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POTENTIAL EFFECTS OF ARTIFICIAL REEFS ON THE GREAT BARRIER REEF: BACKGROUND PAPER

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1 EXECUTIVE SUMMARY

This document reviews available information relevant to the possible creation of artificial reefs on the Great Barrier Reef (GBR), for extractive (fishing) or non-extractive (e.g. diving) purposes. Although the literature on artificial reefs is quite extensive, there is surprisingly little strong evidence on either socio-economic or environmental benefits or impacts, so that conclusive statements about overall costs and benefits should be treated with caution. Elsewhere in the world, against a background of degraded marine ecosystems, artificial reefs can be seen to have some socio-economic and perhaps environmental benefits. In the context of the relatively healthy systems of the GBR, any benefits will be socio-economic, not environmental, and importantly, many of the suggested benefits (e.g. enhanced fishing) are inadequately justified by available evidence, may be only short-term or may be better provided by alternative measures with less risk. Artificial reefs have proven popular for both fishing and tourism/diving uses, although reviews in Australia and overseas question their value.

In general, fished artificial reefs pose more risk than unfished artificial reefs (e.g. diving only), because in many circumstances, available evidence suggests that artificial reefs tend to aggregate existing fish stocks, rather than enhance overall fish production. In the short-term, aggregation of fish on and around artificial reefs may generally increase fishing success nearby, as expected. However, in the long-term, if increased and concentrated fishing on the artificial reef outweighs any increase in overall production, this aggregation effect may increase the vulnerability of the fish stocks, leading to over-fishing.

Creation of artificial reefs in healthy ecosystems involves a range of potential environmental costs and risks. These include the replacement of prior, natural habitat with artificial habitat, impacts on adjacent habitats (such as shifts in trophic or food-web structure), on connectivity and larval dispersal patterns between habitats, and the introduction of pollutants, diseases or marine pests.

There is a need for a careful, evidence-based, risk assessment and cost-benefit analysis, which critically considers:

- The values and motivations underlying the potential social and/or economic benefits of artificial reefs (e.g. enhanced fishing experiences);

- The likelihood of artificial reefs effectively addressing those values;
- Potential alternative solutions;
- The balance between social or economic benefits of artificial reefs and potential loss of value to other interest groups (e.g. loss of naturalness or World Heritage value);
- Evidence for other potential effects, including environmental impacts;
- Potential impacts on fisheries and fisheries management;
- Strategies to maximise benefits and minimise environmental, social and economic risks.

Unfortunately, much of the information required for this assessment is either very limited or unavailable. Key knowledge gaps are identified at the end of this document.

2 RECOMMENDATIONS

If development of artificial reefs were to proceed within the Great Barrier Reef Marine Park (GBRMP), it is recommended that:

- Key information should be sought as a basis for any developments. In particular:
  - Clear documentation of stakeholder needs: Who wants what, why, and what is the best way to satisfy them;
  - Risk assessment for fished species or populations (of both target and bycatch), current status of populations, and total impacts by fisheries and other pressures (e.g. habitat loss); and
  - Nature and extent of other environmental impacts and risks.

- Strategies be developed to minimise any potential negative environmental, fisheries or socio-economic consequences, including impacts of specific developments and the overall impacts of all developments in an area or region.

- Colonisation take place by natural processes, rather than by translocation or artificial stocking of marine organisms.

- Extractive use be carefully managed, again in the context of overall pressure in a region, and that management be considered in terms of fisheries management as well as management of an artificial structure. Ability to regulate fishing pressure and strategies to achieve this in the GBR need to be considered.

- Given the information gaps and risks identified in this document, any development of artificial reefs in the GBRMP should be carefully planned and considered, and based on thorough cost-benefit analysis. A staged process, which starts by addressing outstanding issues, and utilises pilot projects and adaptive management strategies, is recommended.

CONTENTS

3 BACKGROUND

3.1 Purpose and scope of this document

This paper provides an overview and critique of available information on artificial reefs and their impacts, and identifies information gaps, issues and potential problems, in the context of the Great Barrier Reef. The primary focus of this paper is environmental aspects of artificial reefs. Social and economic issues and impacts of artificial reefs are also briefly considered, but related work by CRC Reef Research Centre will report more fully on those important aspects. The paper focuses on the creation of artificial reefs to enhance recreational fishing and/or diving and tourism opportunities, which are the primary objectives of proponents of artificial reefs on the GBR. Given the various information gaps, the paper aims not only to critique existing evidence, but to identify potential problems and issues.

The paper first summarises applications of artificial reefs globally and in Australia, reviews and critiques the potential effects on fisheries and then other environmental impacts, and then considers the broader socio-economic consequences and cost-benefit analyses and potential strategies to assess and address any impacts. Finally, a synopsis of available literature is provided and key information gaps relevant to the GBR are identified.

