks) further consolidated this predication for scour and deposition with minimal sediment deposition or scouring in the vicinity of the reef itself or mooring blocks identified. No threatened or endangered species have been identified by video sampling, direct observation or via ultrasonic telemetry. The three year assessment period will be completed in October 2014 with the final report on the OAR to be released by April 2013.

Species	Scientific name
Yellowfin bream	*Acanthopagrus australis*
Eastern smooth boxfish	*Anoplocapros inermis*
Mado	*Atypichthys strigatus*
Sergeant baker	*Aulopus purpurissatus*
Shorttail stingray	*Dasyatis brevicaudata*
Moray eel	*Gymnothorax prasinus*
Port Jackson Shark	*Heterodontus portusjacksoni*
Sixspine leatherjacket	*Meuschenia freycineti*
Velvet Leatherjacket	*Meuschenia scaber*
Stripey	*Microcanthus strigatus*
Ocean leatherjacket	*Nelusetta ayraudi*
Blue morwong	*Nemadactylus valenciennesi*
Wobbegong	*Orectolobus maculatus*
Snapper	*Pagrus auratus*
Blackspot goatfish	*Parupeneus spilurus*
Bluespotted flathead	*Platycephalus caeruleopunctatus*
Silver trevally	*Pseudocaranx dentex*
Eastern red scorpionfish	*Scorpaena jacksoniensis*
Yellowtail kingfish	*Seriola lalandi*
Yellowtail scad	*Trachurus novaezelandiae*
Eastern fiddler ray	*Trygonorrhina fasciata*
Bluestriped goatfish	*Upeneichthys lineatus*
John Dory	*Zeus faber*

Table 4. List of species identified by video observations at the OAR (source Lowry, 2013).

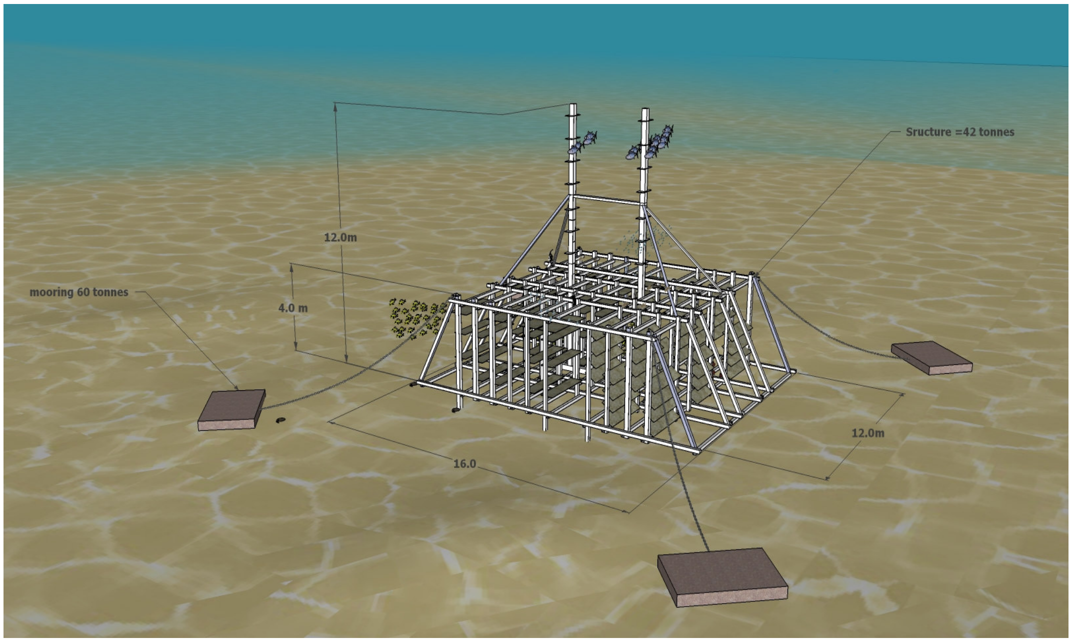

Figure 5: The skeletal steel artificial reef unit, designed by WorleyParsons Pty Ltd and deployed off Sydney in October 2011 epitomises the shift from materials of opportunity to modern purpose-built artificial reefs that combine ecological application with physical site requirements.