3.2 Definitions and Types of Artificial reefs

For the purpose of this review, 'artificial reefs' are taken to mean any structure placed on the seabed deliberately to mimic some characteristic/s of a natural reef, for the broad purpose of habitat creation. Where relevant, the term 'FAD' (fish attraction or aggregation device) is used to mean an artificial, floating object, anchored or not, set up to aggregate fish (mostly pelagic species). This document does not consider the artificial enhancement of natural reefs, such as translocation of corals to damaged reefs, reef rehabilitation methods, etc.

There is inconsistency in the use of the term artificial reef, so caution is needed when interpreting information on artificial reefs. The term 'artificial reef' has been used to encompass a wide range of structures including any objects placed in the ocean either intentionally or accidentally (e.g. shipwrecks). Types of artificial reefs range from man-made reefs intended to mimic natural reefs, through other forms of artificial habitats that increase benthic complexity, to fish aggregating (or attraction)

devices (FADs). The term FAD has been used for a wide variety of drifting, surface-floating or mid-water objects, but is often used in a more restricted way to mean floating artificial objects, with the primary purpose of facilitating harvest of fish (mostly pelagic species) by attracting and thus aggregating them.

A wide range of materials have been used to construct artificial reefs, including transplanted corals and other natural substrate, tyres, concrete, rocks, ship hulls, vehicles, oil rigs, other waste materials and purpose-designed, fabricated modules such as 'Reef Balls'. Several reports have reviewed materials for use in artificial reef applications [e.g. 1, 2]. In developed countries, there has been a trend toward the use of designed, fabricated modules or ship hulls, rather than waste materials as previously used. New techniques such as mineral accretion are also being promoted [3, 4], although their evaluation is outside the scope of this paper.

3.3 Applications of artificial reefs

The purposes of artificial reefs around the world can be categorised into habitat creation, enhancement, restoration or protection. Additionally, structures that are designed for other functions (such as piers and pontoons) can incidentally serve as artificial reefs. The motivations of different user groups to create artificial reefs include:

- Fishing enhancement – commercial, recreational or artisanal fishing [e.g. 5];
- Tourism / recreational opportunity enhancement – diving, submarine tours [6];
- Science – experimentation and research (experimental tool e.g. patch reefs, translocation experiments, techniques for management/restoration) [7];
- Mariculture [8];
- Mitigation / compensation (for habitat loss elsewhere) [9, 10];
- Conservation of biodiversity (e.g. by providing or enhancing habitat for the re-establishment or enhancement or depleted organisms (e.g. red coral, *Corallium rubrum*, in Sardinia, Italy [11]);
- Restoration of damaged habitat (e.g. following ship groundings in the USA[12] or coastal development in Singapore [13])
- Protection of habitat or control of fishing mortality by using artificial reefs as physical barriers (e.g. to protect seagrass from trawling and exclude fishing operations from designated areas in the Mediterranean Sea [14-16])

- Protected (no-take) artificial reefs for fisheries restoration purposes, particularly in severely over-fished areas such as Hong Kong [17, 18].

Given the extent and relative health of natural reefs in the GBR, only the first three or four of these are considered relevant to the GBR at present.

3.4 Artificial reefs overseas

At least 40 countries have artificial reefs, although applications and motivations vary. For example, Japan, the global leader in development and use of artificial reefs, has primarily developed artificial reefs for commercial fishing purposes [19, 20], whereas creation of artificial reefs in the USA and Canada has been primarily aimed at recreational use (diving or fishing) [21, 22].

Deployment of artificial reefs has been widespread in some areas. For example, the USA has over 500 approved artificial reefs in coastal waters, with Florida having at least 350 [23], and the Philippines has over 21,600 artificial reef 'modules' constructed through government funded programs [24].

Development of artificial reefs has involved support and participation by both Government and community groups, and in some countries financial incentives to build artificial reefs for fishing have been considerable. For instance, in the USA, the National Fisheries Enhancement Act 1994 led to the National Artificial Reef Plan in 1985, and many hundreds of millions of dollars have been available for 'fishing enhancement' through the 'Wallop-Breaux' funds, which come from a 10% manufacturers excise tax on sport fishing equipment [24]. However, the construction of artificial reefs is most often proposed in response to signs of overfishing, in which circumstances other management actions may be needed in addition to, or instead of, building artificial reefs [25].

Some countries have national planning for artificial reef development (e.g. the USA has a national plan and database of artificial reefs [22]), yet in many countries deployment of artificial reefs has been largely ad hoc. Some international or regional initiatives have been developed. For example, the European Artificial Reef Research Network (EARRN) was created in 1995 (with funding from the European Commission), to encourage regional collaboration on artificial reefs research programs [26].

3.5 Artificial reefs and related monitoring in Australia.

Guidelines for artificial reefs in Australia are being developed by the Department of Environment and Heritage (www.deh.gov.au), but are not yet available. By the early 1990s, Australia had at least 72 artificial reefs, most of which had been constructed from waste materials (29 from tyres, 22 from vessels, 21 from concrete/rock/other material) for recreational fishing or diving [27]. Branden [28] noted that some Australian artificial reefs have been designated for diver-use only, in an effort to avoid conflict between recreational divers and fishers. In Western Australia, several vessels have been scuttled for use as dive sites, including the HMAS Swan in 1997 [29], and some monitoring of artificial reefs takes place, but the data are not readily available. The largest number of officially endorsed artificial reefs in the country are in South Australia. Since the early 1970s, the then South Australian Department of Fisheries installed several artificial reefs of either tyre modules or ship hulls, which it hoped would improve recreational fishing opportunities and provide economic benefits. However, the South Australian government no longer recommends artificial reef deployment for fisheries enhancement because of risks to fish stocks (see www.pir.sa.gov.au; explanation section 4.2). An article by Les Gray on the website of Primary Industries and Resources South Australia (PIRSA) notes since 1993, PIRSA "has taken the conservative approach and discouraged the construction of any additional artificial reefs in State waters. There is enough available evidence to suggest that the construction of any new reefs would increase the potential for species such as snapper and King George whiting to be taken without actually enhancing stocks of these species. The concept for constructing artificial reefs as a means of enhancing recreational fisheries is now considered questionable by fisheries managers if we are to maintain fish stocks at sustainable levels" (details at www.pir.sa.gov.au/pages/fisheries/environmental/artificial_reefs .htm).

Queensland has three large multi-component artificial reefs south of the GBRMP, in Hervey Bay and Moreton Bay [24]. Monitoring programs are undertaken by community groups, such as the Bundaberg and District Artificial Reef Association [30]. Queensland Department of Primary Industries & Fisheries (QDPI&F) [24] reviewed and evaluated the datasets, but concluded the programs were not generally adequate to detect realistic levels of change in either species composition or mean abundance. Currently, the HMAS Brisbane is being prepared for deployment as an

artificial reef dive site off the Sunshine Coast in Queensland. The lead agency in the 'sinking the Brisbane' project is the Environmental Protection Agency, and it is proposed to prohibit extractive activities by declaring a small marine park (details at www.epa.qld.gov.au/about_the_epa/coming_events/sink_the_brisbane/).

In the GBR, a number of wrecked ships and aircraft sunk unintentionally act as artificial reefs [31], and are popular with fishers and/or divers, the best known being the S.S. Yongala. However, to date, no permits have been issued for intentional creation of artificial reefs in the GBRMP.

4 POTENTIAL ENVIRONMENTAL IMPACTS OF ARTIFICIAL REEF CREATION IN THE GBR

4.1 General factors affecting the nature and extent of impacts

The extent and nature of the effects of artificial reefs and FADs will depend on numerous factors, including:

1) design and construction materials;
2) placement;
3) extent of development (total number, size etc);
4) colonisation and stocking processes ('natural' or facilitated by translocation or artificial stocking of corals or other organisms, including fish);
5) use - in particular, the extent of fishing pressure, if any.

4.2 Effects of fished artificial reefs on fishing, fisheries and fish stocks/populations

4.2.1 Enhancement of recreational fishing experience

Artificial reefs may potentially enhance recreational fishing experience and success in several, not always desirable ways [25, 32] including:

- Increased ease and convenience – by establishing known locations where desirable species are likely to be found, providing convenient fishing spots with easy access and reduced travel time;
- Increased participation – individual anglers may fish more often or for longer periods, and more people may go fishing;
- Increased catchability e.g. by attracting fish away from their natural, more protective habitats, artificial reefs may make fish more susceptible to fishing gears;

- Increasing fishing catches. Serious concerns have been expressed by several authors that high catches around artificial reefs are most likely due to the concentrating effect of artificial reefs making it easier for fishers to catch fish, and hence carry a risk of over-fishing [23, 24, 33-35] and see next section.
  Artificial reefs for recreational fishing enhancement may offer financial benefits to the sports fishing industry and social and economic benefits to local communities, however such benefits are not guaranteed and there may be alternatives to artificial reef deployment that could provide similar benefits at lower environmental risk.

4.2.2 Increased production or aggregation?

Theoretically, artificial reefs may enhance fishing catches by increasing one or more of production, aggregation or pressure (Table 1) [25, 32]:

Table 1: Possible effects of artificial reefs on fish stocks and fishing

Mechanism	Likely effect on fish populations		Likely effects on fishing catch	
	Local Stocks	Regional stocks	Short-term	Long-term
Increased fish numbers at site:				
Increased Production	Increase	Increase	Minor	Increase
Increased Aggregation	Increase	*None/Decrease?	Increase	**Increase/Decrease?
Increased Pressure:				
Increased catchability	Decrease	Decrease	Increase	**Increase/Decrease?
Increased effort	Decrease	Decrease	Increase	**Increase/Decrease?