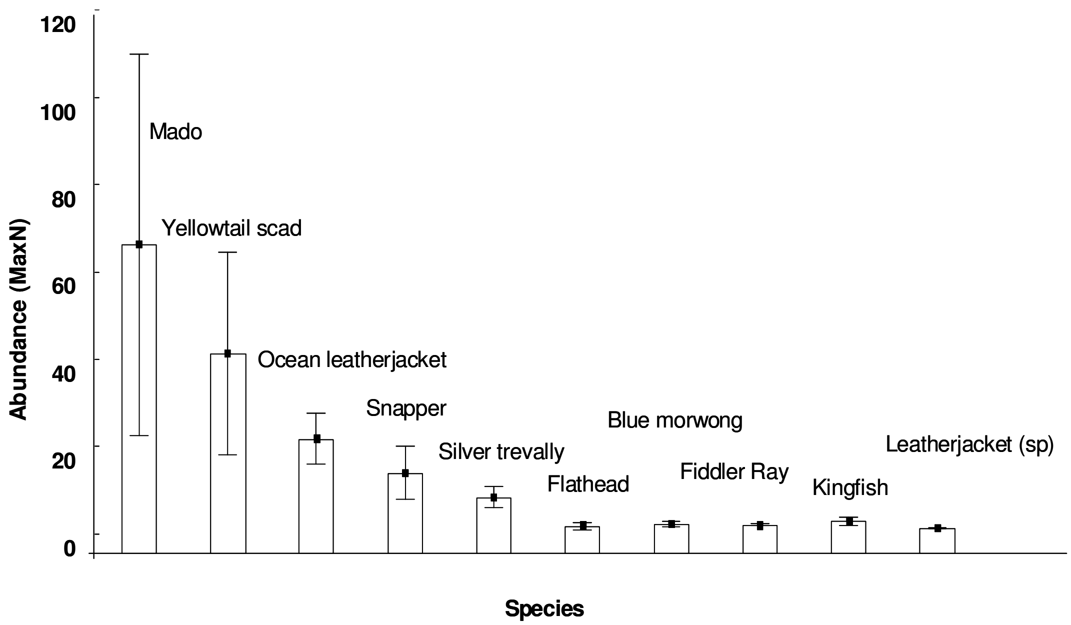

Figure 5. Relative abundance of top ten species associated with the OAR determined by baited remote underwater video (BRUV) (Source: Lowry, 2013).

Conclusion

Artificial reefs can potentially fulfil many of the objectives for which they are constructed; however, their ultimate success will indicatively reflect the quality of the planning and post installation management (Baine, 2001). Where there is very little data and a high degree of uncertainty, the implementation of pilot artificial reef programs with detailed evaluation provides information to guide and support future reef development. The general lack of artificial reefs in fisheries research and management is primarily driven by a lack of robust data on their use (Bortone, 2011). This has undoubtedly led to a situation where the number of anecdotally reported reef failures far outweighs the number of appropriately evaluated and documented successes of their use. This has been the case in Australia, where the past poor performance of artificial reefs (typically of an anecdotal nature), resulted in scepticism surrounding their use. The use of purpose-built reefs coupled with design innovation and thorough post installation evaluation of predetermined goals and the application of responsible principles demonstrated by the Sydney offshore reef project has provided some certainty regarding the future direction of artificial reefs use. The deployment and associated scientific evaluation of the OAR project confirms the breaking of the cyclic failure of Australian artificial reefs and epitomises the shift from materials of opportunity to modern purpose-built artificial reefs that combine ecological application with physical site requirements. It also demonstrates that the evaluation of artificial reef goals in a scientifically structured framework will provide a sound base by which their continued use is validated.

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