Points to note include:

- Increasing production is clearly the most desirable outcome, as it results in increased *overall* fish stocks (by improving aspects of survival or growth). There is very little direct evidence for this [25, and see below];
- Increased attraction and aggregation of pre-existing fish stocks simply increases stock availability to fishers, but not overall stocks. This may take two forms:
  - Attraction and redistribution of already exploited resources;
  - Availability of previously unexploited species or components of populations [34];
- Increased catchability may result for example from attracting fish away from their natural, more protective habitats, where they are less susceptible to fishing gear, or by aggregating pelagic fish;

- Increased effort may arise in several ways:
  - Reducing search times by establishing known locations where desirable species are likely to be found;
  - Providing convenient fishing locations, with improved access and reduced travel time, resulting in increased duration or frequency of fishing trips, increased time spent fishing, and increased numbers of fishers participating [32];
- *Impacts of aggregation and increased pressure on regional stocks, and long term fishing success, will depend critically on the balance between overall production, and overall mortality, including all catch, both recreational and commercial [34, 36]. (Although not widely recognised, the cumulative impact of recreational fishing may be substantial as some 800,000 recreational fishers are based in Queensland [37], and total recreational catch is not currently regulated on the GBR).
- **An increase in fishing mortality due to either increased aggregation, catchability or effort on the longer term response of fishing catches depends on the level of exploitation. If the stock is fully exploited or over exploited increased fishing mortality would result in more overfishing and a decrease in long-term catches. It is unlikely these days to have underexploited stocks, but increased fishing mortality in such a scenario should achieve an increase in long-term catches.

Thus, enhanced fishing success, or an increase in fish numbers/stocks in the immediate vicinity of a newly created artificial reef, may represent a redistribution and not an *overall* increase in fish stocks for the surrounding area [23, 24, 33-35, 38, 39]. If the overall effects of increased aggregation, catchability and effort are not outweighed by increased overall productivity, the artificial reef has the potential to contribute to over-fishing, instead of lessening fishing pressure on natural reefs or habitats as intended [23, 24, 33-35]. This is considered most likely if total fishing pressure on artificial reefs is unregulated and allowed to expand freely [23, 38-42].

In general, creation of artificial reefs does not appear to benefit overall fish stocks/populations where extractive use is permitted [24]. Catch rates have indeed been high around artificial reefs [e.g. 43, 44, 45], and around some existing structures in the GBR, but several reviews of international literature related to the aggregation

versus production debate have found very little reliable evidence of increased overall productivity of target fishes due to artificial reef creation [23-25, 46]. For desirable fishery species, most artificial reefs appear to act primarily to aggregate existing fish populations: i.e. an abundance of fish around artificial reefs does not mean more fish overall, but rather that fish have been focussed / attracted from other areas [23, 24, 34, 43, 46, 47]. Although, in some circumstances, artificial reefs have resulted in some increase in production of specific taxa [25, 38], calculations based on experience from around the world indicate that if extractive use (fishing) is freely allowed, then the removal of fish (fishing catches) usually far exceeds any new production due to the artificial reef [34]. By concentrating fish and fishing effort in the same location, and by increasing effort and effectiveness, artificial reefs can increase the risk of overfishing [23, 25]. A review of the effects of artificial reefs on fish stocks by the Queensland Department of Primary Industries concluded the potential for overfishing following aggregation and the increased availability of already depleted fish stocks is a serious risk of artificial reef deployment [24, pg. 11]. The abundant and large fish frequently observed on unfished artificial reefs (e.g. the SS Yongala) may reflect both aggregation/attraction and protection from fishing.

4.2.3 Other issues, variability and scale of effects:

Artificial reefs may also facilitate targeting of bottlenecks in species biology or distributions (e.g. spawning aggregation, migration route, etc), potentially resulting in rapid depletions of fish populations [34]. For example, artificial reefs might allow focused catch of fish that migrate, such as mangrove jack that travel across the continental shelf during their lifecycle (ontogenetic migration) or Spanish mackerel that migrate along the GBR seasonally, potentially resulting in over-exploitation. Similarly, an artificial reef which allowed targeting of the bait ball/ juvenile marlin/ sailfish association off Cape Bowling Green would be highly undesirable due to potential to heavily fish a bottleneck in their complex lifecycles and disrupt their important ecological functions in cross-shelf and inter-oceanic connectivity of the Great Barrier Reef World Heritage Area and other ecosystems [48, 49].

Maintaining healthy fish populations is not only important for economic and social wellbeing, but also for biodiversity and ecosystem health. Fishery or bycatch species may have a number of biological characteristics, such as rarity, late age at sexual maturity, long life span or spawning aggregation behaviour, which make them

vulnerable to depletion under pressure. Effects of fishing artificial reefs and FADs will vary for different species groups and biological characteristics, and with the design, size and placement of the artificial structure [38, 47]. For example, in the GBR context, the effects of artificial reefs on fishes with ontogenetic migratory behaviour (such as mangrove jack) will differ from the effects on benthic reef fishes that tend not to move so far as adults (e.g. coral trouts), or on pelagic fishes which may be aggregated by new structures in previously open waters.

Importantly, there is a risk that these impacts on fish populations and fisheries may occur at regional scales, not just locally if fishing of artificial reefs leads to increased fishing pressure on already depleted stocks or life-stages such that total mortality exceeds sustainable levels. This could harm pre-existing fisheries, vulnerable target species or bycatch, and exacerbate conflicts between fisheries. For example, artificial reef development that facilitated increased targeting of already depleted stocks of Spanish mackerel could have far reaching effects. Similarly, it would be undesirable to allow extractive use of artificial reefs that increased pressure on rare or vulnerable bycatch species such as Queensland groper or sharks. There is a need for expert assessment to explicitly consider the scale of these risks for relevant GBR species or populations (of both target and bycatch) and to assess the degree of risk to biodiversity and ecosystem function. The design, placement and, in particular, the total number and scale of artificial reef development and the degree of extractive use, will influence the extent and scale of the impacts.

4.3 Other ecological / environmental consequences

The creation of artificial reefs involves a number of environmental costs and potentially significant risks beyond those associated with fishing/extractive uses. Many of these have not been assessed in the scientific literature sufficiently to allow proper cost-benefit analyses [33]. Most deployments and studies of artificial reefs have taken place in the context of degraded or over-fished environments, where there is greater scope for beneficial outcomes. In contrast, the relatively healthy ecosystems of the GBR are more vulnerable to negative impacts.

4.3.1 Risk of pollution and contamination

Introducing materials to the marine environment carries considerable risks of pollution and contamination, and even apparently innocuous materials may reduce

water quality or have toxic effects on surrounding marine life. Many commonly used materials may contribute to chemical pollution. For example, ships would require cleaning of all fuel and lubricant residues, cargo, paints, especially anti-foulants, and any potentially polluting construction material (e.g. asbestos). Iron is often a limiting nutrient in marine ecosystems, and addition of iron (e.g. ship hulls) has had surprisingly large and long-term impacts on phytoplankton levels [50]. Long-term impacts through corrosion, leaching or chemical degradation also need to be considered. This is a potentially serious issue, which would require careful consideration and assessment in any proposal.

4.3.2 Loss of pre-existing habitat and species

Creation of artificial reefs intrinsically involves loss of pre-existing habitat: in effect, a natural habitat (lagoonal, inshore etc.) is replaced by an artificial habitat [51]. Inter-reefal and lagoon bottom habitats and their resident species have been undervalued in comparison to coral reefs, often considered 'empty', but they have high ecological and conservation value. Current research (e.g. the Seabed Biodiversity Project, see www.reef.crc.org.au/resprogram/programC/seabed/index.htm) is providing new evidence of complex and highly diverse habitats and roles in ecosystem function, although it also demonstrates the major lack of knowledge about these habitats, their extent, relationships and functions. Altered benthic habitats and increased fish populations around artificial reefs at locations that are atypical of the natural system may affect the integrity or functioning of the marine ecosystem [51].

There is general consensus that artificial reefs may increase biomass of sessile benthic invertebrates, excluding fishery species [e.g. 10, 52]. However, for most targeted invertebrate species, as for fish, there is only very limited evidence that artificial reefs may enhance production rather than merely attract animals from other locations and the specific circumstances (e.g. experimental shellfish culture in the Adriatic Sea [53], octopus in Japan [38]) are not directly applicable to the GBR. Further, invertebrate assemblages on artificial reefs are generally quite different to natural communities of either natural reefs or pre-existing habitat, in community structure, diversity, species composition and relative abundance of species [e.g. 54, 55]. Thus the overall ecosystem has been altered, but not necessarily enhanced.

4.3.3 Changes to surrounding ecology

Importantly, ecological impacts of artificial reef creation on surrounding ecology are not well understood, but are unlikely to be limited to the immediate site. Potential effects include:

- Removal/ depletion of mobile species (e.g. fish) from surrounding areas [47, 56, 57], with potential 'trophic cascades' in which disproportionately larger effects are seen on species lower down the food web (e.g. outbreaks of prey species no longer kept in check by predatory fishes, etc).
- Spill over of predators, competitors or grazers onto surrounding areas, with the potential to create permanent 'haloes' of over-grazed or altered habitat of unknown extent [58-60];
- Altered behaviour, such as movement and migration patterns, as discussed above (Section 4.2.2).
- Changed relative abundance and distribution patterns [61-64];
- Effects on local hydrology [65].
- Interference with natural connectivity patterns between reefs. The dispersal of larval fish, corals and other organisms, may be altered by:
  - the presence of new habitat which captures recruits destined for natural reefs inshore;
  - feeding by planktivorous fishes on artificial reefs; or
  - providing an intermediate stepping stone, linking naturally separate populations or facilitating invasions of diseases or pest species;

Most of these impacts on surrounding habitats have not been adequately assessed, and most previous impact assessments only looked for very localised effects. Furthermore, other authors have suggested that some assessments were based on seriously flawed survey designs or questionable figures [33, 65-71], providing little indication of the spatial and temporal scales of impacts and any stabilization [54, 55, 59, 72]. Clearly the extent and severity of any impacts will depend on the nature of the surrounding habitats, and may in some cases be minor, or stabilise rapidly, but better information is required.

4.3.4 Dislodgement or break-up of structures

Dislodgement or break-up of vessels or other artificial reef structures, particularly during severe weather events such as cyclones, may affect adjacent marine habitats

and their values (and may reduce the benefits of the artificial reef). Documented effects of storms on artificial reefs in the USA have ranged from no impacts, to partial or total structural modification [73, 74]. Movement can be considerable, and has exceeded 1.9 km for small structures, and even large structures can be affected. For instance, movement of a 140 m long ship in 33 m of water has been documented [75]. This potential for damage to valued marine habitats should be included in risk analyses.

4.3.5 Introduction of diseases, marine pests, or contamination of genetic stocks.

There is a growing realisation that the introduction of diseases, marine pests or contamination of genetic stocks could have devastating consequences in the marine environment, and even large marine systems such as the GBR are potentially vulnerable to such problems. Translocation of organisms to colonise artificial reefs is not recommended as this practice carries serious risks of adverse environmental outcomes, including introduction of diseases or interference with natural gene flows [76]. Similarly, transporting a vessel for use as a dive wreck, would require measures to prevent introduction of marine pests.

5 NON-EXTRACTIVE USE OF ARTIFICIAL REEFS FOR TOURISM/RECREATION

Given the interest in the creation of artificial reefs for tourism/recreation purposes on the GBR, it is unfortunate that this aspect has received relatively little attention in the international literature, although various guidelines have been developed [e.g. 77, 78-80]. Artificial reefs may potentially enhance diving/tourism opportunities in several ways by providing: a focus and guaranteed experience for recreational divers; convenient, all weather access to dive sites; and new marketing/economic opportunities for local communities. However, beneficial outcomes are not guaranteed, and Bohnsack & Sutherland's [33] warning that " the potential exists for major mistakes which could be difficult, costly, or impossible to correct" still holds true. The environmental impacts of unfished artificial reefs are addressed above (Section 4.3), but would avoid the risks of overfishing etc (Section 4.2). Socio-economic effects are also not well documented, but artificial reefs for diving only have proven popular in other areas of Australia [28]. After public debate, Canadian groups have attempted to create ecologically responsible artificial reefs for sports diving, with apparent economic benefits to local communities [21]. Applications

overseas have included creating artificial reefs for submarine tourism [81]. Although some proposals have included use of artificial reefs for both diving and fishing on the same structures, these uses are generally considered incompatible (see Conflict and resource allocation issues Section 6.1).

6 SOCIO-ECONOMIC CONSEQUENCES AND COST-BENEFIT ANALYSIS

The major motivation for creation of artificial reefs in the GBR is the perceived social and/or economic benefits, principally to sports diving or to recreational fishing, so it is important to ensure that these benefits are realised. However, there is surprisingly limited evidence to document the validity and extent of those benefits [33, 51, 67, 82, 83], notwithstanding the demonstrated popularity of existing structures (e.g. the S.S. Yongala).

Although some authors have reported favourable social/economic benefits [e.g. 6, 84], Whitmarsh [83] noted that from the perspective of both commercial enterprise and society as a whole there is still considerable doubt regarding the circumstances under which artificial reefs are a worthwhile investment. Brock [81] argued that non-extractive use of artificial reefs by the tourism industry may provide higher economic gain than use by fisheries. A possible lower cost and lower risk alternative to creation of new artificial reefs is to look at ways to enhance fishing or diving opportunities by making use of existing wrecks.

There is a need for detailed cost-benefit analyses for creation of artificial reefs in the GBR. Such analyses should include careful assessment of both project risk and project worth [85], and the evidence to support the potential socio-economic benefits of such developments must be as carefully critiqued and analysed as the evidence for environmental impacts [33]. For example, perceived benefits to fishing may be short-term only or only realised if fishing effort is carefully managed (as above, Section 4.2 [20, 32]), or might need to be balanced against potential effects of any ecological impacts on adjacent tourism sites. In some areas (e.g. South Australia), problems and risks associated with artificial reefs have outweighed the benefits, resulting in specific recommendations against further deployments as discussed in Section 3.5. Further, removal of an unsuccessful artificial reef is likely to be very costly and difficult [33].

In assessing social and economic benefits, it is important to understand the underlying values and expectations of all sectors of the community, in order to critically assess both the extent to which artificial reefs are realistically likely to provide the expected benefits, and whether alternative approaches may better address those values and expectations or may have less risks associated. (Before doing what we think the public wants, we should actually ask them what they want.)

Even with best management practices, artificial reefs may have negative impacts on some World Heritage values of the GBR as a natural phenomenon, and may be unpopular with some interest groups (e.g. conservation groups) as 'not natural.' Such social costs must be weighed against social benefits to other interest groups in risk assessments and cost-benefit analyses. In this context, the GBR situation is exceptional, because artificial reefs elsewhere have generally been deployed against a background of degraded natural value (degraded habitats or over-fishing), and so may be seen as enhancing or rehabilitating natural worth. In contrast, on the GBR, deployment would be against a background of high natural value, potentially degrading that value. Finally, artificial reefs will have management costs; poorly managed artificial reefs or unregulated fishing harvest can lead to environmental, economic or social problems [e.g. 40].

6.1 Conflict and resource allocation issues

Creation of artificial reefs may give rise to conflicts over use and resource allocation [33]. Conflicts over artificial reefs can arise over 1) common stock; and/or 2) user congestion [32]; and 3) resource allocation. For example, if artificial reefs are allocated to enhance recreational fishing, to the exclusion of commercial fishing, this may have real or perceived costs to commercial fishers, especially if reduction in overall common stocks results; alternatively, if artificial reefs are open to both sectors, overall fishing pressure and associated risks may be significantly higher. Similarly, conflicting interests may arise between fishing and tourism sectors, or conservation and pro-development groups. Diving and fishing may be incompatible uses of the same artificial reef areas as each interferes with the goals of other [33]: large fish are amongst the first to be depleted by fishing, but are of considerable economic value to dive tourism. Artificial reefs of realistic size are likely to be too small to support both activities without conflict.

Finally, it is important to ensure that artificial reef deployment overall is compatible with the goals of GBRMP zoning and plans of management: although individual developments may be assessed as low impact, it is important that increasing and broadening demands do not result in an overall outcome inconsistent with the primary purpose of conservation management within the GBRMP.

7 STRATEGIES TO ASSESS AND ADDRESS POTENTIAL IMPACTS

7.1 Strategies to mitigate impacts

If creation of artificial reefs were to proceed in the GBRMP, potential problems and impacts should be carefully identified, assessed and addressed prior to any development, and strict guidelines and permitting conditions should be implemented. In particular, it is essential that an overall strategic approach is developed, considering cumulative and overall outcomes (benefits and impacts), as well as case by case assessment and permitting. Minimisation of socio-economic conflicts may be addressed, prior to any development, by ensuring good evidence that the development will satisfy the intended objectives in the best possible way, and minimise impacts on other community sectors. Alternative options to artificial reef deployment should be evaluated, including utilisation of some of the many existing wrecks [31]. After deployment, strategies might include restricted access, limited effort, or segregation of users in space and time [32].

Given the paucity of information on the environmental, economic and social costs and benefits, developments should be considered within a sound research and monitoring framework, and take an adaptive management approach. Initially, any developments should involve small pilot studies to help address knowledge gaps and concerns, including issues of scale in ecological impacts.

The potential for impacts on fish populations and fisheries suggests that fished artificial reefs be considered in terms of fisheries management as well as management of the artificial structures [27, 32]. Fisheries assessments should address both target and bycatch species, the current status of populations, the total impacts on populations, including other fisheries targeting the same species and other

impacts (such as habitat loss), and the likely resilience of the populations to those pressures. There may be a need to regulate total fishing pressure, or at least limit the increased pressure due to artificial reefs, using measures such as limiting number of moorings. There may be a particularly high risk of overfishing in the initial period after deployment, given that any increase in production will take time to be expressed. This suggests that, in the long-term, benefits to recreational fishing may maximised and environmental damage minimised by imposing a "waiting period" before fishing is allowed.

7.2 Design, placement, construction materials and management

Considerable information exists on artificial reef materials, design, placement, deployment etc., although their consequences for ecological dynamics and biophysics are not well understood. Detailed review is beyond the scope of this paper, but the primary purpose of an artificial reef is a major determinant of design and placement. Elsewhere, the design, configuration and siting of artificial reefs and FADs has considered factors such as:

- Water flow/ currents/ hydrology;
- Light penetration;
- Nutrient availability;
- Whether construction materials meet requirements of desired target species (life-stages) or communities.

Other management and policy issues also cannot be addressed in detail here, but include permitting, planning, zoning, site, safety, legal, legislative, and operational aspects. Permitting issues that need to be considered include:

- Total number of artificial reefs (or FADs);
- Overall size;
- Proximity to natural reefs;
- Construction materials, including durability and toxicity;
- Removal: feasibility and costs of removal;
- Limits on high usage.

8 OVERVIEW OF AVAILABLE INFORMATION

8.1 Information sources, quantity and quality

There is an extensive international literature on artificial reefs, with 768 hits for 'artificial reef' in the combined Aquatic Sciences and Fisheries Abstracts and Oceanic Abstracts (ASFA/OA) database, and 47,300 hits in Google. However, no official global database on artificial reefs exists, and much of the information is in unpublished 'grey' literature. Further information will exist in long-term datasets from community monitoring programs of artificial reefs, but these data may be of limited value, and restricted in availability. The following overview is based on a review of available literature, including local library catalogues at James Cook University and the Great Barrier Reef Marine Park Authority, peer-reviewed literature, reports and web pages.

Of the 768 abstracts on artificial reefs in the ASFA/OA database, a preliminary analysis suggests relatively few are relevant to management of the GBRMP (Table 1), and of those, relevant topics were not always addressed in detail or the intended focus of the paper. It is notable that few of the articles (less than 3%) deal with the evaluation of how well artificial reefs perform in meeting their stated objectives, and of those that do, the evidence to support suggested benefits is often limited.

Table 1: Relevance of articles on artificial reefs to GBR in the ASFA/OA database

Topics of ASFA/OA abstracts	Articles (% of total)*
Australian artificial reefs	1.6
Tourism applications	4.6
Fishing enhancement	11
Performance evaluation of artificial reefs	2.6
Policy/legislative aspects of artificial reefs	5.2
Socio-economic issues	6.3

* *Articles may cover more than 1 topic of interest. The remaining articles were not relevant.*

Many more articles covered design, construction and placement of artificial reefs, aspects which have also been the subject of a number of technical reports and reviews. Natural science aspects of artificial reefs have also been covered by a large number of papers, with the majority being descriptive and relating to basic scientific research. A considerable body of research has focused on ecological and physical

aspects of artificial reefs, and biological-physical linkages on artificial reefs have received increasing attention in recent years. However, there is still considerable uncertainty about actual effects on marine ecosystems, the time and spatial scales of impacts, and ecological mechanisms producing any benefits [51].

Numerous international and regional conferences and workshops have addressed aspects of artificial reefs and other artificial habitats in the last 25 years. Seaman [86] analysed the types of artificial reefs and information reported in research presented at the 7th International Conference on Artificial reefs and Related Aquatic Habitats (7th CARAH) in 1999. The majority (37%) of articles dealt with 'usage reefs' deployed to meet specific purposes, a quarter were concerned with 'research reefs' built strictly for scientific research, whereas other articles were not use-specific. The information reported is summarised in Table 2, and again, few papers focus on evaluation of how artificial reefs meet their intended purposes, and of these, most only consider the importance of such evaluation, rather than actually present the evaluations. The 8th International Conference on Artificial reefs and Related Aquatic Habitats (8th CARAH) will take place in April 2005, in Mississippi USA, and aims to promote international exchange of information on the use of artificial reefs to enhance and manage marine and freshwater resources (such as fisheries) and protect the natural environment. It is likely that considerable new information will become available after this conference; more information is available from www.cfi.lsu.edu/carah/default.asp

Table 2: Information reported at artificial reef conference [Source: 86]

Intent of 7th CARAH articles	**Articles (% of total)**
Scientific description and understanding	51
Design aspects	44
Performance evaluation	5

8.2 Information relevant to the GBR

Although there is a considerable body of information on artificial reefs world-wide, only a small proportion addresses questions of relevance to the GBR. Relatively few journal articles and reports have focused on Australian artificial reefs. Australian research into artificial reefs, although limited, was most active in the mid 1970s [27], and an artificial reef symposium was held in Brisbane in 1977. Reviews and a

bibliography on artificial reefs and FADs were provided by Pollard & Matthews [87]. Kerr [27] reviewed artificial reefs in Australia from 1965 when the first recorded artificial reefs was deployed in Victoria. Artificial reefs and FADs for fisheries purposes in each state of Australia were covered by Pollard [88] over a similar time period. Branden summarised artificial reefs deployment in Australia from mid-1980s to the early 1990s [28].

One report of particular relevance to the GBR is the aforementioned review by the Queensland Department of Primary Industries & Fisheries of the effects of artificial reefs on fish stocks, which concluded that there may be little benefit to fish populations from creation of artificial reefs and noted that increased catches of fishes concentrated at artificial reefs sites could result in overfishing [24]. This review integrated international peer-reviewed literature, analysis of data from community monitoring of Queensland artificial reefs, and experimental evaluation of design and construction aspects.

8.3 Key information gaps relevant to the GBR

Some key information gaps include:

Fisheries and other ecological/biophysical aspects:

- Lack of robust and specific information on potential benefits or impacts on GBR fish populations:
  - To what extent would artificial reefs contribute to enhanced production, and for which species (including target, potential future target and bycatch species)?
  - To what extent would artificial reefs aggregate fish in each location?
  - To what extent would this reduce surrounding populations, and for which species and life-history stages (not limited to target species but including others, such as herbivores, with significant ecological roles)?
- Lack of robust information on the likely environmental impacts of artificial reefs in the relatively healthy ecosystems of the GBR:
  - What effects will artificial reefs have on immediate and surrounding natural marine habitats, species and ecosystem functions (e.g. grazing, aggregation, trophic shifts)?

  - What is the 'radius of influence' or scale of effects, i.e. at what distances are the effects ecologically strong, significant or insignificant?
  - What effects do they have on larger scale processes such as larval connectivity, migration and hydrodynamic processes?

Social and economic aspects:

- "Who wants what and why?" There is a lack of robust information on underlying values and motivations of:
  - Recreational fishers, as a basis for enhanced recreational fishing experience;
  - Divers and tourism industry as a basis fr enhanced diving/tourism opportunity; and
  - Other users e.g. how much does addition of artificial structures impinge on perceptions of naturalness, beauty and World Heritage value, and hence on tourism value?
- Lack of information on the social benefits and costs of artificial reefs, and how they address the values and motivations.
- Careful consideration of potential alternative solutions to enhance recreational fishing and other experiences of the GBR.
- Procedures to manage fishing and fisheries:
  - To prevent overfishing either on artificial reefs or of total fishing effort;
  - To address issues of resource allocation between recreational and commercial fishing.

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